The Management of Radioactive Wastes Produced by Radioisotope Users

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1965
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SAFETY SERIES No. 12

THE MANAGEMENT OF RADIOACTIVE WASTES PRODUCED BY RADIOISOTOPE USERS

A CODE OF PRACTICE BASED ON THE REPORT OF A PANEL OF EXPERTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1965
International Atomic Energy Agency.


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FOREWORD

An important part of the work of the International Atomic Energy Agency is to advise on the safe handling of radioactive wastes. The code of practice presented here as part of the Agency's Safety Standards deals with the problem of handling the relatively small quantities of waste arising from the use of radioisotopes in laboratories, hospitals and industry when no special facilities for radioactive waste disposal are available on the site. It is based on proposals from two panels set up by the Agency, the panels including members drawn from nine countries and representatives from three international organizations (including IAEA).

The Board of Governors of the Agency considered this code of practice in September, 1964 and authorized its application to Agency and Agency-assisted operations, and a recommendation to Member States that it be taken into account in the formulation of national regulations.

This code of practice is intended for the guidance of radioisotope users and of other persons or authorities responsible for the individual or collective management of such wastes. It stresses the need for proper governmental control of the arrangements made for receiving, using and disposing of radioactive materials. Succeeding chapters discuss waste management that can be left to the individual user, waste management in a central facility serving a number of users, and waste storage and environmental containment. For reference, a table showing the types of waste associated with some of the more common uses of a number of radioisotopes is appended, together with some extracts from the relevant regulations of three of the Member States.

The document should serve to clarify some of the problems confronting the radioisotope user and so contribute to a greater acceptance of radioisotopes as a standard tool for modern science and technology.
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CHAPTER 1

INTRODUCTION

1.1 Purpose

1.1.1 This manual is presented within the framework of the Agency's Safety Standards as a code of practice on the management of radioactive wastes produced by radioisotope users.

1.1.2 It is intended for the guidance of radioisotope users and of other persons or authorities responsible for the individual or collective management of such wastes. Its application to actual uses will vary with the types of waste involved, the government controls, and especially the environmental conditions encountered.

1.2 Scope

1.2.1 The manual is limited in scope and deals only with radioactive wastes originating from one or more radioisotope users in a given country or under the jurisdiction of a single government. It does not deal with wastes resulting from the operation of nuclear reactors or of fuel fabrication or fuel reprocessing facilities; neither does it deal with the uranium mining and milling industries nor with the production and processing of isotopes.

1.2.2 The radioactive wastes with which this document is concerned include materials that become contaminated by physical contact with radioactive materials. These materials may be solid objects, such as absorbent paper, rags, hypodermic needles or glassware used for handling or containing radioactive solutions; they may also be animals used in biological experiments. Waste materials may be liquids resulting from the washing or rinsing of contaminated solids, or they may be actual discarded isotope solutions or excreta from patients treated with isotopes; they may also be aerosols or gases resulting from the evaporation of liquids or from the combustion of flammable materials. Annex I contains
a list of types, amounts and uses of radioisotopes, together with an indication of the kinds of radioactive wastes associated with the various uses.

1.2.3 For maximum safety and protection of public health, it is necessary to have rules and regulations governing the uses of radioisotopes and also the waste-management operations of small-scale users of radioisotopes. Chapter 2 of this manual presents a brief review of the scope and nature of the necessary control. In particular, it gives guidance on the establishment of permissible limits for the discharge of radioactive wastes. Pertinent extracts from the regulations of several Member States are given in Annex II as examples of government controls. These vary in scope, severity and detail, depending on the nature and extent of the uses of radioisotopes in the country concerned.

1.2.4 Only simple, well-proven procedures should be recommended for use by individual users of radioisotopes. More complicated procedures should, generally speaking, be reserved for special waste treatment centres. Chapter 3 includes sections on waste management procedures relevant to the individual user of radioisotopes, i.e. collection, transfer, storage of liquid and solid wastes, controlled discharge and burial of low-activity wastes, and decontamination of exhaust gases. The subject is dealt with in Chapter 3 up to the level of a small waste treatment centre.

1.2.5 Chapter 4 contains sections on more complicated methods, recommended for waste treatment centres, as well as basic information on compression, evaporation, incineration, chemical treatment and ion exchange.

1.2.6 Chapter 5 deals with the requirements for temporary and long-term storage and for disposal of radioactive wastes arising from the use of radioisotopes. The sections on storage and ground disposal of solid and liquid waste emphasize the importance of preliminary investigation of the local environment.
1.2.7 The manual should be read in conjunction with the following Agency safety standards:

**Basic safety standards for radiation protection**¹

**Safe handling of radioisotopes, 1st ed. with rev. Appendix**¹

**Regulations for the safe transport of radioactive materials**¹

**Code of practice for provision of radiological protection services**
Safety series, IAEA, Vienna (in course of preparation).

1.2.8 Detailed information on disposal of radioactive wastes into the environment is given in the following Agency reports:

**Radioactive waste disposal into the sea**¹

**Disposal of radioactive wastes into fresh water**¹

**Radioactive waste disposal into the ground**
Safety series, IAEA, Vienna (in course of preparation).

1.2.9 Information and further technical guidance on waste management procedures, including practical examples, are given in the following Agency publications:

**Technology of radioactive waste management avoiding environmental disposal**²

**Techniques for controlling air pollution from the operation of nuclear facilities**
Technical reports series, IAEA, Vienna (in course of preparation).

1.2.10 Bibliographies on the processing and disposal of radioactive wastes are to be found in:

**Processing of radioactive wastes**²

¹ Available in English, French, Russian and Spanish
² Available in English only
Disposal of radioactive wastes into marine and fresh waters\textsuperscript{2}


\textsuperscript{2} Available in English only
CHAPTER 2

CONTROL OF THE USE OF RADIOISOTOPES
AND OF THE DISPOSAL OF RADIOACTIVE
WASTES

2.1 Restriction of the use of radioisotopes

2.1.1 Because radioactive materials are potentially hazardous it
is strongly recommended that each country should have re-
gulations governing the use of radioisotopes. This is par-
ticularly necessary in view of the fact that the hazard may
extend far beyond the premises in which the isotopes are
stored or used and may persist for a considerable time. The
responsibility for drawing up and enforcing the regulations
should be delegated by the national government to a national
authority, which would be empowered through a system of
licensing or notification to restrict the possession and use
of radioisotopes to those who can handle them safely. Ex-
tracts from three sets of national regulations are given in
Annex II.

2.1.2 A licensing and enforcement system including control of
supply is an effective means of controlling the uses of radio-
active materials and the methods of their disposal. With
such a system a competent authority can maintain continuous
surveillance of the whereabouts of all the radioisotopes under
its jurisdiction. In brief the system works as follows:
(a) The prospective user of radioisotopes makes application
to the authority for a licence; the experts of the authority
review the licence application in the light of certain health
and safety standards; if the standards are met a licence is
issued to the user enabling him to obtain the desired radio-
isotopes and to use them subject to the prescribed standards.
(b) If the standards are not met the licence application is
rejected with a notification of the reasons; the applicant must
then revise his proposed procedures and re-apply for the
licence.
(c) After a licence is granted the authority should send in-
spectors periodically to the user's installation to ensure
that he is actually complying with all standards and regulations; if he is not, the licence can be revoked and the right to use radioisotopes withdrawn.

2.1.3 The purpose of the application to use radioisotopes is to show that the proposed user is qualified to use them and that the methods he intends to apply will not jeopardize either his own health and safety or the health and safety of others. An application to use radioisotopes should include statements as to the competence and experience of the applicant (or of the person supervising the work), the quantities and kinds of radioactive materials to be used, the radiation fields likely to be encountered, the proposed manner and conditions of use (from the time of receipt of the material through to that of ultimate disposition, i.e. discharge or transport), the equipment and facilities available for handling the radioactive materials, the radiological safety (monitoring) procedures to be applied and also the purposes for which the isotopes are to be used.

2.1.4 If waste materials are to be discharged by the user, he should also submit his own analysis and evaluation of pertinent environmental factors (e.g. topographical, geological, meteorological and hydrological conditions, the uses of ground and surface waters in the vicinity of the disposal point and the nature and location of facilities which could be affected) and of the operational procedures to be carried out.

2.1.5 In the event of the user being unable to dispose of the wastes, he must make an agreement providing for their delivery to a facility for the collection, treatment and disposal of wastes.

2.1.6 Each application should be reviewed and evaluated by the competent authority, particular attention being paid to the question of safe disposal of possible radioactive wastes. If review and evaluation by experts within a country is not possible, the Agency can provide assistance. General guidance is given in the Agency's publication 'Basic safety standards for radiation protection'.

2.2 Individual and collective disposal of radioactive wastes

Waste management may be carried out entirely by the individual user or else the wastes may be sent by the user to a
central facility for their treatment and disposal. Treatment may include incineration in the case of solids and evaporation, ion exchange or chemical processing in the case of liquids. There will probably be facilities for long-term storage or burial of solid wastes, adequate storage tanks for ordinary wastes and special tanks for concentrated liquid wastes. The regulatory authority should decide which wastes can be dealt with more safely by transfer to special national or regional centres for collective management and long-term control. It should be borne in mind that the hazard of a particular radionuclide depends upon its toxicity to man, its physical and chemical form, and its capacity to contaminate the environment. Toxicity of radionuclides is discussed further in IAEA Safety Series Nos. 1 and 6 and in an IAEA Technical Report.  

2.3 Assessment of consequences of discharge of radioactive wastes and establishment of permissible discharge limits

2.3.1 The prime and overriding consideration in all radioactive waste management is the safeguarding of human health. It is the view of the International Commission on Radiological Protection (ICRP) and similar groups of experts that man can receive certain small doses of radiation without significant risk of somatic or genetic injury. However, every practicable step must be taken to minimize radiation exposures. The ICRP has drawn up recommendations on the subject which have been endorsed by the Agency (see Safety Series No. 9; cf. section 1.2.7). These recommendations are revised from time to time, as more data and experience are obtained. Such changes must be taken into account when establishing waste management procedures. In particular, any reduction in the recommended maximum permissible exposures may necessitate more stringent waste management procedures.

2.3.2 The aim of regulatory control should be to specify limits on environmental disposal. The competent authority —

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3 International Atomic Energy Agency, A basic toxicity classification of radionuclides Technical reports series No.15, IAEA, Vienna (1963) 39pp., available in English only.

4 For more detailed information, reference should be made to the other Agency documents indicated in paragraphs 1.2.7 to 1.2.9.
which may be a user of radioisotopes if no other competent authority exists — must show, by calculation or experiment, that discharges up to the specified limits would not cause the prescribed exposure limits (usually those recommended by ICRP for the general population) to be exceeded. Consideration must be given to processes of dispersion and reconcentration of radioisotopes in the environment, and allowance must be made for other sources of radiation exposure, e.g. fall-out contamination. Safety factors must also be applied to allow for the approximate nature of the calculations.

2.3.3 In calculating exposure limits, appropriate use should be made of the maximum permissible concentrations (MPCs) of radionuclides in air and water, as calculated by the ICRP. These are maximum concentrations of individual radionuclides in air and water, continuous exposure to which would not, on the basis of conservative assumptions, lead to radiation exposure beyond the maximum permissible as defined by ICRP. Great care must be used in the application of these recommendations in cases where the consumption of air and water may not be the principal source of radiation exposure of man. In the case of intake via a food chain, the concentrations may be used to assess maximum permissible intakes by man but should not be applied directly either to the air and water of the environment or to the foodstuffs themselves. The values for maximum permissible concentrations can be used either as absolute limits which must not be exceeded (as in the Union of Soviet Socialist Republics), or as average limits over a specified period. The intent of ICRP is that, over a period, an average might be used.

2.3.4 The sampling, analysis and other measures necessary to ensure that maximum permissible average concentrations over a long period are not exceeded may involve considerable additional expenditure. If this expenditure is not feasible the best solution is to keep the concentrations within the maximum permissible levels. When more than one radionuclide is present, the concentration of each element must be considered; when the composition of the radioactive mixture is unknown, the maximum permissible concentration specified by ICRP for an unknown mixture must be used.
2.3.5 Although MPCs are defined by ICRP for air and water only, the value for water \((\text{MPC}_w)\) may be used to calculate the maximum permissible daily intake in microcuries for man, i.e. by multiplying the \(\text{MPC}_w\) by 2200 (the average daily water intake in millilitres per capita). This represents the maximum permissible intake from all sources, assuming that there is no external exposure. It must be remembered that organisms used as food often concentrate radionuclides from the environment; for example, in a fresh-water environment seriously deficient in natural phosphorus, fish flesh may contain 50 000 times as much phosphorus-32 per gram as the water from which the fish are taken. On the other hand, some isotopes may not be extensively concentrated by living matter.

2.3.6 The information required to make detailed estimates of intake and external exposure is seldom available in sufficient detail, and therefore special investigations may be necessary to collect geological, hydrological, climatological, meteorological and other data, as well as information about production and consumption of food-stuffs, and industrial, recreational and other uses of the environment, etc. Very often there are official organizations able to collect such data in the course of their normal duties. Recourse to such organizations may eliminate the possible risk of unnecessarily alarming the public.

2.4 Permissible limits on discharges to sewers

2.4.1 It must be emphasized that every waste disposal process is an individual matter because local conditions differ widely. Nevertheless, in the case of small discharges, certain broad principles can be laid down and some general guidance given. In discharges to sewers, the following factors should be considered:
(a) Contamination of sinks, drains, traps and sewers which might present a hazard during repair processes.
(b) Contamination of sewage, which could represent a danger to men working in the sewer.
(c) 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.
(d) Possible build-up of certain radionuclides in filter beds or other units of the sewage treatment system.
(e) Possible use of sewage sludge.

2.4.2 Each radioisotope discharged may behave differently and thus give rise to one or more potential hazards. Hence it is not easy to fix general limits. Account must be taken of the dilution of the isotope by flushing at the time of discharge into the sink or drain, the dilution by other non-radioactive waste discharges from the same facility and the dilution which the contaminated sewage undergoes in the collection sewers and main sewers. It is also necessary to consider whether or not other isotope users are discharging radioisotopes to the same sewer system and whether or not the regulations permit the daily or monthly averaging of flows in the sewers, in other words, whether limiting concentrations are average or instantaneous.

2.4.3 In populous areas sewage may provide high dilution factors whereas in sparsely populated areas the only dilution may be that taking place at the local site. In certain countries where the sewage system is not well developed, radioactive discharges will have to be limited to a level dependent on any subsequent use of the effluent. It is advisable in all cases to survey the sewers and downstream uses of sewage before planning the method of discharge.

2.4.4 As regards the use of sewage sludge as a fertilizer, there is evidence that such radionuclides as radiostrontium, which are more readily absorbed by plants than many other isotopes, are not incorporated in a sludge to any great extent.

2.4.5 In certain countries it has been found possible to lay down widely applicable limits on discharges to sewers. Examples from regulations in force in the United States of America and the Union of Soviet Socialist Republics are given in Annex II. In other countries, limits are determined primarily on a case-to-case basis. An example, taken from United Kingdom practice, is also included in Annex II. Where a country has no established guides or regulations, individual users should consult with local public health and sanitary engineering authorities and agree on provisional criteria.
and procedures for discharge to the local sewage system. Advice and assistance are also available from the Agency.

2.4.6 As a rough guide for use before maximum disposal limits have been worked out, one can take it as an obvious fact that no unacceptable risks will be run if the discharge of liquid wastes is effected in such a way as to ensure that the maximum concentration of radioisotopes in an underground municipal sewer does not exceed the concentration permissible for drinking water. In many countries the average rather than the maximum concentration is used for this purpose.

2.4.7 It is often possible to discharge certain radioisotopes to sewers at several times the levels recommended by ICRP for water. However, the radioactivity of material in which radioisotopes are likely to concentrate should be measured from time to time, so that discharge procedures may be modified if there are any indications that radiation hazards might develop.

2.4.8 Materials to be sampled include sediments, slimes and sludges in the sewage treatment plant, crops (irrigated with treated effluent or for which sewage sludge has been used as a soil conditioner), and sediments, fish and algae near the outfall if the sewer drains directly to a watercourse. The Agency reports on disposal of radioactive wastes into fresh water and on radioactive waste disposal into the sea deal with the subject of the monitoring of waters in greater detail, see section 1.2.8. External radiation levels in the neighbourhood of traps and other places where sediments can accumulate should be monitored periodically, particularly before repairs and maintenance work are carried out. The interval between the taking of samples for monitoring depends on the amount and rate of activity discharge. In some cases it may be weekly or monthly, in others, quarterly or semi-annual.

2.4.9 Waste should be released to sewers in such a manner that protective measures will not be required during maintenance work on sewers outside the establishment, unless otherwise agreed with the authority in charge of such sewers.
2.4.10 Because volumes of higher activity wastes from users of radioisotopes are usually small and can often be handled in other ways, dilution and discharge to a sewer should not be encouraged (cf. section 3.1.3 and Chapters 4 and 5).

2.5 Permissible limits on burial of radioactive waste in soil by individual users; use of municipal and industrial refuse dumps

2.5.1 Burial sites must be carefully selected to avoid contamination of water supplies through leaching of buried materials. There must also be assurance that the sites will remain undisturbed for long periods, the actual period in any particular case being determined by the radioactive half-lives of the buried materials.

2.5.2 Certain countries exempt limited amounts of short-lived radioisotopes from strict controls and permit local burial, provided that certain conditions are met.

2.5.3 Regulations for burial should be drawn up by the competent authority, which should bear in mind that it will usually not be easy to remedy potential hazards by recovering buried materials. Further guidance is given in Chapter 3.

2.5.4 In some cases individual users of radioisotopes can be authorized to bury certain low-activity wastes. The permissible limits on this type of disposal should be determined by calculation or experiment.

2.5.5 In densely populated areas it may be inadvisable to permit individual users of radioisotopes to bury wastes, because of the possibility of the ownership of the site being transferred or of accidental uncovering of the buried materials. However, if the user is able to demonstrate that the radioactivity involved cannot, under any conceivable circumstances, give rise to a hazard due to internal or external exposure, permission may be granted in special cases.

2.5.6 In some circumstances, use may be made of municipal and industrial refuse dumps for burial of certain low-activity wastes. The decision should, however, be left to the competent authority, even if the municipal or industrial authorities are not in opposition. The following are some of the questions that must be asked in this situation:
(a) Has the dump been carefully sited with a view to avoiding contamination of surface and underground waters?
(b) Is it fenced in and free of fire risks?
(c) Will the ground remain undisturbed for a long period after burial at the site has been discontinued?

The choice of burial sites and methods of burial are discussed in greater detail in Chapter 5.

2.6 Permissible limits on incineration

2.6.1 In general, it is not considered advisable to recommend incineration of solid waste as a radioactive waste management procedure for all individual users of radioisotopes. Regular hospital incinerators, modified to handle radioactive off-gases and ashes have been used in the United States of America, and some biological laboratories have successfully adapted small incinerators of a special type for burning radioactive organic wastes.

2.6.2 Permission to incinerate radioactive wastes, including those from luminizing plants, should be granted only after careful consideration of the nature of the wastes, the type of incinerator, and the nature of the local environment. These points are discussed more fully in the section on incineration in Chapter 4.
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CHAPTER 3

WASTE MANAGEMENT BY INDIVIDUAL USERS OF RADIOISOTOPES

3.1 General considerations

3.1.1 The quantities of radioisotopes employed by most users are quite small, and the half-lives are usually short. Consequently most of the wastes produced are not very hazardous and can be dealt with fairly easily. The waste management problem can be reduced by using a minimum amount of radioactive materials, by maintaining strict laboratory discipline and by using equipment which can be decontaminated easily. The Agency manual on Safe Handling of Radioisotopes, Safety series No.1 (see section 1.2.7), provides further information on these points.

3.1.2 In practice, a large proportion of the liquid wastes produced by such individual users as university laboratories contain concentrations of radioactive materials below the maximum permissible levels prescribed for direct discharge to the local sewer. Disposal of these wastes through a sump presents no difficulty. Low-level wastes can sometimes be rendered innocuous by addition of the non-radioactive isotope, thus reducing the specific activity to an acceptable level.

3.1.3 Liquid wastes which are too radioactive to be discharged to the sewer immediately can often be discharged after a period of radioactive decay. In practice, however, this applies only to smaller amounts of wastes containing radioisotopes with half-lives of less than 30 days.

3.1.4 Liquid wastes which cannot be discharged to the sewer, even after decay storage, must be segregated and other arrangements made for dealing with them (see Chapters 4 and 5).

3.1.5 Solid wastes present a different problem. It is usually difficult to measure the extent to which they are contaminated
and therefore materials which may be insignificantly con-
taminated must often be regarded as radioactive.

3.1.6 Solid wastes containing only short-lived radioisotopes can
be stored until their activity has decayed to such insignifi-
cant levels that they can be disposed of safely with normal
refuse.

3.1.7 Wastes which cannot be disposed of in this way must be
stored and other arrangements made for dealing with them.
(See Chapters 4 and 5).

3.1.8 Airborne wastes are usually of low activity and can in some
cases be discharged directly to the atmosphere without ha-
azard. Where this is impossible, purification of exhaust
air by filtration or scrubbing, and occasionally by adsorp-
tion of radioactive gases, is required.

3.2 Procedures for waste collection

3.2.1 General considerations

3.2.1.1 All receptacles for radioactive wastes should be
clearly identified. In general, it is desirable to classify
radioactive wastes according to methods of disposal or stor-
age used, and to provide separate containers for the various
methods. Depending upon the requirements of the instal-
lation, one or more of the following categories for the clas-
sification of wastes may be useful:
(a) gamma radiation levels (high, low);
(b) total activity (high, intermediate, low);
(c) half-life (long; short);
(d) combustible, non-combustible.
For convenient and positive identification, it may be de-
sirable to use both colour coding and wording.

3.2.1.2 Shielding containers should be used when ne-
cessary.

3.2.1.3 It is generally desirable to maintain an approxi-
mate record of quantities of radioactive wastes released
to drainage systems, to sewers, or for burial. This may
be particularly important in the case of long-lived radio-
isotopes, for which purpose it is desirable and even neces-
sary to maintain a record of the estimated quantities of ra-
dioactivity deposited in various receptacles, particularly
those intended for high levels of activity or long-lived isotopes. Depending upon the system of control used at the installation, it may be desirable to mark or tag the receptacle in such a way as to indicate its contents.

3.2.2 Collection and segregation of liquid wastes

3.2.2.1 Liquid wastes should be collected and segregated according to level and type of activity, the method of disposal for each waste to be determined by these factors.

3.2.2.2 Special containers, large enough to hold the volume of waste anticipated, should be made available and kept at a readily accessible location. To facilitate subsequent handling, it is good practice to segregate liquid waste according to radioactivity level and chemical composition. The best method of handling wastes containing only short-lived radioactivity is to collect them separately, because storage for a limited time may greatly simplify the disposal problem. Containers for liquid waste should be placed in a tray or, preferably, enclosed in a strong outer casing with enough inert absorbent material, such as expanded vermiculite to limit the spread of contamination in case of accidental breakage.

3.2.2.3 Concentrated radioactive liquid wastes. Concentrated liquid wastes from a laboratory usually consist of limited volumes of unused source solutions and experimental end-products. These should be placed in containers selected in accordance with the properties of the waste solutions. Plastic containers are to be preferred for most solutions, but the presence of certain organic solvents may require the use of stainless steel. The use of glass containers is not recommended and only unbreakable materials should be used. The containers should be kept in shielded enclosures appropriate to the radiation characteristics of the radionuclides concerned. Thermally unstable solutions containing radioactive materials in nitric acid or other oxidizing solutions containing even traces of organic material, and also stable solutions with an alpha activity in excess of 5 mc or a beta activity in excess of 50 mc should always be stored in vented vessels. A suitable record should be kept of the contents.
3.2.2.4. Dilute radioactive liquid wastes. Dilute liquid wastes may result from leftover solutions, rinse waters from such operations as the cleansing of laboratory equipment (e.g. beakers, flasks), experimental by-product wastes (e.g. excreta of animals), waste water from the laundering of contaminated clothing, or from the cleansing of areas (e.g. hoods) where radioactive materials have been used.

3.2.2.5. The volume may vary considerably, depending on the nature and extent of the use of radioisotopes. Some operations may produce less than 20 l per week, others up to hundreds of litres per week. If the volumes are relatively small, e.g. less than 50 l per day, it will probably be feasible to collect these liquids in special containers.

3.2.2.6. Plastic or stainless steel are suitable containment materials because they are non-breakable, although glass and ceramics can be used for small containers if they are carefully handled. Containers set in a large tray can be placed directly beneath a sink with a flexible hose or drain extending well into the container to prevent splashing. When full or nearly full, the container should be replaced by an empty one, as required. The full container is then monitored and disposed of in accordance with the composition of the waste and the discharge, treatment or transport requirements.

3.2.2.7. If the volumes of dilute waste are large or the discharge is continuous, and if it is necessary to monitor these wastes prior to further disposition, it may be desirable to install a holding tank system. Special disposal sinks can be connected to a holding tank outside the working area. Tanks are usually constructed of carbon steel or stainless steel, depending on the corrosiveness of the wastes. The waste can also be neutralized prior to discharge to the tank. Experience has shown that mild steel tanks lined with rubber or plastic are very practical.

3.2.2.8. More than one laboratory may be connected to the same tank. A pipe of plastic, or stainless steel, or cast iron or steel (in that order) is a satisfactory means of connecting the sinks with the holding tanks, depending on the
chemical or corrosive nature of the wastes. The tanks should be provided with a means for mixing the contents, so as to permit withdrawal of a representative sample for analysis. They should be valved so as to permit discharge to a sewer (if within discharge limits) or to permit pumping to a tank truck for hauling to a central waste treatment facility. The radiation levels of the piping system and tanks should be monitored regularly.

3.2.3 Collection and segregation of solid waste

3.2.3.1. Solid waste should be segregated during collection with a view to subsequent treatment and handling processes. Bags used for solid waste collection should be kept in containers to prevent tearing and the spreading of contamination, e.g. during floor cleaning. Refuse bins equipped with foot-operated lids and lined with removable paper or plastic bags should be used where practicable. Care is necessary when using certain kinds of foot-operated lids to avoid spreading contamination on opening if the contents are dusty. Bags should be sealed by clips or adhesive tape before removal from containers.

3.2.3.2. Combustible solid waste for incineration. Combustible materials such as rags and paper can be collected in waterproof paper or thick gauge plastic bags. It may be necessary to exclude large quantities of materials such as polyvinyl chloride (which gives rise to acid gases on combustion and is very liable to cause corrosion of steel and stainless steel components of an incinerator plant).

3.2.3.3. Solid waste for pressing. Solid waste for pressing can be collected in water-resistant paper or plastic bags. Materials containing large quantities of liquid should be excluded.

3.2.3.4. Putrefiable solid waste. Putrefiable waste can be collected in polyethylene bags. If refrigerated storage space is not available, it is useful to add materials such as vermiculite or diatomaceous earth to absorb fluids. The addition of formaldehyde, lime or hypochlorite solution may also be advantageous. A small amount of dilute formaldehyde delays decomposition and concentrated formaldehyde leads
within about a year to the mummification of small animal carcasses.

3.2.3.5. Miscellaneous solid waste. Segregation of solid wastes such as broken glassware, jagged metals and precipitates from chemical experiments may be advisable in particular circumstances. Unusual solid waste, such as contaminated laboratory furniture and linoleum, may have to be segregated for storage or transport. Encasement by painting or spraying is not to be recommended unless the surface activity is firmly fixed. Wrapping in inexpensive plastic sheeting is usually satisfactory.

3.3 Airborne waste

3.3.1 Special work hoods and exhaust systems must be used in operations involving the production of significant amounts of airborne waste. For most uses of radioisotopes the purification of exhaust air streams is unnecessary. However, ventilation systems should be so designed that contamination cannot spread to other parts of the building and that the exhaust outlet is suitably placed. However, provision must be made for the removal of radioactive material unless it can be demonstrated that no hazards will arise.

3.3.2 Methods used for the retention of gaseous waste, including the use of carbon filters, chemical absorbents and cold traps, are referred to in the Agency Technical report (see section 1.2.9) on techniques for controlling air pollution from the operation of nuclear facilities. It must be emphasized that the design and installation of anything more than the simplest types of exhaust and air cleaning equipment should be undertaken only by specialists in those fields.

3.3.3 There is always some risk of release of active materials from filters in case of fire. Care must therefore be taken to reduce fire hazards by proper choice of filters and control of operations carried out in fume hoods.

3.3.4 Air cleaning equipment should be inspected regularly and filters replaced carefully when defective, or when external radiation levels approach prescribed limits. Precautions must be taken to prevent subsequent dislodgement of radio-
active materials from filters, for example by wrapping them in polyethylene film. Very active filters should be subjected to indiscriminate compaction only under controlled conditions.

3.4 Transfer and emptying of waste containers

3.4.1 When a waste container is full or nears the prescribed radiation limit, it should be removed from the working area to a special storage area of the pick-up point.

3.4.2 The receptacles used for waste collection should be suitable for transporting waste in order to avoid any transfer of radioactive materials. In some cases the wastes themselves or preferably the original receptacles may have to be transferred to special transport containers. It is convenient if the latter containers can be left intact at the disposal area. Useful information is given in 'Regulations for the safe transport of radioactive materials', Safety series No. 6 (see section 1.2.7).

3.4.3 Special precautions must be taken to limit dispersal of radioactive material. Protective clothing, including respirators, may be needed for the protection of personnel, and ventilation and possible contamination of the transfer area are important considerations. Many problems can be avoided by causing smaller amounts of liquid wastes to be absorbed by such materials as expanded vermiculite in order to avoid transporting them as liquids.

3.4.4 Experience has shown that contamination can easily develop if liquid wastes are poured from one container to another. To avoid this, special pumps or vacuum devices should be used, care being taken to ensure that all drippings fall back into the containers.

3.5 Methods of discharge to the sewer

3.5.1 Radioactive wastes discharged to drains should be readily soluble or dispersible in water. Account should be taken of possible changes in pH-value due to dilution and of other physico-chemical factors which may lead to the precipitation or vaporization of diluted materials.
3.5.2 Where maximum permissible concentrations or maximum daily or weekly limits on discharge to sewers have been established (see section 2.4) it is advisable to estimate transient concentrations in the sewer in order to decide what discharge methods should be adopted.

3.5.3 Once the maximum permissible transient concentrations have been established it is necessary to decide what practical arrangement will be required to ensure that they are never exceeded. Consideration must be given to the variable flow rate of water in the sewer.

3.5.4 If it appears that the maximum permissible transient concentrations could be exceeded by simple discharge methods, e.g. by pouring into a sink when the tap is running, or by flushing a toilet used by a patient being treated with radioisotopes, arrangements should be made for the discharges to be effected in small batches at intervals, or through a constant head orifice or similar means, so as to maintain a relatively uniform low rate of discharge.
CHAPTER 4

PROCEDURES FOR THE TREATMENT OF RADIOACTIVE WASTE NOT NORMALLY DISPOSED OF BY INDIVIDUAL USERS OF RADIOISOTOPES

4.1 General principles

This document deals with two systems of waste management. In the first, disposal is carried out entirely by the individual user himself; in the second, it is carried out by a regional centre for collective management. In the first system, the individual user stores or otherwise disposes of his own radioactive wastes, making use of such processes as decay or resorting to burial or discharge. It is not recommended that every user of radioisotopes should carry out treatment; this can be carried out more advantageously at waste treatment centres serving groups of users. Only simple ion exchange and chemical decontamination should be used by individual users. In the second system each user transports his wastes, usually untreated, to a central treatment and disposal facility where wastes from a number of users can be more efficiently decontaminated or concentrated and stored. An advantage of the central facility is that all the radioactivity is accumulated at one place, where its contamination potentiality can be more effectively controlled.

4.2 Treatment of solid waste

4.2.1 Compression

The volume occupied by many types of solid waste materials can be conveniently reduced by compression in a commercially available press, duly modified. The reduction in volume varies, depending mainly on the type of waste; advice in the matter should be sought directly from the manufacturers of presses. The usual reduction is to between one half and one-tenth of the original volume. Generally, there is little or no advantage in increasing the pressure
beyond about 10 kg/cm². The waste can either be pressed into a suitable container (commonly a metal drum) or pressed and then baled. Special precautions must be taken to avoid the creation of dust hazards when materials are placed in the press and during operation of the press.

4.2.2 Incineration

As a considerable proportion of solid waste is combustible, incineration is often a convenient means of volume reduction. This method has the advantage of transforming waste into a form unattractive to rodents and in certain cases is an advantageous means of dealing with contaminated animal carcasses and other putrefiable wastes.

4.2.3 Any incineration operation should always be carefully analysed. Account should be taken of such matters as incomplete combustion, release of radioisotopes to the stack (and subsequent dilution available), fall-out of radioisotopes emitted from the stack, plating out of radioisotopes on stack walls, retention of radioisotopes (in the form of dust) in the ashes and the subsequent handling of the ashes.

4.2.4 The burning of radioactive wastes in the open can result in widespread contamination from fine dust and airborne gases. Almost all types of combustible waste can be incinerated, but possible corrosion of equipment is an important consideration. It must be borne in mind that during incineration the chemical toxicity of the products of combustion of contaminated waste materials, cf. Teflon, may be the greatest hazard.

4.2.5 The main requirements for incinerator handling of large amounts of radioactive waste may be summarized as follows:

(a) Complete combustion, which requires the use of auxiliary firing with gas or fuel oil.
(b) Efficient decontamination of the flue gases.
(c) Ash handling arrangements which do not give rise to dust hazards.
(d) Adequate monitoring and maintenance (periodic measurements should be made of radioactivity deposited in the environment of the incinerator). Care must be taken to ensure that filters or scrubbers remain in good working order.
4.2.6 Contamination hazards can be minimized by making arrangements to keep the incinerator pressure below atmospheric. Formation of aerosols can be reduced by pre-drying of the waste materials.

4.2.7 Permissible limits on incineration

It is difficult to lay down maximum limits for incineration (see section 2.6). Much depends on the toxicity of the isotopes present, the efficiency of the gas purification, the dispersal after discharge from the stack and the ash handling facilities.

4.2.8 Decontamination factors

The ratio of the activity originally present to that disposed into the environment via the stack depends on the isotopes present, the combustion temperature and the efficiency of the air cleaning system. For all isotopes except those in a volatile form, e.g. radioactive iodine, the average ratios at the AERE (UK) incinerator have been roughly $10^4$-$10^5$. When a water scrubbing system is used, the ratio for radioactive iodine and other volatile isotopes can be improved by maintaining the pH-value of the scrubbing liquid at 9.0 to 10.0. However, this is difficult due to the formation of large quantities of carbon dioxide. Consequently, volatile radioisotopes must not be incinerated unless it can be demonstrated, on the basis of conservative assumptions, that no hazards will arise.

4.2.9 Volume reduction

The extent of volume reduction by incineration depends upon the types of materials handled and the degree to which these are compressed beforehand. In the case of paper and similar materials, tightly packed, a volume reduction up to 80:1 can be obtained. With carcasses and denser material, a volume reduction of up to 30:1 is possible. Wastes from treated scrubber-liquids and filters permit of less volume reduction, the figure of 80:1 becoming approximately 50:1.

4.2.10 Construction materials

In general, it is advisable to use conventional firebrick linings for the furnace. This helps to obtain and maintain
the high temperatures required for disposing of certain wastes such as animal carcasses. Only in exceptional cases are corrosion-resistant metals required. Filters for off-gases should be fire-resistant.

4.2.11 Handling of ashes

In some installations the ash is collected in water and then pumped as a slurry to a liquid waste treatment system or transferred to a collection drum fitted with an expandable cloth bag filter. In most cases the ash can be handled as a solid waste, the only precaution necessary being that of moistening the residue to avoid dust hazards.

4.3 Treatment of liquid waste

4.3.1 Evaporation

Evaporation has proved to be an exceedingly useful method of concentrating radioactive liquid wastes. Its main advantages may be summarized as follows:
(a) The distillate normally satisfies requirements for discharge to the sewer.
(b) Almost any liquid waste, including both the ionic and non-ionic, can be treated by evaporation provided that the right type of evaporator is chosen.
(c) The decontamination factor is normally higher than that obtained by other common methods.
(d) In many cases the volume of concentrate for storage, or ultimate disposal, is small.

4.3.1.1. It must be borne in mind, however, that evaporation has certain disadvantages. Difficulties may arise if volatile radioactive substances, such as ruthenium tetroxide and iodine, are present. With solutions of unknown composition, the decontamination factor obtained is largely dependent on boil-up rates and entrainment. Foaming entrainment and scale deposition can be serious problems. Care has to be taken to control corrosion and to destroy or exclude materials such as ammonium nitrate which can cause serious explosions. Thermal decomposition of waste constituents may also have to be considered.
4.3.1.2 Foaming can be controlled to some extent by the addition of anti-foaming agents, silicones being very effective for this purpose. The use of a film type evaporator may also help overcome foaming difficulties. Other effective procedures include the use of baffles, pH-value control and liquid level control.

4.3.1.3 In the design of an evaporator, reliability and ease of maintenance should be the first considerations.

4.3.1.4 Corrosion-resisting alloys like stainless steel are the structural materials normally used except where high chloride wastes are involved.

4.3.1.5 Evaporation is usually an expensive method of concentration, as relatively high capital investment is involved. For this reason the process is more attractive to the large user or treatment centre than to the small-scale user. The operating costs are largely dependent on the cost of the fuel. These costs can be reduced by using forced-vapour compression or multiple-effect evaporation.

4.3.1.6 Handling of final concentrate. Unless the evaporator is specially designed, it is normal practice to cease evaporation before crystallization occurs. This permits the residue to be removed from the plant without undue trouble. Experience has shown that a figure of about 60% solids in the final concentrate is a suitable average value. Above about 65% the concentrate becomes difficult to handle. In some cases, however, evaporation is carried to dryness.

4.3.1.7 Wet concentrates can be stored as such or absorbed by means of expanded vermiculite or natural clays and then handled as solid waste. Alternatively, they can be mixed with cement and allowed to set. The last-mentioned procedure generally produces a poor quality mortar which, because it leaches rather easily, may have to be enclosed in good quality concrete or in a suitable container to minimize leaching. Incorporation of concentrates into bitumen results in a product with favourable leaching characteristics.

4.3.1.8 The volume of concentrate depends on the solids present in the feed and the process used. For conventional processes, ratios of feed to concentrate may be between
10:1 and 50:1. The plant must be carefully designed and have the necessary instrumentation.

4.3.2 Ion exchange

Ion exchange is frequently used for the decontamination of aqueous active effluent. Its advantages are easy operation and easy adaptation to automatic and remote control. However, several important factors must be considered when high efficiency is required. Not only must the radioisotopes be efficiently removed, but they must also be concentrated into the smallest possible volume. Some of the considerations which influence the practicability of ion exchange are as follows:

(a) When the method is used directly, the total amount of suspended solids in the influent (feed) should be very low in order to avoid blockages in the resin bed. If the amount of suspended solids is high, pretreatment may be necessary.
(b) It is preferable that the content of dissolved non-radioactive materials in the influent should be low, so as to prolong the life of the bed and thus keep waste production at a minimum.
(c) The concentration of radioisotopes in non-ionic and colloidal forms should be very low.
(d) There is a possibility of interference by unusual complexing agents.

4.3.2.1 Some measure of control over these factors may be exerted in the following ways:

(a) Suspended matter can be controlled by segregation of the various waste streams. Cooling waters with a low content of suspended matter can be sent straight to the ion exchanger while laboratory wastes can be prefiltered. (Segregation also keeps the volume requiring pretreatment to a minimum).
(b) If segregation is not practicable, all the waste can be filtered or treated by chemical coagulation to remove suspended matter as well as some of the radionuclides.
(c) Partial removal of radiocolloids and non-ionic activity may result from the mechanical filtration stage of chemical treatments. Certain ion-exchange resins can be used for pretreatment to remove interfering non-radioactive ions.
prior to passage of the waste through the main ion-exchange bed being used for removal of radioactive material.

(d) Dissolved solids can often be kept at a low level by the use of demineralized water in those areas of an establishment handling radioactive material.

4.3.2.2. Concentration factors. Published information on the degree of concentration attainable by ion exchange shows widely differing results. Laboratory work on a small scale would be desirable in the interest of demonstrating the feasibility of the method and of developing processing procedures and determining equipment requirements.

4.3.2.3. Where waste is treated with ion exchangers without previous chemical treatment, the efficiency of the process depends upon the ionic content of the waste. If this content is high the ion exchanger will be rapidly exhausted. Regeneration results in a large volume of radioactive liquid and this presents a disposal problem.

4.3.2.4. When exchangers (usually inorganic) are used after chemical treatment and are not regenerated, the concentration factor depends solely on the throughput. This is greatly affected by the relative affinities of the cations present. Advantage may be taken of these relative affinities by converting the exchanger into the most suitable form.

4.3.3 Biological treatment

Biological processes may be satisfactory pretreatment methods for the removal of organic material from radioactive waste. The waste should not be highly acidic or alkaline, and should be free from toxic materials present in concentrations sufficient to inhibit growth of the organisms upon which the process depends. The decontamination factor for radioactive material is small, variable and unreliable. The main advantage of biological treatment is that it reduces the organic content to a level which enables the waste to be treated satisfactorily in other ways, e.g. by chemical treatment or ion exchange.

4.3.4 Solidification

Small volumes of liquid wastes, of medium to high activity, accumulate at all establishments from time to time and it
is often undesirable to mix them with other wastes. For safe storage or transport, it is advantageous for such waste to be solidified. This can be achieved by mixing with cement or a hard type of plaster, or by absorption on expanded vermiculite or clays (such as montmorillonite or kaolinite).

4.3.5 Chemical treatment

The object of chemical treatment is to concentrate the radionuclides present into a small bulk of insoluble sludge which can be separated.

4.3.5.1. Although chemical treatment of liquid radioactive waste does not normally yield high decontamination factors, it is often the most economical and practicable solution where large volumes are concerned. Some chemical conditioning may also be required prior to evaporation, in which case it is good practice to use a treatment which is also effective for decontamination. Such treatment is also advantageous in the removal of suspended matter before treatment by ion exchange.

4.3.5.2. Other advantages of chemical treatment are that it is relatively cheap, that it involves methods and equipment for which considerable experience is available and that it is largely independent of the inactive constituents of the waste. One disadvantage is the production of chemical sludges requiring further handling.

4.3.5.3. Many precipitating and flocculating agents can be used for this treatment: these include oxalates, sulphates, carbonates, phosphates, alum, caustics, tannic acid, ferrous and ferric salts, activated silica, nickel and copper ferrocyanides and clays such as bentonite. The activity level of the main volume of liquid can often be reduced to levels safe enough for dispersal to the sewer or the environment. In general, and especially when mixed fission products are present, the higher the pH-value at which the work is performed, the greater the efficiency of removal. It is for this reason that the phosphate precipitation method, which can be carried on at up to pH 11.5, has proved attractive. Ferric salt may also be used in this pH range.
considerable amount of work on chemical treatment processes has been carried out in a number of countries and there are many plants where such methods are employed.

4.3.5.4. Coagulation aids. Care must be taken to obtain from the precipitators an effluent with the minimum amount of suspended floc. Constant control of flow rates through the precipitators and correct choice of coagulants is required. If difficulties are encountered, the use of coagulation aids may be necessary. Many such agents are available, the synthetic polymers of high molecular weight known as polyelectrolytes being efficient in most cases.

4.3.5.5. Batch treatment. Where the volumes involved are small, chemical treatment in batches is feasible. The wastes can be collected in a central tank and transferred to another tank with a steeply sloping bottom on which a stirring device is mounted. The chemicals are added to the waste in the tank and the mixture is stirred rapidly for a short period (1 to 10 min) and then stirred slowly for a longer period (10 to 60 min). If the tank is small enough the stirring can be done by hand with a suitable paddle. After the stirring has been completed and good flocculation achieved, the precipitate is allowed to settle to the bottom of the tank (this may require several hours) and the sludge is drawn off and handled in a suitable manner. The supernatant solution should be monitored and if the radioactivity is low enough it may be discharged. If not, the waste can be treated again with different chemicals or processed further by ion exchange or evaporation.

4.3.5.6. Handling of sludge. The sludge resulting from chemical treatment can be filtered, centrifuged, absorbed by means of expanded vermiculite or similar material, or mixed with cement. It can then be handled as solid waste.
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CHAPTER 5

METHODS OF STORAGE AND ENVIRONMENTAL CONTAINMENT OF RADIOACTIVE WASTES

5.1 General considerations

5.1.1 Storage of radioactive waste in engineered facilities may be necessary for one of the following reasons:
(a) To provide temporary storage prior to transfer to a special treatment or disposal facility.
(b) To allow for decay of shorter-lived radioisotopes to permit discharge to the environment or decrease of activity before treatment.
(c) To permit regulation of the rate of release to the environment.
(d) To permit monitoring of materials presenting an unknown degree of hazard.
(e) To provide long-term containment, i.e. many years or indefinitely.

5.1.2 The type of storage facility required will depend on the nature of the waste, how it is packed or contained, the radiation emitted, and the reason for storage.

5.1.3 Storage facilities may be located above ground but are often placed wholly or partially underground. Contamination of ground water must be avoided. A record should be kept of materials stored, and an adequate system of monitoring must be established to detect potentially hazardous leakage of radioactive materials into the environment. If leakage occurs, steps should be taken to correct the situation by modification of equipment or practices.

5.1.4 Storage facilities should be located away from normal working areas and arrangements made, through suitable marking and fencing, to restrict admittance to authorized personnel. The area may be roofed, and an impervious, easily decontaminated flooring or pavement is generally desirable. In enclosed areas, adequate ventilation should be provided to prevent any hazards due to inhalation of dust and vapours.
5.1.5 Persons working in the facilities should wear normal protective clothing. If the storage facilities are enclosed, provision should be made for air circulation, monitoring of air and surfaces (walls, floors) in the storage room and for air purification in the event of accidents or spills.

5.2 Temporary storage

5.2.1 Liquid wastes can be kept in individual small containers while undergoing temporary storage. Corrosive liquids should be stored in resistant containers.

5.2.2 The user should be aware of the possibility of gas formation from organic decomposition and of the fact that formation of precipitates sometimes changes radiation fields outside containers.

5.2.3 Arrangements should be made to prevent the spread of contamination by animals and to avoid harmful or unpleasant effects of organic decomposition.

5.2.4 Wastes should be segregated during temporary storage to facilitate subsequent handling, e.g. segregation of wastes for baling, incineration, burial, etc. It may also be necessary to segregate alpha-emitting contaminated materials or long-lived radioactive materials from short-lived beta-gamma emitting materials. Wastes should be stored so that radiation exposure of workers is minimized, e.g. more active wastes should be placed in less accessible regions or shielded by less active wastes. Care should be taken not to obstruct transport and handling equipment.

5.3 Long-term storage

5.3.1 In arranging for the long-term storage of radioactive wastes, it is essential to make a careful study of possible hazards. The long-term storage of radioactive waste can involve hazards from fire, corrosion of containers and the spread of radioactive materials by animals.

5.3.2 Certain geological features may be used to good advantage in providing long-term storage. For example it may be possible to contain waste materials in abandoned mine shafts
or tunnels. Since these facilities should be dry during the period of use, abandoned shafts or workings in salt formations appear very suitable. Coal mines usually have water drainage problems and should generally be avoided. Other hard rock (mineral) mines may be dry and acceptable. The volume of waste should, of course, be reduced as much as possible.

5.3.3 Where wastes cannot be stored underground, it may be possible to use surface storage trenches. These should be designed to prevent the escape of radioactivity. It is essential that trenches be lined and covered with concrete to keep them dry. Dividing walls can be built to segregate different types of waste and to reduce radiation levels.

5.3.4 Individual storage cells consisting of steel or concrete tubes set in a concrete block in the ground can be used for long-term storage of individual items such as sealed sources.

5.3.5 Special buildings can be constructed above ground for the long-term storage of radioactive wastes. These are expensive and are generally used only when easy recovery of the wastes is planned.

5.3.6 If it is necessary to store a large volume of liquid waste (e.g. for decay), neutral wastes may be stored in concrete or mild steel tanks. Acidic or corrosive wastes may require stainless steel, rubber or plastic lined tanks. A reliable liquid-level indicator is essential. Spare tankage should be kept available in case of failure and arrangements should be made for detection and repair of leaks. Sampling methods should include the use of mixing devices, and precautions should be taken to avoid blocking of pipes by sediments.

5.4 Environmental containment (ground disposal of solid and liquid wastes)

5.4.1 Ground disposal of radioactive waste can, in certain circumstances, be regarded as a method of long-term storage. The possibility of recovery exists, but if the site and method of burial have been carefully selected it should never become necessary.
5.4.2 It is possible to modify the wastes to make them more compatible with the environment, e.g. by incorporating them in asphalt or concrete.

5.4.3 Before a site is used, an assessment of the likely fate and effect of the radioisotopes in or on the ground should be made by the user and the responsible authority. In particular, careful geological and hydrological studies are necessary to ensure that full consideration is given to the possibility of contamination of water supplies. Laboratory and field experiments should be carried out to determine probable rates of leaching of radioisotopes. Agricultural and other utilization of the environment should be investigated and conservative estimates made of radiation exposures to man over long periods of time.

5.4.4 Provisional limits on ground disposal should then be drawn up in accordance with the assessment. However, owing to the unavoidably approximate nature of any assessment, careful surveys and monitoring of environmental radioactivity should be carried out, so that appropriate steps can be taken at any time to avoid unforeseen hazards.

5.4.5 In practice, any large-scale use of ground disposal becomes expensive in areas where groundwaters are likely to be significantly affected. This is due to the fact that adequate investigation of groundwater movements requires a large number of borings, and analyses must be made over long periods of time to take account of seasonal and other variations. For example groundwater flow during the summer may be the reverse of that in winter. More detailed information on techniques of investigating the hydrology of ground-disposal sites and monitoring dispersal of radioisotopes by groundwaters is given in the Agency manual on radioactive waste disposal into the ground (see section 1.2.8).

5.5 Disposal into the sea

The subject of sea disposal of radioactive wastes has been studied by an Agency panel and will not be re-examined here. Information on the techniques of treating and preparing radioactive waste for sea disposal is given in an Agency
publication on radioactive waste disposal into the sea (see section 1.2.8).

5.6 Monitoring in connection with discharges of radioactive waste to the environment

The possible hazards to man arising from any discharge of radioactive materials to the environment should be evaluated by the competent authority or its delegate, in order to determine the need for such action as routine measurement of concentrations of radioactive materials and radiation levels in the environment, and of concentrations and amounts of radioactive materials discharged. The aim of the monitoring should be primarily to test compliance with the appropriate radiation standards or codes of practice. It is not satisfactory for monitoring to be left entirely to the producers of the wastes. More information on this subject is given in the Agency publication 'Environmental monitoring in normal operation'.

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5 INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental monitoring in normal operation, Technical reports series, IAEA, Vienna (in course of preparation).
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## AN EXX I

### TYPES OF WASTE ASSOCIATED WITH SOME USES OF A NUMBER OF RADIOISOTOPES

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Main use</th>
<th>Amounts</th>
<th>Type of waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ac$^{227}$</td>
<td>22 yr</td>
<td>Actinium-227/beryllium neutron sources</td>
<td>1-100 mc</td>
<td>None unless source is broken or lost</td>
</tr>
<tr>
<td>Sb$^{124}$</td>
<td>60 d</td>
<td>(a) Antimony-124/beryllium neutron sources</td>
<td>$10^2 - 10^3$ c</td>
<td>None unless source is broken or lost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) As tracer</td>
<td>microcurie of millicurie amounts</td>
<td>Small hazard</td>
</tr>
<tr>
<td>Ba$^{140}$</td>
<td>12.8 d</td>
<td>Tracer in steel industry</td>
<td>10-50 mc</td>
<td>Remains as insoluble in slag</td>
</tr>
<tr>
<td>Br$^{80}$ and Br$^{82}$</td>
<td>1.5 yr</td>
<td>(a) Diagnostic use</td>
<td>$\sim 10 $ mc</td>
<td>Excreted in urine</td>
</tr>
<tr>
<td></td>
<td>36 h</td>
<td>(b) Industrial tracer, e.g., study of retention in tanks</td>
<td>$\sim 100$ mc</td>
<td>Liquids and solids</td>
</tr>
<tr>
<td>Cs$^{137}$</td>
<td>30 yr</td>
<td>Sealed sources used in therapy and radiography</td>
<td>1 mc to 1000 c</td>
<td>None unless source is broken or lost</td>
</tr>
<tr>
<td>C$^{14}$</td>
<td>5760 yr</td>
<td>(a) Over 200 labeled compounds.</td>
<td>$\sim 10$ mc</td>
<td>Various depending on type of experiment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Tracer in biological work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr$^{51}$</td>
<td>27.8 d</td>
<td>Clinical purposes</td>
<td>10 mc per patient</td>
<td>Excreted slowly</td>
</tr>
<tr>
<td>Isotope</td>
<td>Half-life</td>
<td>Main use</td>
<td>Amounts</td>
<td>Type of waste</td>
</tr>
<tr>
<td>---------</td>
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</tr>
<tr>
<td>Co$^{60}$</td>
<td>5.27 yr</td>
<td>(a) Wide range of sealed sources for radiographic, medical or general use</td>
<td>up to 50 c</td>
<td>Very little use as an industrial tracer; almost entirely used as a sealed source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Industrial irradiation. Sealed sources up to megacurie level</td>
<td>Up to megacuries</td>
<td></td>
</tr>
<tr>
<td>Au$^{198}$</td>
<td>2.7 d</td>
<td>Therapy: (a) Colloidal</td>
<td>Colloidal metal - up to 150 mc per dose</td>
<td>Largely retained in patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) &quot;Grains&quot;-sources sealed in platinum</td>
<td>Grains - millicurie amounts</td>
<td>Often left in patient but could constitute solid waste</td>
</tr>
<tr>
<td>H$^3$</td>
<td>12.26 yr</td>
<td>Various industrial uses: biological tracers, etc.</td>
<td>Very varying</td>
<td>Large proportion gets into liquid effluent</td>
</tr>
<tr>
<td>I$^{131}$</td>
<td>8.04 d</td>
<td>Diagnosis and treatment</td>
<td>1-50 μc</td>
<td>Approximately 75% excreted in urine</td>
</tr>
<tr>
<td>I$^{132}$</td>
<td>2.26 h</td>
<td>Diagnosis and treatment, e.g.: (a) hyperthyroidism</td>
<td>5 to 10 mc</td>
<td>As for I$^{131}$ but short half-life reduces hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) thyroid carcinoma</td>
<td>100 to 150 mc</td>
<td></td>
</tr>
<tr>
<td>Ir$^{192}$</td>
<td>74.4 d</td>
<td>Industrial radiography</td>
<td>Usually 1 to 10 c per source</td>
<td>Sealed sources</td>
</tr>
<tr>
<td>Fe$^{59}$</td>
<td>45 d</td>
<td>Diagnosis and research purposes</td>
<td>~ 10 μc per patient</td>
<td>Some excreted</td>
</tr>
<tr>
<td>Isotope</td>
<td>Half-life</td>
<td>Main use</td>
<td>Amounts</td>
<td>Type of waste</td>
</tr>
<tr>
<td>---------</td>
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</tr>
<tr>
<td>Hg(^{197}) and Hg(^{203})</td>
<td>65 h and 47 d</td>
<td>Rising in importance in diagnoses</td>
<td>~10 μc per patient</td>
<td>Some excreted</td>
</tr>
<tr>
<td>P(^{32})</td>
<td>14.2 d</td>
<td>(a) Diagnosis</td>
<td>Up to 300 μc</td>
<td>Largely excreted in urine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Treatment of blood disorders</td>
<td>5 to 10 mc per dose</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Agricultural research work including field trials</td>
<td>Up to 100 c</td>
<td>Liquid and solid waste depending on type of experiment</td>
</tr>
<tr>
<td>Ra(^{226})</td>
<td>1620 yr</td>
<td>(a) Clinical</td>
<td>Millicurie amounts</td>
<td>Valuable expensive closed sources - should be little if any waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Industrial - as a foil-type source and in certain types of electronic valves and switches</td>
<td>Microcurie amounts in sources; microcurie amounts in valves and switches</td>
<td>Mainly solid waste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(c) Manufacture of luminous compounds</td>
<td>Up to about 50 mc/kg</td>
<td>Mainly solid waste</td>
</tr>
<tr>
<td>Sc(^{46})</td>
<td>84 d</td>
<td>Silt tracer in rivers, etc.</td>
<td>Curies per operation</td>
<td>Various, depending on type of experiment</td>
</tr>
<tr>
<td>Na(^{22})</td>
<td>2.58 yr</td>
<td>Diagnostic tracer for humans</td>
<td>Microcurie amounts</td>
<td>Largely excreted</td>
</tr>
<tr>
<td>Isotope</td>
<td>Half-life</td>
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</tr>
<tr>
<td>Na$^{24}$</td>
<td>15 h</td>
<td>(a) Tracer in industry, e.g. detecting leaks in new water mains. (b) Human diagnostic tracer</td>
<td>Microcurie to millicurie amounts</td>
<td>Liquids and solids; When used for diagnosis largely excreted</td>
</tr>
<tr>
<td>Sr$^{89}$</td>
<td>51 d</td>
<td>Large scale agricultural tracer work</td>
<td>100 to 1000 mc per experiment</td>
<td>Liquids and solids</td>
</tr>
<tr>
<td>Sr$^{90}$</td>
<td>28 yr</td>
<td>Sealed sources for thickness gauges, etc.</td>
<td>1 mc to 1 c</td>
<td>Sealed sources - there should be little waste problem</td>
</tr>
<tr>
<td>S$^{35}$</td>
<td>87.2 d</td>
<td>Agricultural experiments (insecticides and fungicides)</td>
<td>Up to curie amounts</td>
<td>Depending on type of experiment</td>
</tr>
</tbody>
</table>
ANNEX II

EXAMPLES OF NATIONAL REGULATIONS LIMITING DISCHARGE
OF RADIOACTIVE WASTES BY RADIOISOTOPE USERS

A. INTRODUCTION

National regulations limiting discharge of radioactive wastes by radioisotope users have so far developed along two main lines. The first has been to specify discharge limits of wide applicability and the second to specify discharge limits on a case-by-case basis. The regulations of the Union of Soviet Socialist Republics and the United States of America are presented as examples of the first and those of the United Kingdom as an example of the second.

B. REGULATIONS OF THE UNION OF SOVIET SOCIALIST REPUBLICS

The following paragraphs are reproduced from the Soviet Union's health and safety regulations governing work with radioactive materials and sources of ionizing radiation.

Section I, paragraph 6

Installations shall be divided into three categories according to the amounts of unsealed radioactive material which they use in one year:

Category I - Yearly consumption over 100 c;
Category II - Yearly consumption 10-100 c;
Category III - Yearly consumption less than 10 c.

Note: The activity of exhaust air and drainage water must not exceed the levels indicated in Sections VII and VIII of these Regulations.

Section VI, paragraph 98

Liquid and solid wastes from installations shall be considered radioactive if their activity (in c/1 and c/kg) is more than 100 times the maximum permissible concentration in open water (c/1) in the case of materials with a half-life of up to 60 d, or more than ten times the maximum permissible concentration in open water in the case of materials with a half-life of over 60 d.

Section VII, paragraph 100

Air removed through fume cupboards, cells and boxes must be efficiently filtered before being released into the atmosphere.

* The State Publishing House for Literature on Science and Technology (Gosatomizdat), Moscow (1960).
Section VII, paragraph 101

Installations engaged in work of classes I and II\(^7\) must, in addition to filters, be provided with chimneys, the height of which will be determined by calculation but which in no case will be less than four metres above the ridge of the roof.

If there are other buildings within a radius of 50 metres the chimney must be not less than four metres higher than the ridge of the roof of the highest building.

Section VII, paragraph 102

The ventilation systems of installations engaged in work of class III\(^7\) shall be constructed in accordance with the requirements and specifications laid down for chemical laboratories.

Section VIII, paragraph 131

Class III\(^7\) laboratories must be provided with normal sewage systems. Two separate drainage systems must be installed in premises intended for class I and II work:

(a) a normal sewage system,
(b) a special drainage system.

Special drainage systems with purification facilities should be installed where the daily quantity of liquid waste is 200 l or more, with a specific activity higher than those stated in paragraph 98.

Where the quantity of liquid waste is less than 200 l per day, such waste should be collected in special containers for subsequent burial.

Highly active liquid wastes with a specific activity greater than \(10^{-4}\) c/1 must be collected in special storage containers at the place where they are produced and removed to the burial area.

Section VIII, paragraph 138

Waste water from installation showers and laundries and from the washing of floors and walls, etc. may be discharged into the normal sewage system provided that its activity, without preliminary dilution, does not exceed the levels indicated in paragraph 98 and provided that a tenfold dilution by non-radioactive waste water is ensured in the installation's collecting tank. Waste water released directly into bodies of water must not contain more activity than the maximum permissible concentrations for open water.

Any discharge of radioactive waste water into pits or holes or use for irrigation purposes is prohibited.

Section VIII, paragraph 139

Any discharge of radioactive water into ponds used for breeding fish or water-fowl, or into watercourses or other bodies of water from which it might gain access to such ponds, is prohibited.

\(^7\) 'Class' is tabulated in the USSR regulations in terms of the quantity of radioactive isotope of a defined toxicity used.
The following paragraphs are reproduced from the Atomic Energy Commission's regulation.

20.301 General requirement

No licensee shall dispose of licensed material except
(a) by transfer to an authorized recipient as provided in the regulations in Part 30, 40 or 70 of this chapter, whichever may be applicable, or
(b) as authorized pursuant to paragraph 20.302, or
(c) as provided in paragraph 20.303 or 20.304, applicable respectively to the disposal of licensed material by release into sanitary sewerage systems or burial in soil, or in paragraph 20.106 (Concentrations in Effluents to Unrestricted Areas).

20.302 Method for obtaining approval of proposed disposal procedures

Any licensee or applicant for a licence may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment including topographical, geological, meteorological, and hydrological characteristics, usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

20.303 Disposal by release into sanitary sewerage systems

No licensee shall discharge licensed material into a sanitary sewerage system unless;
(a) it is readily soluble or dispersible in water, and
(b) the quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of sub-paragraphs (1) or (2) of this paragraph;

(1) the quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table 1, Column 2 of this part; or

(2) ten times the quantity of such material specified in Appendix C of this part; and

(c) the quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an
average concentration exceeding the limits specified in Appendix B, Table I, Column 29 of this part, and
(d) the gross quantity of licensed and other radioactive material released into the sewerage system by the licensee does not exceed one curie per year.

Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

20.304 Disposal by burial in soil

No licensee shall dispose of licensed material by burial in soil unless:
(a) the total quantity of licensed and other radioactive materials buried at any one location and time does not exceed, at the time of burial, 1000 times the amount specified in Appendix C9 of this part, and
(b) burial is at a minimum depth of four feet, and
(c) successive burials are separated by distances of at least six feet and not more than 12 burials are made in any year.

20.305 Treatment or disposal by incineration

No licensee shall treat or dispose of licensed material by incineration except as specifically approved by the Commission, pursuant to paragraphs 20.106 (a) and 20.302.

D. REGULATIONS OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND10, 11

In the United Kingdom it is considered that each case of waste disposal is peculiar to itself because local conditions differ so widely.

Before a discharge of radioactive waste is authorised two considerations arise. First, what quantity of waste could be discharged to the environment without producing by any route a level of exposure in excess of that recommended by the International Commission on Radiological Protection and the Medical Research Council as permissible. Second, what lower level can be achieved by all reasonable and practicable measures, bearing in mind that it would be excessively uneconomic to attempt to prevent any increase at all in the level of radiation already present in the environment.

The recent Radioactive Substances Act 1960 has been introduced to enable still greater control on the discharge of radioactive wastes to be exercised than has been the case in the past. The main Clauses of this Act may be summarised as follows:

9 Not reproduced in this text.
10 Authorized summary communicated to the Agency by the United Kingdom Atomic Energy Authority, under cover of their letter of 27 September 1962.
11 References:
1. Persons who keep or use radioactive material are required to register with the Minister of Housing and Local Government or the Secretary of State for Scotland, or the Minister of Health and Local Government in Northern Ireland.

2. No accumulation or disposal of radioactive wastes will be permitted without authorisation from the appropriate Minister.
   In the case of premises belonging to the United Kingdom Atomic Energy Authority and sites to which the Nuclear Installations (Licensing and Insurance) Act 1959 apply, this provision gives permanent effect to the temporary provisions in the Atomic Energy Authority Act, 1954, and the Nuclear Installations (Licensing and Insurance) Act 1959.

3. No account shall be taken by local and public authorities of radioactivity in the exercise of powers in relation to nuisances, pollution and the discharge of wastes. Nevertheless, such authorities must, in general, be consulted and will be supplied with copies of certificates of registration issued for premises in their areas and with copies of the authorisations for waste disposal in their areas.

4. Certain classes of radioactive waste may be exempted from authorisations and any authorisation granted may be altered or revoked by the responsible Ministers at any time.

5. The Minister is empowered to appoint Inspectors who have right of entry in order to satisfy themselves that the authorisations are not being or are not likely to be exceeded.

6. If it appears to the Minister that adequate facilities are not available for the safe disposal or accumulation of radioactive waste, the Minister may provide such facilities, or may arrange for the provision thereof by such persons as the Minister may think fit.

Although it is considered impossible to lay down realistic levels which could be used in all cases, certain broad principles can be stated and some general guidance given.

For example, in the case of discharges to sewers the following considerations arise:
(i) the contamination of the drains which might present a hazard during repair processes;
(ii) the contamination of the sewage itself which could endanger men working in the sewer;
(iii) the contamination of the purified sewage effluents which may affect their ultimate discharge;
(iv) the build-up of radionuclides on filter beds;
(v) the possible use of sewage sludge.

Each radionuclide discharged may well behave differently and contribute to one or more of the above potential hazards. In consequence, the fixing of general limits is not easy, but a level of $10^{-4}$ μC per ml in the sewage flow from the user establishments would normally be permissible. Exceptions would have to be made in the case of the more hazardous isotopes or, for example, where a large factory or hospital drains to a small village sewage works.

As to the use of sewage sludge as a fertilizer, there is evidence that those radionuclides, such as radiostrontium, which are taken up readily by plants, are not adsorbed on the sludge to any great extent.

The above suggested level of $10^{-4}$ microcuries per ml in the discharge assumes a hundredfold dilution in the main sewer.
The normal formula for assessing the dose inside an infinite medium is:

\[ S \times E \times 2.15 \, \text{r/1 hour} \]

where \( S = \mu\text{c/g} \) and \( E = \text{Energy emitted in MeV} \). If one takes an average figure of 0.8 for \( E \), then the dose to a man totally immersed in the contaminated sewage for a working week (45 hours) would be approximately 0.07 mr. This is well below those levels considered acceptable by the ICRP for the general population.
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27-30 March 1961

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