Basic Factors for the Treatment and Disposal of Radioactive Wastes
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BASIC FACTORS
FOR THE TREATMENT AND DISPOSAL
OF RADIOACTIVE WASTES

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BASIC FACTORS
FOR THE TREATMENT AND DISPOSAL
OF RADIOACTIVE WASTES

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1967
BASIC FACTORS FOR THE TREATMENT AND DISPOSAL OF RADIOACTIVE WASTES
(Safety Series, No. 24)

ABSTRACT. Prepared by a panel of experts convened by the IAEA in Vienna, 24-28 October 1966, it gives a guide to the factors to be evaluated in selecting a waste management system, so that establishments, especially in developing Member States, can choose the methods most suitable for their particular needs.

Contents: Introduction; Definition of a waste management system; General factors in the selection of a waste management system; Selection factors for waste management systems; References; Bibliography; Annex I - Data question sheet.

Separately available in English and French.

(41 pp., 14.8 x 21 cm, paper-bound, 2 figures)

THIS REPORT IS ALSO PUBLISHED IN FRENCH

BASIC FACTORS FOR THE TREATMENT AND DISPOSAL OF RADIOACTIVE WASTES
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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 establish-
ments 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.

![Diagram](https://via.placeholder.com/150)

**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.
FIG. 2. General breakdown of waste management system.

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.
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 oblige 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 costs¹ that should be allocated to waste management as a percentage of the total capital cost of the establishment are of the following order:

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, U²³⁵ 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 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-

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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 en-
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 backtracking 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.
(ii) The probability of contamination of the drainage system, which might present a hazard during repairs.

(iii) The probability of contamination of the sewage itself, which could present a hazard to men working in the sewer.

(iv) The type of treatment, if any, to which the sewage will be subjected, and contamination of treated sewage effluents which might affect their subsequent use or disposal.

(v) The probability of possible build-up of certain radionuclides in filter beds or other units of the sewage treatment system.

(vi) The possible use of sewage sludges.

The locality and environment of the site will decide the type of disposal and the amount of radioactivity that can be released. A pre-operational environmental study may probably be necessary to establish the disposal limits after account has been taken of the applicable legislation. Each site will present different problems and different factors will therefore have to be taken into account in assessing each site.

Detailed information on disposal of radioactively contaminated wastes into the environment is given in various IAEA publications [6, 10-15].

The following is a brief summary of the general factors for fresh water, sea, ground and atmospheric disposal which should be investigated or upon which information should be obtained.

It is important to note that very often there are official organizations who collect or are able to collect such data in the course of their normal duties. Recourse to such organizations may, firstly, often lessen the amount of investigation that has to be done since the information is already available, and, secondly, if these organizations carry out the investigations this may eliminate the possible risk of unnecessarily alarming the public.

In all cases it is desirable to prepare charts or maps showing the situation of various areas from which wastes will be received, and the proposed waste treatment and disposal areas. Local streams, rivers, lakes, coast-lines, populated and industrial areas, and districts under crops should be shown where appropriate.

It is also desirable to have knowledge of the radionuclides to be released and their activity level (see Section 4.2) and if possible the proposed method of release. In many cases this knowledge will be required by the regulatory authorities.
When freshwater disposal is being considered it is desirable to obtain the following information:

(i) Location of the river or lake relative to the origin of the effluent or the proposed treatment plant and distance from estuarine waters;
(ii) Maximum, minimum and average river flows;
(iii) Nature and quantity of other industrial or radioactive wastes including thermal pollution being discharged into the river or lake, and details of any dilution studies performed relative to their disposal;
(iv) Chemical quality of the water particularly with respect to suspended and colloidal material;
(v) Water usage (quantity) for drinking water, irrigation (and the crops which are grown) and for other purposes;
(vi) Species and quantity of fish, shellfish or edible flora collected or harvested from the river or lake, and the per capita consumption;
(vii) Other uses of the river or lake, e.g. bathing or dredging of river bottom;
(viii) Upstream or downstream regulation of river flow.

When marine disposal is being considered it is desirable to obtain the following information:

(i) Location of the estuary or ocean relative to the proposed treatment plant;
(ii) Tidal and current movements;
(iii) Water usage for cooling water or other industrial purposes;
(iv) Nature and quantity of other industrial wastes being discharged into the estuary or ocean, and details of any dilution studies performed relative to their disposal;
(v) Species and quantity of fish, shellfish or edible flora collected or harvested from the nearby marine environment, and the per capita consumption;
(vi) Use for bathing and sport;
(vii) Other uses of the marine environment, e.g. dredging from the ocean bottom;
(viii) If solid waste disposal is being considered it is also desirable to know the depth at the disposal area, and the effect of that depth on the structure of the waste container to be used.
When ground disposal is being considered it is necessary to appreciate the difference between shallow land burial which tends to be relatively simple and inexpensive, and disposal into deep formations that are normally more complicated and expensive.

(a) For shallow land burial the basic information required is:

(i) Depth of water table;
(ii) Permeability of the soil;
(iii) Distance to nearest point of water usage (river, well, etc.);
(iv) Ability of the soil to absorb radionuclides.

Further details such as the direction and rate of flow of the ground water, climate (particularly the distribution of rainfall and the evaporation rate) and the proximity of population centres would be desirable.

In some countries (e.g. the United Kingdom) and under certain conditions (see p. 73 in Ref. [8]) use may be made of municipal and industrial refuse dumps for burial of certain low activity solid wastes. It is then desirable to obtain the following information:

(i) Locality of the dump with special reference to the avoidance of contamination of surface and underground waters;
(ii) Whether, after burial at the site has been discontinued, the ground will remain undisturbed for a long period or if it will be used for some particular purpose;
(iii) Security of the site with respect to whether it is fenced and substantially free from fire risks.

(b) For disposal of wastes into deep formations it is desirable to obtain the following information:

(i) Hydrologic situation including depth of water table, direction and rate of flow of the ground water and relative rate of movement of the radioactive substances;
(ii) Geographical situation including physical features of the area, vegetation, climate (particularly precipitation – monthly average, maximum and minimum – and evaporation rate – monthly average, maximum and minimum), location of adjacent water bodies and water usage, and location of population centres;
(iii) Geological situation including type of soil, type of lower geological structures, permeability of formations, chemical and mineral compositions of formations and the physical chemistry of formations (sorption and desorption characteristics).

It is necessary to have a record of the various geological horizons, particularly the interconnection of the water-bearing strata. For injection purposes probably the most important data are the porosity of the receiving formation and the compatibility between the injected solutions and the naturally resident fluids.

When atmospheric disposal is being considered it is desirable to obtain the following information:

(i) Geographical situation including physical features of the area, vegetation, location of crop-growing and animal-raising areas, and location of population centres;
(ii) Micrometeorological data for the area including prevalent wind direction and wind speed throughout the year, vertical temperature gradient, precipitation (monthly average, maximum and minimum);
(iii) Other releases to the environment of airborne industrial wastes.

It should be noted that analysis and meteorological interpretation of the above data are necessary, preferably by an experienced meteorologist.

After consideration of the preliminary evaluation as outlined above it can then be decided what further information is required and what studies are necessary. The pre-operational assessment will decide if disposal is possible and the limits of disposal, but the same factors must be taken into account in determining the post-operational environmental monitoring programme that may be required.

4.2. Types and categories of waste

The second starting point in evaluating waste management is the type of waste. This varies with the type of establishment and the operations performed there.

For information on the various types of waste that arise at the various stages of the nuclear industry, reference should be made
to textbooks on waste management [16-18]. For specific information on the type of waste associated with some uses of a number of radioisotopes see Ref. [5].

Once the types of wastes likely to arise at an establishment are estimated the categories into which waste should be segregated should be provisionally set. These categories may have to be amended later because of the treatment methods chosen or the disposal limits. The working scientist prefers to have a single or limited number of categories, which means that the waste problem is one of processing a very large volume of waste that is only slightly contaminated. The waste processor prefers to divide the wastes at the source into many categories by physical state and activity level resulting in the treatment of a very much smaller volume of waste at a somewhat higher activity level, but a large part of the waste will be able to be disposed of without treatment. Either view if taken to extremes is uneconomic so a sensible compromise must be reached.

In estimating the categories and quantities of waste likely to occur at an establishment use should be made of information available from establishments that have been operating for considerable periods. This estimate of the quantities of waste likely to occur is very important. In the past it has been a common occurrence in many countries to overestimate the amount of activity in the waste and the quantities to be treated, which has resulted in handling and treatment facilities being provided for much greater quantities than have actually occurred. In fact many establishments have waste treatment facilities that are rarely used simply because of the original overestimate of the quantities of waste.

Both the volume and activity of waste vary considerably from establishment to establishment. This applies particularly to the so-called low-level activity liquid wastes and is mainly due to differences in the extent of segregation that is practised. A very significant factor is whether cooling-water and industrial waste arising from non-radioactive contamination areas is segregated either fully or in part from the low-level activity liquid wastes arising from radioactive contamination areas. This factor accounts mainly for the apparent large discrepancies between various establishments. Another factor influencing the volume of this type of waste is the type of operations and research performed at the establishment. Naturally an establishment with a high proportion of radiochemical work will have greater volumes of liquid waste than an establishment where
high energy physics research is performed. A third factor is the way categories are defined. For instance, Establishment A defines low-level liquid waste as waste collected with an activity level of $10^{-3}$ $\mu$Ci/ml whereas the waste collected actually has an average activity level of $10^{-5}$ $\mu$Ci/ml. Establishment B defines low-level liquid waste as waste collected with an activity level of less than $10^{-5}$ $\mu$Ci/ml whereas the waste collected actually has an average activity level of $10^{-7}$ $\mu$Ci/ml. This establishment further defines waste collected with an activity level between $10^{-1}$ and $10^{-5}$ $\mu$Ci/ml as intermediate level waste and the waste collected in this category has an average activity level of $10^{-4}$ $\mu$Ci/ml. These two examples show the problem in comparing waste categories in different establishments. However, as a general guide, providing segregation of cooling-water and industrial waste is practised, the amounts of low-level liquid wastes arising per person producing radioactive wastes will vary between 10 and 100 m$^3$ per year, or arising per worker at the establishment, between 2 and 30 m$^3$ per year. If segregation of cooling-water and industrial waste is not practised, the amounts of low-level liquid wastes will increase to between 200 and 600 m$^3$ per year per person producing radioactive wastes, or to between 50 and 200 m$^3$ per year per worker at the establishment. It has also been shown that with efficient segregation of very low-level activity wastes at an establishment no more than 5 to 10% of the water used at the establishment will require other than minimal treatment and be considered as liquid wastes containing radioactivity.

The quantity of low-level activity solid wastes which occur at various research establishments has been shown to vary generally between 0.3 and 0.8 m$^3$ per person producing waste each year.

The quantities of intermediate- and high-level liquid wastes arising at an establishment depend almost entirely on the type of operation performed; to obtain a reasonable estimate for comparison reference should be made to an establishment performing similar functions.

The above figures are only very approximate as so much depends on the operations performed at the establishment, and they should be used only as a rough guide.

4.3. Waste collection, treatment and storage

Once the disposal limits have been set for discharge to the environment, and the types of wastes and their quantities have been
estimated, the proposed systems for waste collection, treatment and storage should be investigated.

4.3.1. Waste collection

After the collection categories for the waste have been decided the collection system must be considered. Basically this will consist of various types of containers for the different wastes, especially for intermediate- and high-level activity liquid wastes and for solid wastes. It is important to standardize the collection containers as soon as possible, keeping the number of types to a minimum but at the same time allowing flexibility to segregate wastes at the point of collection to avoid further segregation of wastes necessitated by treatment processes, etc., at a later stage (see Chapter 2 in Ref.[8]).

It has generally been found preferable for low-activity liquid wastes to provide separate collection systems with individual delay tanks at laboratories where radioactivity is handled. Delay tanks have the following advantages:

(i) They enable segregation to be made to avoid over-treatment, e.g. if after monitoring the radioactivity is low then discharge can be made to a central drainage system. It has been found that the cost of treating industrial waste is about 30 to 40 times less than treating low-activity liquid wastes;
(ii) They enable it to be determined whether the system is being mis-used;
(iii) They enable it to be determined whether unexpected leaks and faults have occurred in experimental and operational work;
(iv) They enable costing to be carried out of individual laboratories for waste quantities.

For low-level liquid waste a decision will have to be made as to whether the volume is sufficient to install a piping system or whether the liquid should be transferred from the collection point to the treatment, storage or disposal point by tanker. Distance from the collection to the treatment point also should be taken into consideration.

In the past many low-level activity liquid collection systems have been over-designed, and certain materials, e.g. stainless steel, have been used regardless whether they were necessary or not. This is a very important economic factor, and the design and
materials of construction of collection systems must be given full attention. For drainage systems from laboratories to delay tanks stainless steel has been found to be good but troubles may occur if the correct welding techniques are not used or if high chloride concentrations are present. PVC is now being widely used for this purpose but it is important when using polyvinyl chloride or polyethylene plastics that the correct grades or types are used. From delay tanks to treatment plant ceramic pipes are often used. Rubber-lined mild steel delay tanks have been found to be the cheapest but in hot countries a cover has to be provided to prevent deterioration from sunshine.

It is important for developing countries to use where practical materials available in the country. Stainless steel and PVC are not manufactured in many countries and therefore it may be better to use mild steel pipes which have been rubber or bitumen lined or have had an internal surface coating applied. Even cheaper piping may be used but this means that there must be a strict check on leaks. It may be better in these cases to condition the waste at the source, e.g. by neutralization, and use cheaper materials of construction for the later stage.

4.3.2. Waste treatment

It is important to realize that there is no general method of treatment of liquids which can be applied at all locations if the most economic method is to be chosen. The technology of the various methods and their expected decontamination factors is very well established, and the decision as to which treatment method should be used can be mainly based on a purely economic evaluation. The technology of treatment of gases and aerosols is also well established and methods of air cleaning can generally be the same for most establishments, unlike the methods for liquids. Generally the treatment of solid wastes is minimal and the main problem that has to be solved on an economic basis is to decide the collection categories, and if it is economical to endeavour to reduce the volume of the collected solid waste for disposal purposes.

Detailed information on the treatment of radioactive wastes is given in various IAEA publications [8, 14, 19-26].

Waste treatment for various categories of waste will now be considered. These categories are somewhat arbitrary and an interchange between categories may take place.

For purposes of this report low-activity liquid wastes have been defined as having an activity level less than $10^{-3} \mu$Ci/ml. Wastes
having higher activity levels have not been separated further and are considered intermediate- and high-level wastes.

As a general principle treatment plants should be designed to handle the quantities of waste which normally arise. They should not be designed to handle large quantities of waste which may arise abnormally, i.e. from an accident. However, in cases where the normal flow of waste is discharged without any treatment it may be necessary to have a standby treatment plant capable of partially or wholly treating any wastes, that are more highly contaminated than normal. Generally also it is sufficient to have a hold-up capacity in the liquid collection and treatment system of about 10 to 15 d.

4.3.2.1. Low-level activity liquid waste treatment

Many different treatment processes for radioactive liquid wastes are in use at nuclear establishments. The fact that there are so many different types of processes indicates that each establishment must exercise considerable judgement before installing a process.

This is particularly true for low-level activity liquid wastes but the only processes that should be given consideration are those based on chemical treatment, ion-exchange and evaporation or combinations of them. Electrodialysis is also proving suitable for some sorts of liquid waste but has not yet developed as a routine liquid waste treatment. It is important to realize that while a process may give satisfactory results at one establishment the same process may give indifferent results at another. Many factors such as local water quality, waste-water composition, radionuclide concentration and the presence of small quantities of detergents or chelating agents will have a strong influence on the decontamination factor actually achieved. It is also important to note that national or local regulations may lay down limits for non-radioactive pollutants which may be discharged to the environment, and often low-level liquid wastes collected on an establishment may have to be treated because of the above restriction even when the radioactivity level is below permissible discharge limits. This factor must be taken into account in deciding the capacity of the treatment plant required and in assessing what process should be chosen or what process warrants further investigation.

In many instances careful attention to good segregation practice will almost entirely eliminate the need for liquid waste treatment, since small volumes of more concentrated liquid wastes which do
accumulate may be handled by solidification in concrete or incorporation into bitumen, or some other method without prior treatment.

Where the total solids contents of the waste is relatively high and where a large decontamination factor is not required, chemical treatment is often a satisfactory process. (While a D.F. of 10 is generally obtained with chemical treatment processes it should be noted that D.F.s of 200 or higher can be obtained for a specific isotope with a specific coagulant or co-precipitant.) However, despite the low costs generally associated with the chemical treatment process itself, volume reduction factors are often low and considerable costs and effort may have to be expended in the solidification and disposal of the sludges resulting from chemical treatment. The choice of a particular process will be governed by the nature of the installation and the operations producing the waste. The concentrations of radioactive and non-radioactive materials will affect the choice greatly. It is particularly important to give attention to the concentrations of the non-radioactive pollutants since it will generally be found that these are far greater in concentration than the radioactive contaminants, and if the bulk of the total solids is precipitated in the process, the radioactive materials will also be co-precipitated or adsorbed on the floc. For many of the chemical treatment processes described in the references in Section 4.3.2, a considerable amount of laboratory work is required to determine optimum dosage of chemicals, which, moreover, may vary from day to day, particularly in smaller establishments. On the other hand, if it is necessary to treat only an occasional batch of waste that is unpredictable in its characteristics, use of a massive chemical treatment, i.e. using large concentrations of a mixture of coagulants, etc., will eliminate the need for much laboratory work and will probably be more economic in the long run despite the cost of chemicals involved.

Where wastes have a low total solids content (preferably less than 1000 ppm), ion-exchange treatment is a most suitable method. It has the advantages of simple equipment requirements, high volume reduction factors and the activity concentrated in a form that is easily handled for packaging and disposal. Particularly if synthetic ion-exchange resins are used, the main disadvantage is cost of the resin, but this can be overcome by regeneration of the resin. This means, of course, that a further stage is necessary to treat the regenerant liquid, and sometimes it may be more economic not to regenerate.
the resin but to consider it as solid waste. Further, the regeneration liquid is often difficult to handle. Some naturally occurring ion-exchange materials, while having a lower D.F. than the synthetic ion-exchange resins, have proved satisfactory because of their low cost. Ion-exchange is often a very useful process to follow up chemical treatment to remove radioactivity that has not been removed in the chemical treatment. A filtration step may be needed between the processes or, more important, should be used before the ion exchange even if no other treatment method is employed. Since the bulk of the solids has already been removed, ion-exchange resins that remove specific isotopes may be used even if they are expensive because the useful life of the ion-exchange column may be very long.

Evaporation is a very good method where high D.F.'s are required, or where the waste is otherwise not suited for processing by alternative techniques. Compared with other methods capital costs are high but provided the processing capacity is fully utilized the costs per unit volume are generally not excessive.

All these processes will give concentrates (i.e. sludges, evaporator residues, ion-exchange resins, etc.) that will generally require further treatment before storage or disposal (see Ref. [26] which presents the advantages and disadvantages of the various methods of sludge treatment).

With low-level activity liquid wastes great importance must be given to the decontamination factor that is desirable. If one attempts to remove all the radioactivity the cost of the process will become prohibitively uneconomic. It is therefore wise to set a D.F. that will permit discharge of the treated effluent at a radioactivity level below the permitted discharge level. It may be possible to achieve a higher D.F. by other processes but the simplest and cheapest method that will achieve the above objective is good practice.

Since low-level activity liquid wastes will probably be the type of waste which will receive the greatest attention at most establishments it is essential that the treatment process adopted is such that any equipment, spare parts or consumables used should be available at short notice and preferably obtainable locally. This presents a problem for the less-industrialized countries where generally there is also a shortage of hard currency. This means that in evaluating the treatment process that should be installed in these countries it is preferable that consideration be given to this problem, and that the method chosen should be such that the equipment and consumables
are available locally or relatively easily. Consideration should also be given as to whether it is worthwhile to construct the plant locally rather than to purchase it from abroad.

The selection of the treatment process for low-level liquid wastes is based on many factors. The information that must be obtained includes the following:

(i) The decontamination factor required;
(ii) Characteristics of the water supply to the site, especially the concentration of magnesium and calcium salts and any unusually high impurities. It is also important to know if the water has been given any treatment at the water supply works and if so the process used;
(iii) Characteristics of the influent to the treatment plant with respect to the radioisotopic and non-radioactive contaminants;
(iv) Volume requiring treatment,
(v) Capital cost of plant and equipment;
(vi) Cost of chemicals and other consumables. In this connection it is advisable to obtain information on the availability and approximate cost of the following:
   (a) Commercial grade chemicals: sodium hydroxide, sodium carbonate, trisodium phosphate, ferrous sulphate, ferric chloride, aluminium sulphate and filter alum;
   (b) Vermiculite or other natural ion-exchange material and synthetic ion-exchange resins;
   (c) Bitumens, asphalts and tars;
   (d) Cement;
(vii) Availability and unit prices of power and heat, e.g. electricity, city gas, natural gas, liquid petroleum gas, high- and low-pressure steam and high- and low-pressure hot water;
(viii) Cost of research required to evaluate various treatment methods.

4.3.2.2. Intermediate- and high-level activity liquid waste treatment

For intermediate-level activity liquid wastes, i.e. those with an activity higher than that for the low-level activity wastes, essentially the same considerations and factors apply as for low-level wastes. The three main methods of treatment, i.e. chemical treatment, ion-exchange and evaporation, or combinations of them, can
still be used but the D.F. obtained assumes greater importance. Of great importance is the volume reduction factor obtained in the process since the activity of the concentrate will be such that fixation of the activity by some method is almost certainly necessary.

It may be that for a research establishment or reactor site, if careful consideration has been given to good segregation practice, the small volumes of intermediate- and high-level liquid wastes which do accumulate can best be handled by solidification. Conversely, it may be possible in some areas with a high environmental capacity to receive activity, for intermediate-level wastes to be discharged directly to the environment, e.g. to the ground. However, this involves an extensive study of the environment, and for most establishments it is preferable that intermediate-level wastes be treated so as to reduce the volume for disposal or storage or, alternatively, if the radioactivity results mainly from short-lived isotopes, storage to allow decay of the radioactivity to a level allowing it then to be treated as low-level activity waste may be sufficient.

If the volumes of intermediate-level liquid waste are not sufficiently large it is also worthwhile considering not only the three main methods of treatment mentioned above or combinations of them, but to consider their incorporation into bitumen as well as cement or cement-vermiculite mixtures. The volumes of high-level activity liquid wastes that occur at most establishments will be so low that little consideration should be given to treatment of them. It is probably necessary only to provide storage facilities for the liquids either in special containers, or to incorporate the liquid in bitumen or cement to provide some safety factor with respect to leachability and then to store the incorporated material rather than to dispose of it.

However, with the wastes arising from reactor fuel processing the high-level wastes represent a considerable problem not only because of their radioactivity but also because of the volume. The low- and intermediate-level liquid wastes that occur can be treated and disposed of in a similar manner to wastes arising in other branches of the nuclear industry. It will, however, probably be necessary to install treatment facilities for the intermediate-level activity liquid wastes.

High-level liquid wastes arising from reactor fuel processing represent more than 99.9% of the radioactivity contained in the total wastes produced by the nuclear industry. It may appear at first sight that the very high radioactivity of the high-level wastes (up to
10 000 Ci/litres) is the main source of concern for those engaged in radioactive waste management. That this is not the case is due to the fact that tank storage is a safe procedure. Considerable research work has been expended and is being expended on developing methods of solidification of these wastes so as to reduce the volume and the hazard for ultimate disposal. Considerable effort has also been expended in developing methods of ultimate disposal, e.g. disposals into salt mines. Conversely, a lot of attention is being given to extraction of some of the mixed fission product radioisotopes from the high-level liquid wastes so as to reduce the possible hazard but mainly to develop economic uses for these isotopes. A lot more remains to be done before the problem of high-level activity liquid wastes is overcome. However, until then, the present storage methods assure that no hazard is being caused to man and his environment.

Before a country proceeds with reactor fuel processing a considerable knowledge of radioactive waste management should be available in that country. Only limited attention has therefore been given in this report to the factors involved in the problems of high-level activity liquid wastes. For information on the treatment and storage of high-level radioactive waste see Refs [27, 28].

4.3.2.3. Treatment of solid wastes containing radioactivity

If effective segregation of solid wastes is practised it will be found that a large proportion of the solid wastes arising at an establishment is capable of being disposed of at a burial ground or garbage dump within the establishment or under its control with very elementary precautions and monitoring requirements. It may be necessary to impose some restriction on the amount of material containing alpha activity which has to be buried because of the general long half-life of the alpha-emitting isotopes and the coincidental biological significance of the emitters. Sometimes it will be necessary to store the waste for a period to allow alpha-radioactive decay before disposal.

It is sometimes advisable to reduce the volume of the low-level solid waste before disposal. This is done by compression or incineration. The decision as to whether this should be done should be based mainly on economics.

However, it should be noted that if there are appreciable quantities of alpha activity or of toxic materials such as beryllium in
the solid waste, because of the possible airborne dust hazard com-
pression or baling of the waste can only be carried out if extensive
air-cleaning equipment is installed. It is important therefore to
know whether these materials are liable to be present.

The quantity of biological wastes, e.g. animal cadavers, liable
to occur should be determined, for if the quantity is appreciable the
installation of an incinerator should be considered. Incineration of
general radioactively contaminated solid wastes can be an involved
and costly process unless segregation of non-combustible solids is
carried out before incineration, otherwise difficulties can arise
during incineration and the volume reduction ratio obtained is insuf­
fi cient to warrant the use of incineration. Also, if isotopes are
present which volatilize on heating or the wastes generate excessive
quantities of dusts during incineration, extensive air-cleaning equip­
ment is required. Another problem encountered with incineration
is the presence of non-radioactive materials in the waste, e.g. PVC
plastic, which are liable to cause corrosion problems with the ma­
terials used in the construction of the incinerator. Care must also
be taken that materials which are liable to cause explosions or fires
are not present in the waste. Small domestic or institutional in­
cinerators have been found to be very useful for treating combustible
low-level radioactive solids, particularly putrefiable biological
wastes. However, since no special air-cleaning or ash-handling
facilities are usually associated with such units, activity content of
the wastes must be restricted to levels which will not result in un­
acceptable air-borne contamination.

The use of incineration for the treatment of wastes containing
relatively large quantities of radioisotopes requires specially de­
signed or modified units utilizing elaborate air-cleaning and ash­
handling systems. Because of the cost and complexity involved in
treating such wastes many establishments no longer operate inci­
n erators for this purpose. Therefore, before deciding to incinerate
solid waste a study should be made to see if incineration is war­
ranted. If the highly contaminated solid wastes are segregated from
the larger volumes of slightly contaminated solid waste, these may
be stored or if suitable may be incorporated in bitumen or cement
along with other types of wastes such as sludges and evaporator con­
centrates and medium-level liquid wastes before the material in­
corporated is disposed of or stored.

A major problem with all types of solid wastes is to know what
is the amount of radioactivity present in the waste. It is very easy
to obtain a radiation reading but difficult to associate this reading with the actual radioactivity contained in the waste. Several establishments have derived rough formulae to give a guide to the amount of radioactivity present as derived from the radiation reading but such guides are only approximate (see Ref. [29]). It is therefore essential that strict practice with respect to segregation, recording and labelling of solid wastes be done to ensure that no hazard results in any ensuing treatment process or storage system. This segregation and labelling is also essential to prevent incidents arising from the presence of flammables, alkali metals, acid-soaked rays, etc.

The following factors should be investigated before deciding on any method of treatment of solid waste (it may be desirable to collect and store solid wastes for a period so as to obtain a more accurate assessment of the type of solid wastes):

(i) Type of waste as regards physical and chemical form, i.e. organic or inorganic, combustible or non-combustible;
(ii) Type and amount of radioactivity present;
(iii) Type and amount of toxic and flammable non-radioactive materials present;
(iv) Amount of putrefiable waste;
(v) Presence of materials liable to cause corrosion or other hazard during an incineration process;
(vi) Storage or disposal facilities available and distance that wastes will have to be transported to such facilities.

4.3.2.4. Treatment of air-borne wastes containing radioactivity

The technology of treatment of airborne radioactively contaminated wastes (air-cleaning) is very well advanced, and once the permitted discharge has been established it is a relatively simple matter to determine whether air-cleaning is required and what method has to be adopted. This means that the approach to controlling air pollution from the operation of nuclear facilities is somewhat similar with establishments having similar operations. With airborne wastes it is the type of operation producing such wastes that will dictate the amount and type of air-cleaning required.

The type of operations and the conventional features of the ventilation system can be used to estimate the radioactivity that might be released to the environment if no air cleaning were provided. By
comparing this potential release with the regulatory limits, the degree of air cleaning needed can be determined.

The factors that must be considered and the methods adopted are given in detail in Ref.[15]. Treatment of air-borne wastes is so closely connected with ventilation systems that the following extract from Ref.[15] on the general aims of ventilation and air-cleaning systems applies.

"The problems of ventilation and containment of radionuclides are interrelated. As perfect containment can rarely be guaranteed it may be augmented by a ventilation system designed to prevent the movement of air-borne contamination to places where it is intended that personnel shall work without respiratory protection. An adequate ventilation system should also ensure that discharges of radioactivity to the environment are such that radiation dose rates to the public and to site personnel do not exceed the accepted international standards. This will usually require monitoring in ducts and possibly also in the environment. The ventilation system will also have to meet the ordinary requirements such as heating, cooling, and dust control necessary for the comfort of the operators as well as for technological reasons.

"In order to meet these requirements, it is necessary:

(i) To know how airborne contamination can arise in the facility under normal operation, maintenance and accident conditions.

(ii) To provide filtered and conditioned supply air on a once-through basis. This provides the controlled compensation for the air discharged to the atmosphere. Filtration of the inlet air reduces the dust loading on the exhaust filters. It is also desirable to keep the dust concentration in the working areas to a minimum in order to reduce surface contamination. The heating, cooling or humidification of air will help to provide a satisfactory working environment.

(iii) To maintain directional flows from the point of least contamination to the point of greatest contamination. This provides protection of laboratory personnel from the spread of
contamination by a haphazard ventilation air pattern. In laboratories, this will require controlled velocities in fume cupboards and air hoods and appropriate pressure drop between zones with different radiation and contamination levels.

(iv) To clean the exhaust air before it is discharged to the atmosphere, if it is necessary. In order to determine the degree of clean-up required, a preliminary evaluation of the hazards of continuously releasing the radioactivity and also the consequences of accidental releases is desirable. It may be found necessary to discharge via an exhaust stack to ensure satisfactory dilution.

"To ensure that a ventilation and air-cleaning system is operating effectively at all times it is necessary to monitor for contaminants in the working areas and, if necessary, in the area around the site, to check air flows in the ventilated area and to measure the efficiency of the associated air-cleaning equipment."

Provision of emergency power or emergency shut-down procedures to be followed when power is lost should also be carefully studied.

To decide the necessary height for a stack the following information is required:

(i) From the system designer — the average output of gaseous and suspended material in curies per second.
(ii) From the air-cleaning designer — the decontamination factor that his equipment will provide.

From (i) and (ii) is derived the stack output in curies per second. The radiation dose to the public resulting from using a stack of a given height can then be calculated by means of a formula giving the concentration in breathing air, averaged over a year, at the point of interest.

A stack is most effective within 20 to 30 stack-heights away from the stack. Its principal use is to protect people near to the stack. If the stack is to emit significant amounts of radionuclides it is advantageous for it to be high enough to penetrate above the normal inversion base level. Such emissions should, if possible, only be made under favourable meteorological conditions. This may require a
facility for storage of effluent gas, which is most easily achieved if highly active gases are segregated from the ventilation air.

4.3.3. Monitoring and waste records

Treatment and disposal operations usually involve several monitoring procedures to ensure that releases into the environment meet the pre-established requirements. In addition it is necessary in some instances to carry out environmental monitoring to assess the actual or potential exposure of critical population groups resulting from the disposal practice (see Refs [6, 7]).

It is essential that an efficient recording system showing the location of all wastes and their activities, etc., is established before operations commence. This recording system should not only be established for operational purposes but set out in such a form that it is available for inspection by the national competent authority, e.g. the public health service, which have the responsibility to ensure that waste management operations comply with any legislation or regulation that is applicable.

REFERENCES

WASTE MANAGEMENT SYSTEM QUESTIONNAIRE

The purpose of this Annex is to recapitulate, in the form of a questionnaire, what must be evaluated to enable a waste management system to be selected. It is the aim of this questionnaire to concentrate attention on those factors that need to be studied and enables a preliminary evaluation to be made relatively quickly. It is highly probable that detailed answers cannot be given immediately to some questions but no intensive investigational work should be done until a preliminary evaluation indicates that it is required. For some questions answers should be given not only for the situation at present but also estimates for the situation in two and five years' time; these questions are identified by an "x" beside the question number.

Frequently official organizations have collected or collect information on some of the factors involved. These organizations should be contacted before an investigation is carried out.

1. (x) What is the type of establishment being considered and what type of operational and/or research programme will be carried out?

2. (x) Will the waste treatment and disposal facilities be used for wastes arising at one site or at a central treatment or disposal facility? If the latter, where will the waste originate, i.e. the estimated proportion from research work, reactor operation, isotope users and other sources?

3. (a) What national and local laws and ordinances regulate radioisotope handling, and radiation protection associated with waste disposal, especially the maximum per-
missible discharge into the environment and whether disposal to sewers is permitted?

(b) What national and local laws and ordinances regulate environmental pollution by contaminants other than radioactivity, particularly the permitted discharge concentrations for such materials?

(c) If at present there are no national or local laws or ordinances, are they being prepared? What regulations and guides are used at present?

4. What are the organizations or authorities that exercise control over or are concerned with waste disposal and their relationship to one another?

5. (x) What is the total amount and type of radionuclides used or are expected to be used per year that are likely to produce wastes?

6. (x) What is the number of personnel likely to produce radioactive wastes.

7. (x) What are the categories into which waste is segregated? What is the range of radioactivity for each category? If factors other than radioactivity, e.g. high acidity or presence of solvents, toxic materials or detergents, are taken into account in the segregation specify the sub-categories within each category.

8. (x) What is the quantity of waste for each category per year? For liquid wastes, where possible state the proportion of the total and the activity of specific radionuclides known to be present in the waste.

9. (x) What is the volume of probable non-radioactive wastes per year, e.g. cooling water, engineering workshops waste and sewage?

10. (x) What are the present or proposed waste disposal practices, if any?

11. (x) Prepare a map or chart showing location of various areas from which wastes will be received; streams, rivers and
12. If a public sewage system is available and discharge to a sewer is permitted:
   (a) What is the size of the sewage system and the over-all flow and hourly variations of flow that occur within the system?
   (b) Is there any sewage treatment process?
   (c) Is there any utilization of the sewage sludge and of sewage effluent?
   (d) Are there any other disposers of radioactivity to the sewage system?

13. If wastes could possibly be disposed of into a river or lake:
   (a) What is the location relative to origin of effluent or the treatment plant?
   (b) What is the distance from estuarine waters?
   (c) What are maximum, minimum and average river flows?
   (d) What is the nature and quantity of other industrial or radioactively contaminated wastes, including thermal pollution, being discharged into the river or lake? Give details of any dilution studies relative to their disposal.
   (e) What is the chemical quality of the water, particularly with respect to suspended or colloidal material?
   (f) What is the water usage (quantity)?
      (i) Drinking water;
      (ii) Irrigation (state crops grown);
      (iii) Other.
   (g) What are the species and quantity of fish, shellfish or edible flora collected or harvested from the river, and the per capita consumption?
   (h) What are the other uses of the river, e.g. dredging of river bottom or for recreational purposes?
   (i) Is there any upstream or downstream regulation of river flow?

14. If wastes could possibly be disposed of into an ocean or sea:
   (a) What is the location of the estuary or ocean relative to the proposed treatment plant?
   (b) What are the tidal and current movements?
(c) What is the water usage for cooling water or other industrial purposes?
(d) What is the nature and quantity of other industrial or radioactively contaminated wastes being discharged into the estuary or ocean and details of any dilution studies performed relative to their disposal?
(e) What are the species and quantity of fish, shellfish or edible flora collected or harvested from the nearby marine environment, and the per capita consumption?
(f) Is there any bathing and sport usage?
(g) What are other uses of the marine environment, e.g. dredging from the ocean bottom?
(h) What is the depth at the disposal area if solid waste disposal is being considered?

15. If wastes could possibly be disposed of by shallow land burial
   (a) What is the depth of the water table?
   (b) What is the permeability of the soil?
   (c) What is the distance to nearest point of water usage?
   (d) Can soil absorb the radionuclides?

   (Note: Further details would be desirable such as the direction and rate of flow of the ground water, climate, particularly the distribution of rainfall and evaporation rate, and the proximity of population centres.)

16. If it is permitted to dispose of certain low-level wastes at municipal or industrial garbage dumps:
   (a) What is the location of the dump and whether water from dump drains into surface or underground waters?
   (b) What is the proposed usage of the dump after burial operations cease?
   (c) Is the dump fenced and are there any fire risks?

17. If wastes could possibly be disposed of into deep formations:
   (a) What is the hydrologic situation including depth of water table, direction and rate of flow of the ground water and relative rate of movement of the radioactive substances?
   (b) What is the geographical situation including physical features of the area, vegetation, climate, particularly precipitation (monthly, average, maximum and minimum),
location of adjacent water bodies, and water usage and location of population centres?

(c) What is the geological situation including type of soil, type of lower geological structures, permeability of formations, chemical and mineral compositions of formations and the physical chemistry of formations (sorption and desorption characteristics)?

(d) What is the chemical composition of the liquids being disposed of?

18. If atmospheric disposal is being considered:

(a) What is the geographical situation including physical features of the area, vegetation, location of crop growing and animal raising areas, and location of population centres?

(b) What are the micrometeorological data for the area including prevalent wind direction and wind speed during the year, vertical temperature gradient, precipitation (monthly average, maximum and minimum)?

(c) What are the other releases to the environment of airborne industrial wastes?

19. (x) Has there been any pre-operational study of the environment performed giving data on possible critical pathways determined and type of samples collected? What are future proposals?

20. (x) Give details of any present or proposed collection and treatment plant for radioactive and non-radioactively contaminated wastes. For waste treatment plants at present in operation give details of volume treated to date and decontamination factor obtained.

21. (x) What is the present and proposed storage capacity for the different types of wastes?

22. Consider availability and unit prices of power and heat, i.e. electricity, city gas, natural gas, liquid petroleum, gas, high- and low-pressure steam and high- and low-pressure hot water.

23. What are the characteristics of the water supply to the site, especially the concentration of magnesium and calcium salts
and chlorides and any unusually high impurities? Is water given any treatment before use and if so the method used?

24. Consider availability and approximate cost of the following consumables:
   (a) Commercial grade chemicals: sodium hydroxyde, sodium carbonate, trisodium phosphate, ferrous sulphate, ferric chloride, aluminium sulphate, and filter alum and other coagulants;
   (b) Vermiculite or other natural ion exchange material and synthetic ion exchange resins;
   (c) Bitumens, asphalts and tars;
   (d) Cement.

25. Materials. Consider availability and approximate cost of plastics such as PVC, polyethylene, etc., which may be used for piping or as a sheeting; corrosion-resistant surface coatings; stainless steel, mild steel and ceramic piping; and other materials which may be used for waste collection or treatment plant purposes.

26. If volume reduction of solid wastes by incineration or baling is being considered:
   (a) What is the type of waste according to its physical and chemical form, i.e. organic or inorganic, combustible or non-combustible?
   (b) What is the type and amount of radioactivity present?
   (c) What is the type and amount of toxic non-radioactive materials present?
   (d) What is the amount of putrefiable waste?
   (e) Are there any materials present that are liable to cause corrosion or other hazard during an incineration process?
   (f) What are the storage or disposal facilities available and what is the distance that wastes will have to be transported to such facilities?

27. What is the present situation regarding the availability of local civil, mechanical and electrical engineering consultants and services, particularly those with experience in industrial water and sewage treatment?
28. What are the capital construction and yearly operational expenses that could be allowed for waste treatment and disposal in the Budget?
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24-28 October 1966

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