IAEA-TECDOC-776

Reference design for a centralized waste processing and storage facility

Technical manual for the management of low and intermediate level wastes generated at small nuclear research centres and by radioisotope users in medicine, research and industry

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REFERENCE DESIGN FOR A
CENTRALIZED WASTE PROCESSING AND STORAGE FACILITY

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FOREWORD

The International Atomic Energy Agency (IAEA) has published Technical Reports Series and Safety Series documents on radioactive waste management over nearly three decades. These documents have served Member States presenting basic reference material and comprehensive surveys of the 'state of the art' technologies applied to radioactive waste management.

The need for assistance in specific waste management problems facing many countries has been demonstrated in IAEA activities including technical assistance projects and Waste Management Advisory Programme (WAMAP) missions. Technical Reports Series and Safety Series documents usually reflect:

- technological solutions based on experience and resources normally available in countries managing nuclear fuel cycle wastes;

- volumes and activities of radioactive wastes of orders of magnitude greater than those generated in countries without nuclear power.

A series of technical documents has been undertaken especially to fully meet the needs of Member States for straightforward and low cost solutions to waste management problems. These documents will:

- give guidance on making maximum practicable use of indigenous resources;

- provide step-by-step procedures for effective application of technology;

- recommend technological procedures which can be integrated into an overall national waste management programme.

The series entitled 'Technical Manuals for the Management of Low and Intermediate Level Wastes Generated at Small Nuclear Research Centres and by Radioisotope Users in Medicine, Research and Industry' will serve as reference material to experts on technical assistance missions and provide 'direct know-how' for technical staff in Member States. Currently, the following manuals have been prepared:

- Minimization and Segregation of Radioactive Wastes
- Storage of Radioactive Wastes
- Handling, Conditioning and Disposal of Spent Sealed Sources
- Handling and Treatment of Radioactive Aqueous Wastes
- Handling, Treatment, Conditioning and Storage of Biological Radioactive Wastes
- Treatment and Conditioning of Radioactive Solid Wastes
- Treatment and Conditioning of Radioactive Organic Liquids
- Treatment and Conditioning of Spent Ion Exchange Resins from Research Reactors, Precipitation Sludges and Other Radioactive Concentrates.

The objective of this report is to present a reference design of a centralized waste processing and storage facility (WPSF) intended for countries producing small but significant quantities of liquid and solid wastes. It will be of special value for regulators and waste operators planning to establish or improve national waste management operating capabilities.

For situations where the waste is produced in large quantities during operation and decommissioning nuclear power plants, which is outside the scope of this report, one should refer to the relevant documents in the IAEA Technical Reports Series. For countries having very small generation of radioactive waste, mainly sealed sources and other solid wastes, the concept described in this report may be unnecessarily advanced and for this case the IAEA is preparing a separate concept consisting mainly of a cement conditioning facility and a store.

This report is based on a three volume WPSF reference design package prepared by AEA Technology, Risley, UK, under a contract from the IAEA in 1992. Work under the contract was co-ordinated by G. Plumb, and this report was prepared by J.R. Wiley, both IAEA staff members in the Division of Nuclear Fuel Cycle and Waste Management. To make the design information most useful to Member States, it is presented here in three levels of detail: the Summary gives a brief overview; Section 1 presents the design in sufficient detail for a Member State to judge if the design is appropriate for its needs; Sections 2–4 present the detailed design.

CONTENTS

SUMMARY

This document presents the main features of a generic reference design for a centralized waste processing and storage facility (WPSF) prepared principally for Member States which use radioisotopes in medicine, industry and research, but do not have wastes from the complete nuclear fuel cycle.

The WPSF design consists of two separate buildings, the first accommodating radioactive waste process and support functions and the second providing protective storage for the resulting 200 L drums of conditioned waste, which can be handled and stacked using a forklift truck. The buildings are each steel framed, ground level, rectangular, single storey (5 m high) with a double pitched roof. The process building is recommended to be 29 m × 28 m covered with insulated metal cladding, while the storage building is 39 m × 26 m with uninsulated metal cladding. These designs provide a workable reference that can be easily modified to meet specific needs and conditions in a Member State.

The reference design is outlined in Fig. 1. The liquid waste treatment utilizes precipitation processing. Solid waste treatment for compressible wastes utilizes low force in-drum compaction, and conditioning is based on in-drum cementation. The main waste management activities of the WPSF are presented in Fig. 2.

The WPSF design provides for treating and conditioning the following nominal volumes of wastes:

	Volume (m^3/year)
Aqueous input (see Table I)	
(i) LLW for treatment by sludge precipitation process	100
(ii) ILW for encapsulation without treatment	0.5
Solids input (see Table I)	
(iii) General compactable wastes	80
(iv) General non-compactable wastes	10
(v) Waste carcasses	1
(vi) Spent ion-exchange materials	0.5

The resulting volumes of treated waste will be approximately:

Aqueous sludges (from treatment (i))	10
Aqueous ILW (from (ii))	0.5
Compacted solid wastes (from (iii))	32
General non-compactable wastes (iv)	10
Waste carcasses (v)	1
Spent ion-exchange materials (vi)	0.5

Waste that is compacted is stored without further conditioning, while the other wastes are stabilized with grout, giving the volumes of waste for interim storage in 200 L drums as:

	Volume (m^3/year)	Drums/year
Compacted solid wastes	32	160
Other treated wastes plus grout	28	140

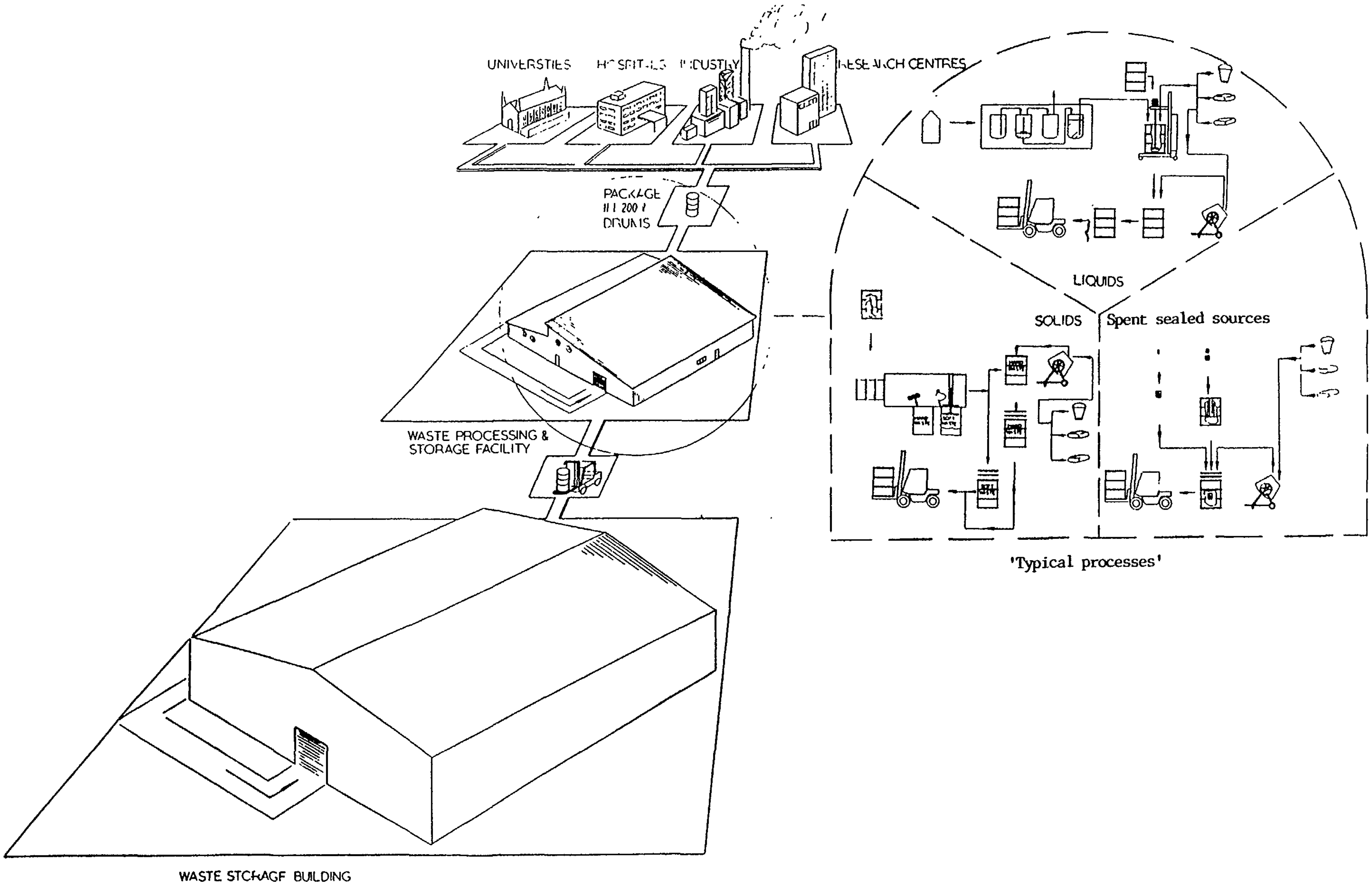


FIG. 1. Overall pictorial flowsheet.

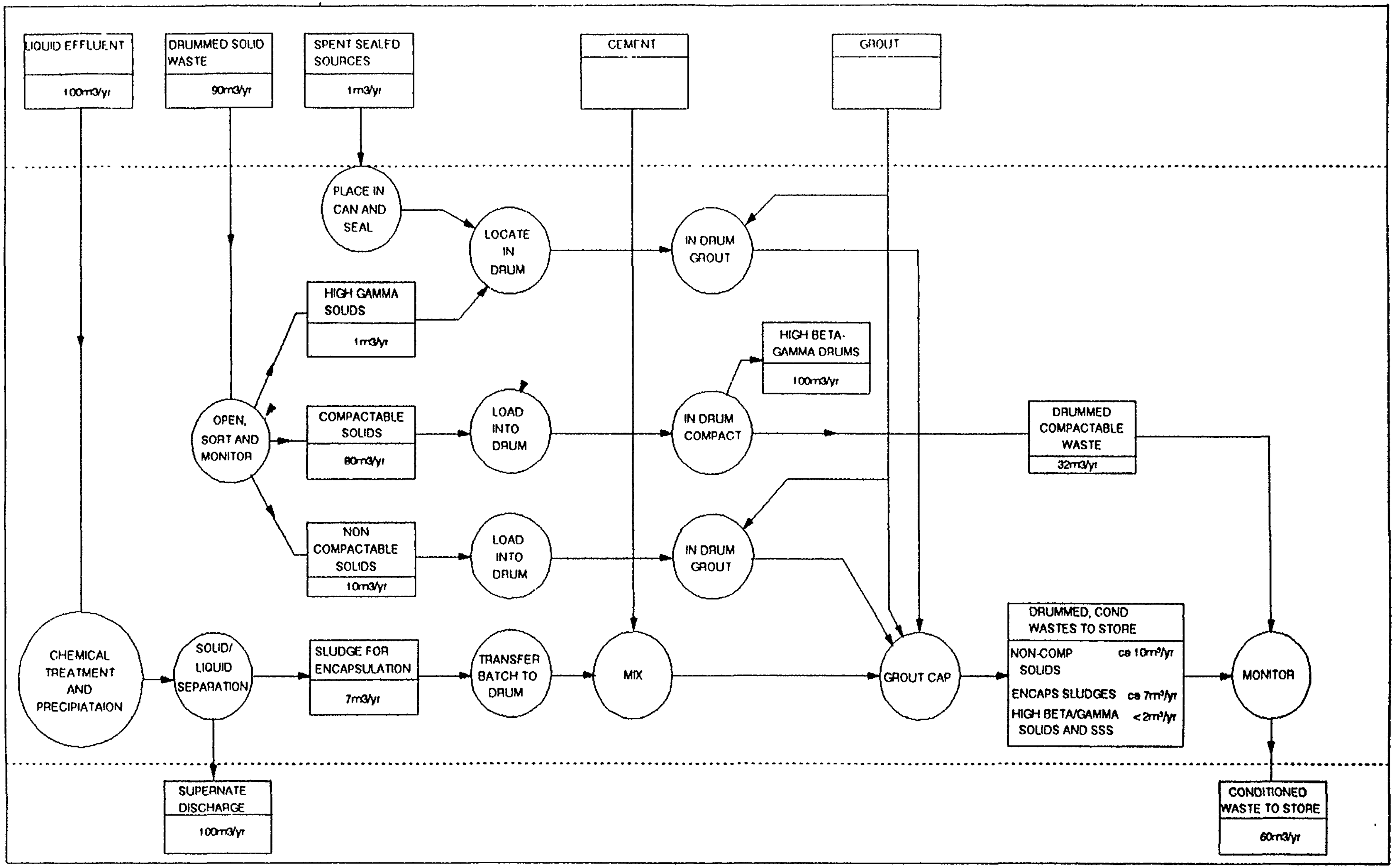


FIG. 2. Flowsheet of main waste management activities.

For short lived wastes that do not require conditioning appropriate receipt, decay storage, segregation and pretreatment operations are provided. Interim storage of solid low level conditioned wastes is provided for 3000 drums (200 L) giving a minimum of 10 years capacity pending eventual disposal.

Support facilities are designed to accommodate services for waste processing and storage including laboratory, office, change room, monitoring, decontamination and maintenance. Utilities provision includes air ventilation, fire protection, water supply, compressed air and radiation monitoring. Local engineering services are expected to provide detailed or site specific design needs.

The reference design includes:

- process flow diagram;
- engineering line diagrams for ventilation;
- building layouts and architectural drawings;
- equipment, specifications with performance data and requirements for review according to local conditions;
- cost data for detailed engineering materials and construction.

1. PURPOSE AND DESCRIPTION OF THE WPSF

1.1. BACKGROUND

The objective of this report is to present the generic reference design of a centralized waste processing and storage facility (WPSF) intended for countries producing small but significant quantities of liquid and solid radioactive wastes [1]. These wastes are generated through the use of radionuclides for research, medical, industrial and other institutional activities in IAEA Member States that have not yet developed the infrastructure for a complete nuclear fuel cycle.

Many of the requests that the IAEA receives from developing Member States for technical assistance in the field of processing radioactive wastes are similar in project scope and objectives. The volumes, characteristics, and activity levels of the wastes generated, or expected to be generated, by the Member States are also often quite similar. Taking this into account, the IAEA embarked upon a strategy for providing technical assistance in the form of a design package for a reference waste processing and storage facility (WPSF). The reference design presented in this report is a "minimum design" which will provide a simple and cost effective solution to the waste management requirements of IAEA Member States.

It is intended that the Member States will be able to use the reference design for the basis of their final design of a WPSF modified for geological, meteorological or other local conditions, as well as any specific waste generated that is outside the scope of this document.

1.2. SCOPE

The WPSF comprises two separate buildings. The first, for receiving and processing waste from the producers, includes the necessary equipment and support services for treating and conditioning the waste. The second building acts as a simple but adequate warehouse for storing a ten year inventory of the conditioned waste. In developing the design, it was a requirement of the IAEA that options for waste management techniques for each of the waste streams should be evaluated, in order to demonstrate that the reference design is based on the most appropriate technology. The resultant reference design is presented in this report. Although specific methods are described, other methods may be advantageous under special circumstances. Therefore a full discussion of these options and alternatives considered in developing the reference design is presented in Appendix II. This may be useful for users who may wish to adapt the reference design to meet their own specific needs. A description of typical activities at a site that produces wastes to be handled at the WPSF is given in Appendix I.

1.3. GENERAL REQUIREMENTS

The reference design presents a facility suitable for treating and conditioning of both solid and liquid low level radioactive wastes, and storage of the conditioned wastes.

The selection of waste management techniques has been made by considering several key parameters identified previously by the IAEA. These are discussed briefly below:

Demonstrated technology	Processes shall be selected which are well established in related applications in developed countries and for which adequate testing has been carried out on versions appearing most suited for the WPSF environment.

Robustness	The facility should be rugged and have a high degree of availability. It should be tolerant to variations in waste input.
Ease of engineering	The equipment should be simple in design and easy to operate. Expanding its capacity should be straightforward.
Economics	The facility should be low cost to construct, operate and expand. Capital expenditures should be staged, if possible so that no costs are incurred before any particular plant units become necessary. High costs may be associated with 'core' facilities, i.e. heating, ventilation, electrical supply and personnel change facilities. The design should address this aspect.
Safety	Radiation protection shall be considered in the design for the workers on-site and to the general public off-site.

As this is intended as a generic design, both buildings have been designed with the need to ultimately satisfy the specific requirements of any given site in any IAEA Member State. This presents special problems, in that the design of any building is strongly influenced by the given parameters and conditions pertaining to its specific chosen siting. The approach has been to propose designs for both buildings which are intended:

(a) to meet the requirements of the process specification and provide suitable accommodation for the proposed process plant and ancillary services and functions;

(b) to provide buildings which are suitable for construction in a wide range of potential sites with minimum modification, but are as adaptable and flexible as possible for modification to suit site specific conditions with minimum cost.

The building designs proposed in this document are to be viewed as generic designs rather than detailed designs. It is anticipated that for each specific application, the generic designs will be developed into detailed designs taking full account of local conditions and meeting appropriate adaptations. The foundation design, in particular, will be entirely dependent on the site ground conditions in the proposed building location. It is expected that the primary site specific conditions which would have to be considered are as follows:

(a) Specific waste handling/process requirements — this will affect the room layout, internal access routes, need for biological shielding, etc.
(b) Local building and industrial safety regulations, and design standards.
(c) Environmental conditions — due to wind, snow, rainfall, temperature, seismicity, etc.
(d) Local ground conditions.
(e) Availability of on-site services (water, power, drainage, etc.).
(f) Availability of construction material.
(g) Availability of skilled labour.
(h) Availability of construction facilities and equipment.
(i) Site access and transportation for building materials.

For the purpose of this generic design, standards pertaining to currently accepted UK practice have been used. Environmental loadings and ground conditions typical of UK conditions have been assessed. Extreme environmental loadings, such as seismic and extreme winds, have not been considered. The need to address such matters must be considered in the site specific, detailed design stage. However the design of the buildings does take into account the possible need to accommodate such loadings, in the choice of structural form and materials.

Basic layout

The overall building size and layout are derived from the following:

- Waste handling and operational requirements (Sections 2.1–2.5).
- Building service requirements (Section 2.6).
- UK building regulations.

Attention throughout has been given to producing a building layout which is of a symmetrical form and will lend itself to a simple structural framing system.

Structural framing system – General

Of the numerous options available, various framing solutions where initially considered as potentially suitable; these included:

(a) A simple steel framed structure with lightweight metal cladding to the roof and exterior walls. Non-load bearing block perimeter and internal partition walls.

(b) A reinforced concrete framed building with precast concrete roof units, brick/block non-load bearing exterior wall cladding panels and non-load bearing internal block partition.

(c) Load bearing block/brick walls supporting a steel framed roof structure.

(d) Load bearing block/brick walls supporting a precast concrete roof structure.

Based on past experience of similar buildings within the UK it is judged that option (a) will offer an economic solution and one which will be adaptable to most site specific requirements/restrictions. Currently in the UK, this form of construction is recognised as being very economical and can be built quickly without the need for specialized skills or equipment unlikely to be available elsewhere. The inherent flexibility of steel framed construction means that it can readily be adapted, and if necessary, upgraded to suit more rigorous design requirements at the detailed design stage.

It is recognized, however, that some developing Member States may prefer reinforced concrete construction due to easier access to the raw materials and greater experience using them. Site specific building design and construction options are best selected by competent local engineering firms.

1.4. WASTE ARISINGS AND CHARACTERISTICS

Compared with the sources and quantities of radioactive wastes generated in developed countries with an extensive nuclear programme, relatively small volumes of low level wastes are generated at nuclear research centres, universities, industries and research establishments in developing countries.

The types of waste arising from each of these sources are briefly discussed below. Appendix I provides a more detailed description of the waste generator's usual duties and responsibilities regarding the waste arisings.

Nuclear research centres

In smaller nuclear research centres a number of radioisotopes are produced in research reactors for different purposes by irradiation of special targets or in a particle accelerator from which the desired isotopes are subsequently extracted or processed in nearby hot cells or laboratories. Besides the institutions in a nuclear research centre some other installations are located where radioisotopes in tracers are used and handled. The volume of liquid and solid radioactive wastes produced by the individual users of radioactive materials is not likely to be large. Most of the radioactive wastes, solid and liquid are contaminated with short lived radioisotopes and are directed for decay, dilution and subsequent discharge. Wastes containing long lived fission products including transuranic nuclides, are not produced within the vast majority of laboratories in small nuclear research centres of developing countries. Only a small part of the radioactive waste is contaminated with long lived radioisotopes, i.e. ^{14}C and ^{3}H from laboratory experiments, or from uranium and thorium from processing investigations in laboratory and pilot plant scale tests.

Hospitals

The application of radioactive materials in medical diagnosis and therapy is extremely important and continuously expanding. In many instances alternative methods are not available. The main areas of application are radioimmunoassay, radiopharmaceuticals, diagnostic techniques, radiotherapy and research. These represent the use of not only small quantities of unsealed sources, but also highly concentrated sealed sources housed in shielded assemblies.

Industry

Certain industrial establishments use particular forms of radioactive material such as sealed sources, luminous displays, and specialized electronic devices for non-destructive testing, quality control, evaluation of plant performance and development of products. The quantities of radioactive materials used depend largely on the development and level of the national technology.

Universities and other research institutes

Users of radioactive material in research establishments and universities are most commonly involved in monitoring the metabolic or environmental pathways associated with materials as diverse as drugs, pesticides, fertilizers and minerals. The range of useful radionuclides is normally restricted and the activity content of the labelled compounds low, but at some research establishments rather exotic radionuclides may also be used. The radionuclides most commonly employed in studying the toxicology of many chemical compounds and their associated metabolic pathways are ^{14}C and tritium, as they can be incorporated into complex molecules with considerable uniformity. ^{125}I has proved to be very valuable in the labelling of proteins. A very wide spectrum of radionuclides is available for research and investigation.

Table I shows details of the wastes expected annually from the applications described above. The volumes and activities are averages, and are based on realistic data obtained during missions to different Member States for technical review of radioactive waste management practices [2].

The wastes arising from these sources can be categorized in a number of ways [3]:

- by amount and type of radionuclide content, i.e. low/intermediate level;
- by physical and/or chemical properties, i.e. solid/liquid, aqueous/organic liquid;
- by suitability for particular waste treatment techniques, i.e. compactable/non-compactable, combustible/non-combustible.

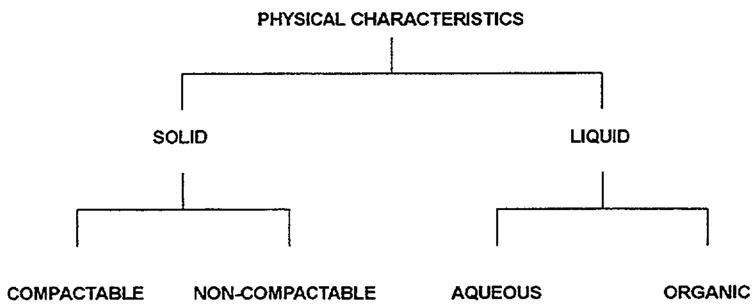
TABLE I. WASTE ARISINGS ASSUMED FOR WPSF DESIGN[a]

Raw wastes Waste type	Volumes m^3/year	Activities Bq/m^3	Typical Isotopes
Liquids for treatment	50–100	10^4 to 4×10^9	Corrosion products ^{55}Fe, ^{59}Fe, ^{58}Co
Liquids for direct conditioning	0.5		^{134}Cs, ^{137}Cs, ^{121m}Te
Organics (liquids)	0.1–0.3	approx. 10^4	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{51}Cr, ^{59}Fe, ^{99m}Tc, ^{111}In, ^{131}I
Solids (compactable) (paper, plastics, filters)	20–80		U nat, Th nat, ^{125}I, ^{90}Sr, ^{90}Y
Solids, (non-compactable) (trash, sealed sources, radium needles, etc.)	5–10	Up to 10^{10}	^{3}H, ^{14}C, ^{111}In, ^{99}Mo, ^{99m}Tc, ^{125}I, ^{35}S, ^{24}Na, ^{32}P, ^{131}I, ^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra
Carcasses	0.1–0.2	approx 10^6	^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I
Ion exchange resins	0.5–1	(2 to 4) $\times 10^9$	^{60}Co, ^{134}Cs
Total	100–200		

[a]These are typical annual arisings of untreated waste in a developing Member State with multiple users of radioisotopes and a nuclear research centre capable of producing those isotopes. Other developing Member States that use radioisotopes to a lesser extent will produce lower quantities of wastes.

Low and intermediate level wastes to be dealt with in the WPSF are defined by the IAEA as radioactive wastes in which the concentration of or quantity of radionuclides is above clearance levels established by a regulatory body, but with a radionuclide content and thermal power below those of high level waste [4].

The WPSF design is based on categorizing these wastes according to their physical/chemical characteristics:



The typical types of waste which will arise in developing Member States are identified in Table II under these four sub-categories.

TABLE II. THE PRINCIPAL TYPES OF RADIOACTIVE WASTE GENERATED IN DEVELOPING COUNTRIES

Waste categories	Waste types
Liquids, aqueous	Laboratory effluents Hot cell (isotope production) effluents Fuel storage pool (research reactor) purges Decontamination effluents Sump and rinsing waters Mining and milling raffinates from laboratory and pilot plant scale extraction with uranium and thorium
Liquids, organic	Oil from pumps, etc. Scintillation liquids Extraction solvent (TBP/kerosene, amine, etc.)
Solids, compactable	Tissues Swabs Paper Cardboard Plastics (polyvinylchloride (PVC), polyethylene (PE)) Rubber Gloves Protective clothes Filters Excreta Glassware
Solids, non-compactable	Metallic scrap Brickwork Sealed sources Radium needles Ion exchange resins Carcasses

1.5. SUMMARY OF WPSF REFERENCE DESIGN

The WPSF consists of two separate buildings, one housing the waste processing equipment and all the support functions (see Fig. 3), the second providing storage for conditioned waste drums. Two separate buildings are provided because:

(a) this provides flexibility in the siting of the buildings at any particular location;

(b) this provides flexibility to actually place the store at a location remote from the processing facility if required due to site limitations or other factors;

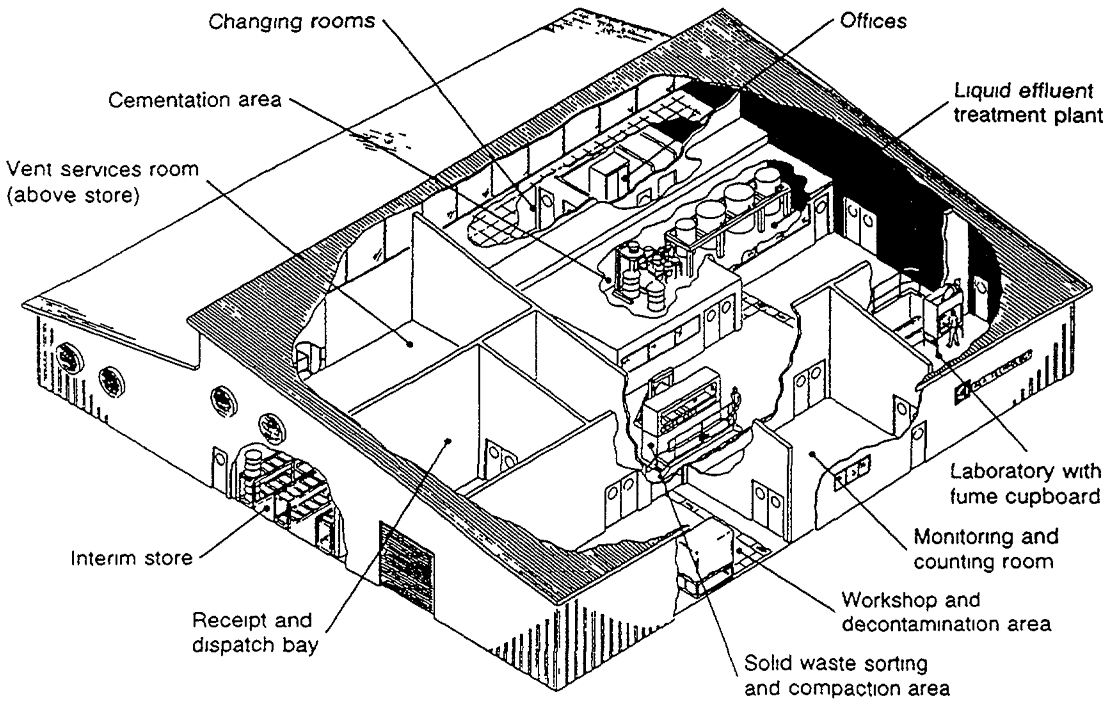


FIG. 3. Isometric of waste processing building.

(c) the size and construction requirements of the buildings are different, so to engineer them together as one building would be a compromise which might not suit either;

The processing building houses the following facilities and services:

- change rooms;
- offices;
- spare parts store;
- electrical distribution rooms;
- ventilation room;
- main operating area, sub-divided into:
  · liquid effluent treatment area;
  · solid waste sorting and compaction area;
  · cementation area;
- receipt bay;
- interim drum store;
- monitoring area;
- laboratory;
- maintenance and decontamination area;
- dispatch area.

The separate waste store is a large, simple building with no installed services or extra facilities other than lighting.

The design and operation of the components of the WPSF are discussed below. The amount of detail varies for different areas of the plant; specialized items and items highlighted by the IAEA are given in more detail than routine areas such as changerooms, offices and services.

The reference WPSF design incorporates the facilities to handle the range of low level waste streams that would be expected to arise within a Member State. The bulk of these are summarised as:

- aqueous liquids 50–100 m^3/year;
- compactable solids 20–80 m^3/year;
- non-compactable solids 5–10 m^3/year.

In addition to these major streams, there may be minor arisings of organic liquids, ion exchange resins and animal carcasses. Simple, small batch, often manual, processing is more appropriate than complex, large, automated continuous processing because these volumes are small. Also, because of the low throughput it has not been necessary to build in redundancy of equipment or parallel processing lines to ensure throughput targets are met. Indeed, it is estimated that the process equipment proposed could satisfactorily handle much larger throughputs than those expected.

Normal operation to meet the required throughput will be relatively slow, typically:

- aqueous liquids <0.5 m^3/day, yielding ~1 drum/week of cemented sludge;
- compactable solids ~2 drums/day input, ~1 drum/day output;
- non-compactable solids ~1 drum/week of cemented solids.

Rather than operate the WPSF continuously at such a low level, it may be more economic to operate intermittently in a few campaigns per year.

1.5.1. Receipt

It is expected that drums of waste will be transported by lorry to the WPSF. The WPSF is provided with a receipt bay which has a roller shutter door allowing vehicles to back up to or even into the receipt bay. Drum unloading will be performed using powered or manual fork lift trucks and drum trolleys. While drums provide a rugged, standardized way to transport and handle the waste, it is recognized that other waste containers can be used. Provision for their handling can be addressed on a site-specific basis, according to the needs of both the waste generator and the WPSF.

Documentation for each container of waste must be checked against each consignment on receipt before each drum is moved in turn through the monitoring area.

1.5.2. Monitoring

The monitoring area is located immediately adjacent to the receipt bay to minimize transfer distances. Each drum on receipt will be measured for gross radiation levels and surface contamination. Any drums found to be contaminated will be moved to the decontamination workshop. It is expected that drum surface radiation levels will not exceed 2 mSv/h (200 mR/h), and will normally be significantly lower than this. Drums with high radiation levels must be marked as such, and arrangements made to store them separately within the interim store. These drums will generally require special procedures for handling, record keeping, and senior management approval.

After satisfactory monitoring, all drums will be placed in the interim store, and their storage locations included with the other drum documentation.

1.5.3. Interim storage

The store is located adjacent to the receipt and dispatch bay (Fig. 3). The store provides operational storage for approximately 100 drums of waste, which represent approximately 4 months normal throughput of the plant, and also the maximum expected single consignment delivered by lorry to the WPSF.

Drums are placed on racks in the store using a manual fork lift truck. The drums are stacked 2 high, and the racking system allows any single drum to be directly retrievable for processing.

Solid waste drums will be retrieved from the store for processing by compaction or in-drum grouting, probably in campaigns. Containers of liquid wastes will be taken to the laboratory which houses the facility for transferring liquids to the aqueous treatment plant.

1.5.4. Liquids treatment

Liquids are expected to be delivered to the WPSF in a variety of containers from 1 L up to 55 L carboys. The containers will be taken to the fume cupboard in the laboratory. Here, samples will be taken for analysis in the laboratory. Details of the treatment process will depend on the result of this analysis as well as information provided by the waste producer. For the WPSF, precipitation has been selected as the most appropriate means of treating a wide variety of liquids, although other options are discussed in Appendix II. After the analysis is completed, liquids will be transferred from their containers to the small arisings hold tank in the liquid effluent treatment plant (see Fig. 4). This is performed using a pump mounted in the plant and a long suction line which runs in a duct back to the decontamination cabinet. Empty containers are washed out to decontaminate them, and the washings sent to the low active drain (LAD) tank.

The liquid effluent treatment (LET) plant uses a batch precipitation process for decontamination of the effluent. A batch of liquor is transferred to the reaction vessel from either the small arisings hold tank or the LAD tank, and then sampled. For the most general reference case an 8 step precipitation process is recommended, although it may be simplified for specific wastes:

- pH adjustment to ≤ 2 using nitric acid;
- addition of ferric ions to a concentration of ~ 100 ppm;
- pH adjustment to ~ 9.5 yielding a ferric floc precipitate;
- addition of nickel ferrocyanide to a concentration of ~ 10 ppm for improved ^{137}Cs removal;
- settling of the floc;
- coarse separation of sludge floc and supernate, with supernate transferred to a sentencing tank, and floc to the sludge tank;
- sampling of the supernate and discharge as appropriate;
- longer term settling of the floc with occasional removal of supernate as required.

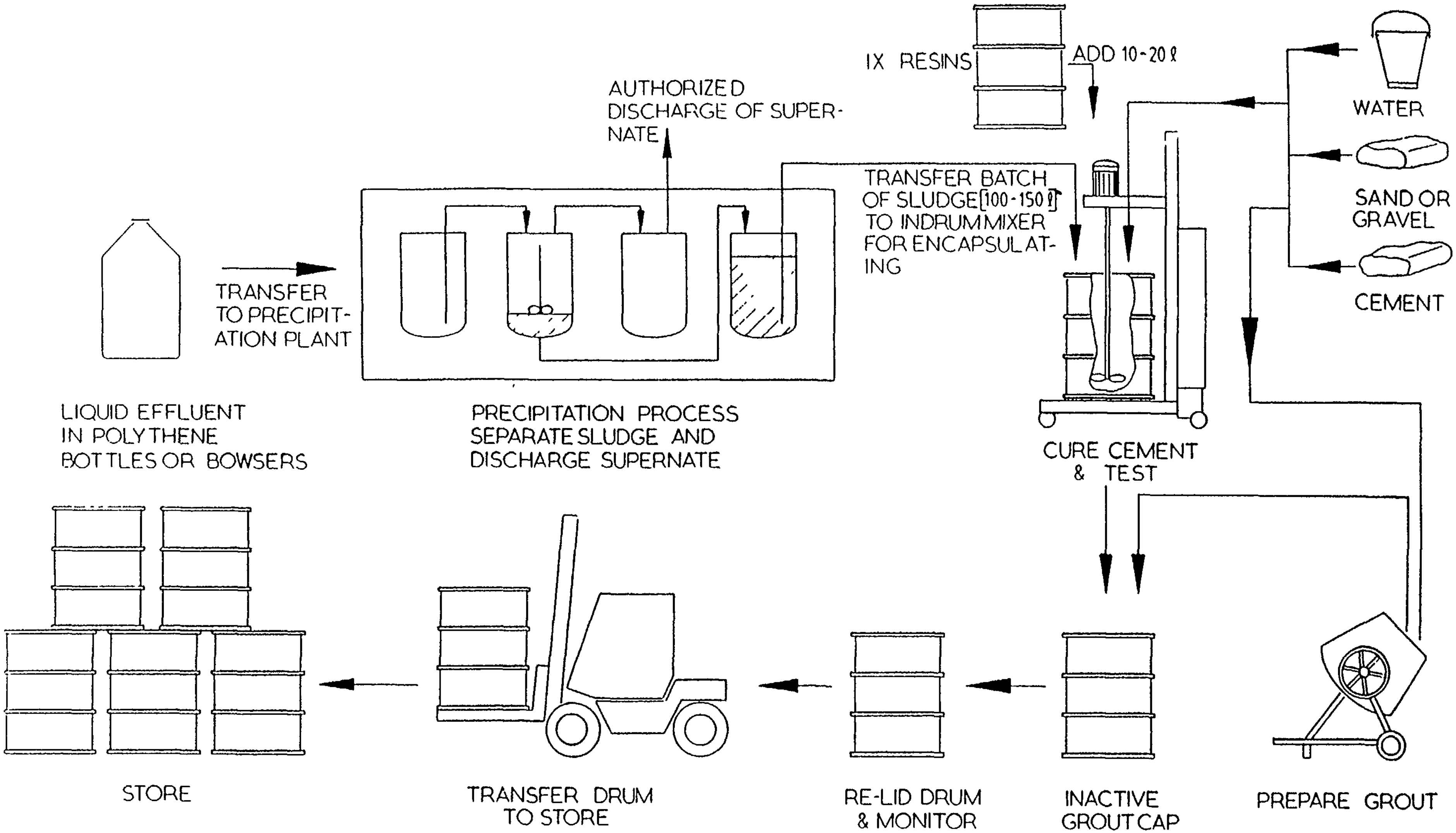


FIG. 4. Pictorial flowsheet of liquid waste processing.

When sufficient sludge has accumulated, sludge will be transferred in batches to the cementation area for encapsulation.

The LET plant comprises basically four vessels, interconnecting pipework, valves and transfer pumps. The majority of equipment is constructed of plastics for reasons of economy, ease of construction, and compatibility with the liquids handled. In particular, the main tanks are in natural polyethylene to allow levels to be determined visually. Other materials can also be used, e.g. stainless steel, depending on local circumstances.

The plant is designed as a skid mounted module allowing off-site fabrication and testing. The plant could also be operated as a mobile plant.

A small chemical dosing plant is provided as a separate module. This can either be mounted above the LET plant with a gravity feed to the tanks, or alongside the plant with a pumped feed.

The plant is located within an enclosure in the main operating area. Access into the enclosure is via a personnel door. The enclosure is ventilated separately from the main operating area, and HEPA filtration of the exhaust is provided in the vent room.

1.5.5. Solids treatment

Only simple solid waste treatment processes are employed because of the relatively small volumes of waste expected (see Fig. 5). Solid waste may be checked/sorted in the sorting cabinet and segregated into compactable and non-compactable streams. This may be a more rigorous segregation than that already performed at the waste consignor, however it is best if the waste is reliably sorted by the generator (see Appendix I).

The sorting cabinet is a simple fume cupboard with a fixed sash opening fitted with sliding glove ports and gloves for handling waste. Waste is posted into the cabinet via a drum port in the back of the cabinet. After sorting, the segregated waste is placed into one of two drums located beneath ports in the floor of the cabinet.

An in-drum compactor operates in conjunction with the compactable waste drum to give improved waste drum loading, and an expected volume reduction factor of 2 to 2.5 relative to the delivered raw waste. The in-drum compactor is a standard commercial item of equipment, adapted for use in the WPSF and built into the sorting cabinet.

In-drum compaction is a low-cost, economic method of processing the compactable waste. At the same time, it leaves the options open for possible further treatment of the waste at a later date, prior to disposal, if required, i.e. by high force compaction or by incineration, although this would not be technically necessary.

Non-compactable wastes will be repacked into drums and transferred to the cementation area for grouting.

The sorting cabinet is equipped with lighting and large viewing windows. It is also ventilated, with single stage HEPA filtration. There is no primary filtration at the cabinet itself. The cabinet is able to process used HEPA filters by compaction into 200 L drums.

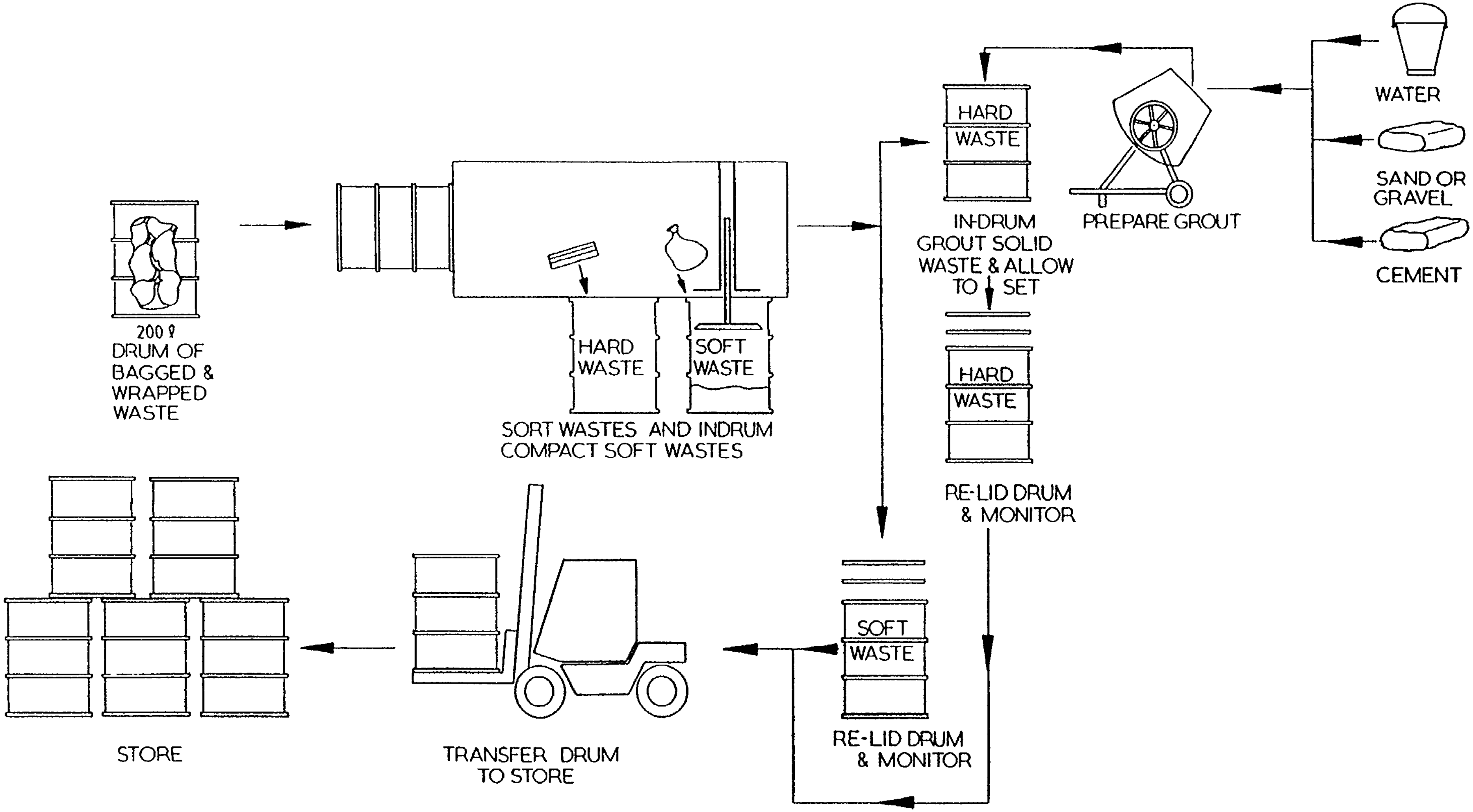


FIG. 5. Pictorial flowsheet of solids waste processing.

1.5.6. Other wastes

Small quantities of ion exchange resins, animal carcasses and organic liquids are expected to arrive at the WPSF for treatment. These wastes will be treated as they arrive, rather than being accumulated. Direct encapsulation in cement is the preferred waste treatment process. Small quantities of ion exchange resins will be added to a batch of sludge (from the precipitation process) and encapsulated by in-drum mixing. Organic liquids will be absorbed on to solid material e.g. vermiculite, before again being mixed with a drum of sludges and encapsulated in cement by in-drum mixing. Small animal carcasses will be encapsulated in cement by in-drum grouting. Spent sealed sources will also be encapsulated in cement.

1.5.7. Cementation

Encapsulation of liquid wastes, and in-filling of drums of non-compactable wastes will be by cementation in 200 L drums. For the liquid wastes, sludges and ion exchange resins, a simple in-drum mixing station is provided, using a high shear mixer with a reusable agitator. For solid wastes, and grout capping, a commercial grout batching unit is provided, although a simple tumble mixer could also be used. Test equipment to verify the acceptability of the resulting product is described in Section 2.5.3.

A batching system is also provided for measuring known volumes of sludges or resins into a drum. This system has connections to the LET plant for transfer of sludge and water, and also to a station within the cementation area where containers of ion exchange resins can be emptied.

The cementation area is an enclosure within the operating area, and separately ventilated with coarse filters in the enclosure to remove cement dust, and HEPA filtration at the vent room.

After in-drum grouting or in-drum mixing, the drum of cemented waste will be left for approximately 16 hours, or overnight to cure. An inactive group cap will then be added, and allowed to cure before the drum is relidded.

1.5.8. Dispatch

Completed waste drums, either of compacted solid waste or encapsulated waste will be moved to the dispatch area using a manual fork lift or pallet truck before going to storage.

In accord with the philosophy of a minimum cost facility, the reference design provides that the receipt and dispatch operations are performed in the same room (Fig. 8). This design can be modified to provide separate areas, if necessary, to meet the regulatory requirements or operating needs of a Member State.

The first operation will be to monitor each drum and check for contamination. As before, if contamination is present the drum will be moved to the decontamination area. If satisfactory, the drum will be temporarily held in the dispatch area. The documentation for the drum will be checked, and the unique drum identification number permanently marked on the drum.

Drums may be accumulated in the dispatch area awaiting transport to the store. Obviously, if the store is on the same site as the waste processing facility, then drums could be transported to the store as they arise, at the rate of approximately 1 drum/day. However, it may be more economic to transfer a number of drums in one shipment. This will clearly be the case if it is necessary that the store is located on a site away from the waste processing facility.

The dispatch area is sized to enable waste drums to be accumulated by simple stacking, and to provide access for a powered fork lift truck via a roller shutter door.

1.5.9. Store building

The store (see Fig. 6) is a single storey rectangular building of steel framed construction with commercial uninsulated metal cladding attached to the roof and exterior walls. It has no internal partitions. Although not required at present, consideration has been given to the possible future option of providing a shield wall, of concrete block or reinforced concrete construction, all around the building perimeter within the metal cladding envelope.

The building stanchions are founded on individual mass concrete bases, whilst the ground floor comprises a reinforced concrete ground bearing slab thickened locally all around the building perimeter.

The reference design for the store is 39 m × 26 m, with an eaves height of about 4.5 m. This size of building will hold 3000 200 L drums. The building can be expanded to increase this capacity, or a smaller store can be constructed if a Member State expects to produce a lessor volume of waste over an approximately 10 year period.

Drums will be stacked 3 high in rows 2 drums wide in a half-offset stacking pattern. A central corridor will be formed through the middle of the store to enable the fork lift truck to manoeuvre. Narrow aisles will be formed between each double row of drums to enable personnel access for visual inspection.

2. WASTE PROCESSING FACILITY

2.1. BUILDING DESCRIPTION

2.1.1. Construction

The waste processing building is a single storey rectangular building with overall plan dimensions of approximately 29 m × 28 m, rising to an eaves height of approximately 5 m. The general arrangement of the building is indicated in Figs 7, 8 and 9.

The building is of simple steel framed construction. Steel stanchions located around the perimeter and two lines of internal stanchions provide support to steel roof beams. The steel layout is such that the internal stanchions are generally located within internal partitions and in particular no stanchions are located within the central operating area, thus providing free working space in this area. Lateral stability to the steel building frame is achieved by a system of symmetrical bracing to the roof and exterior wall elevations. This bracing system will ensure that all lateral loads at roof level are transmitted to the building foundations.

The stanchions are generally founded on individual mass concrete bases which are then taken down to a suitable soil bearing strata. Combined reinforced concrete bases are

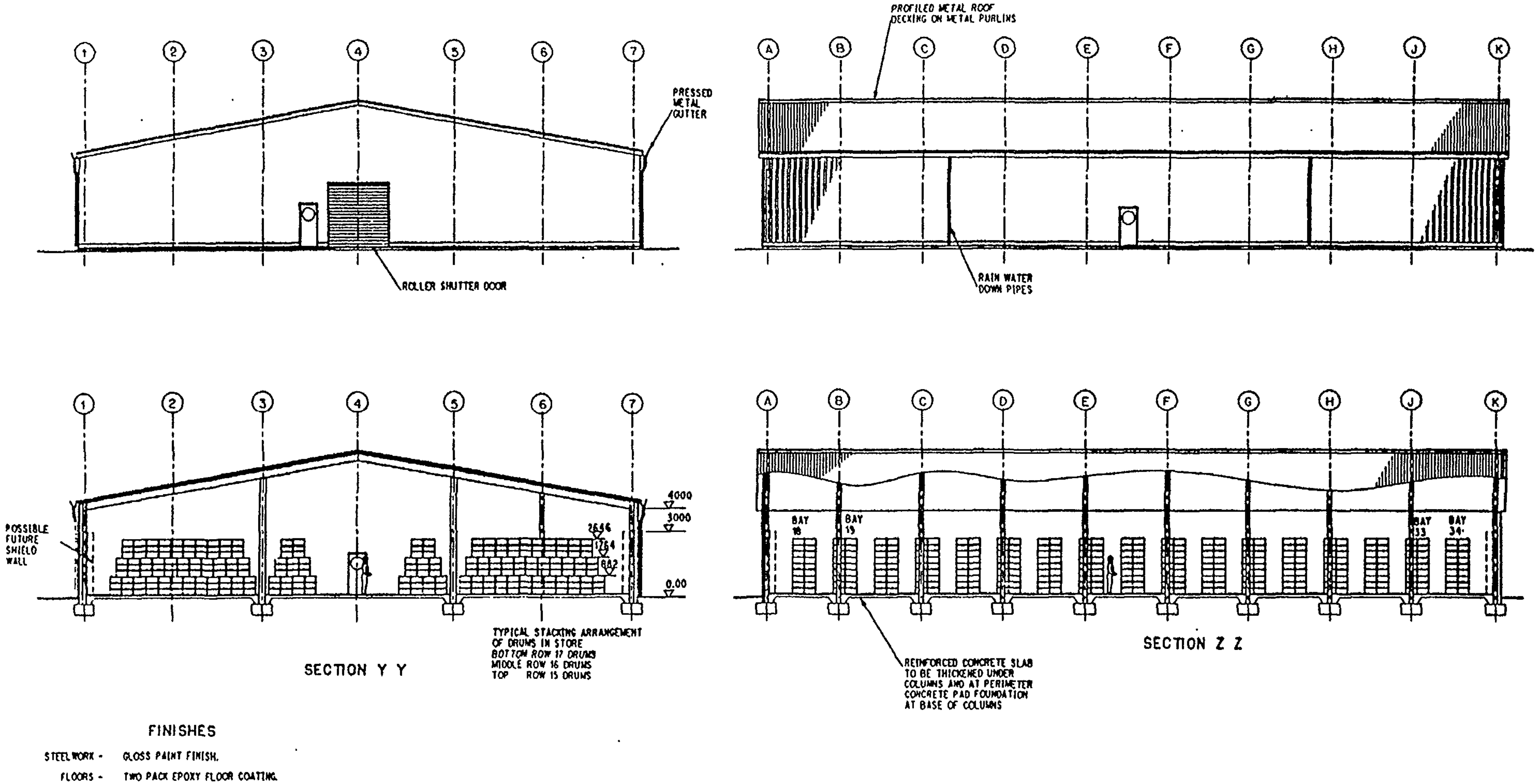


FIG. 6. Storage building — Elevations and sections.

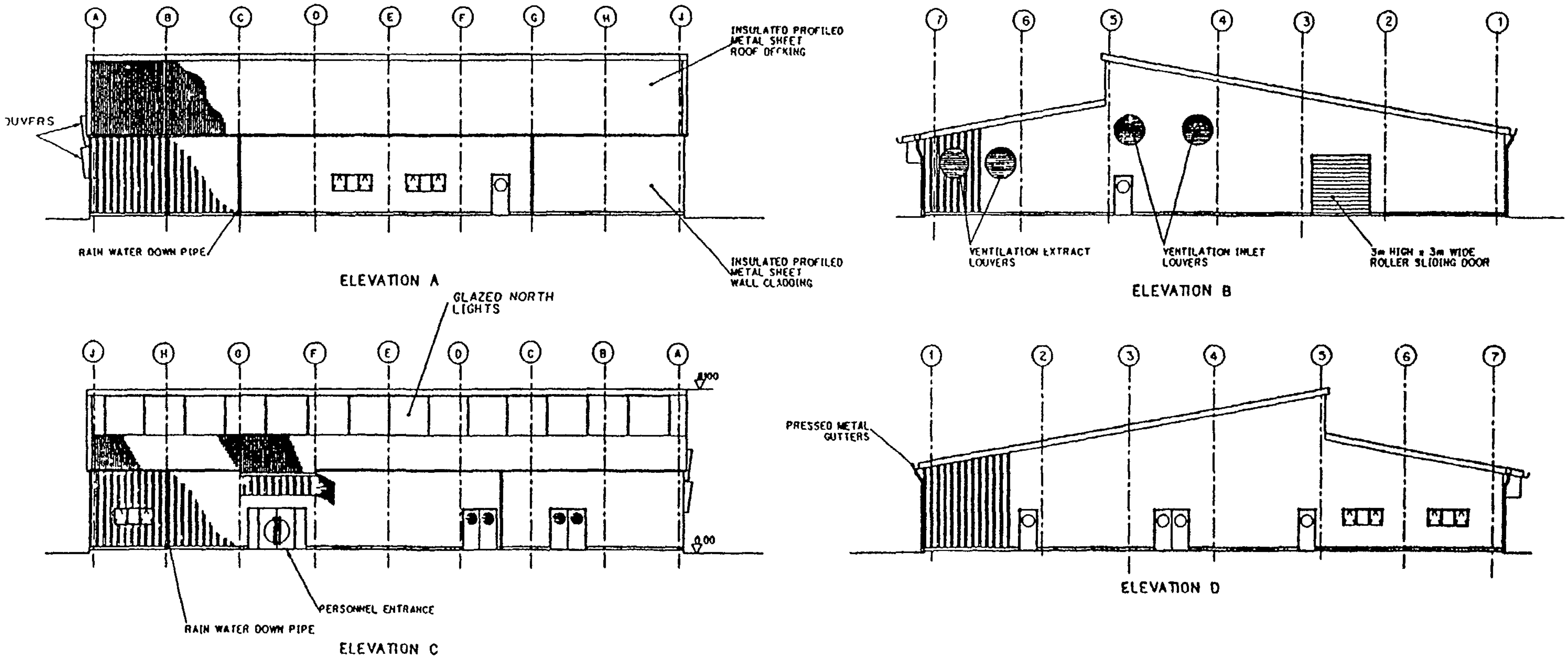


FIG. 7. Waste processing building — Elevations.

necessary on the stanchions which reinforce part of the vertical bracing system. This provides adequate resistance for uplifting.

The roof comprises commercial insulated metal cladding on steel purloins which span between the main roof beams. Roof drainage is achieved by pressed metal gutters on the eaves which discharge into downpipes on the exterior of the building envelope.

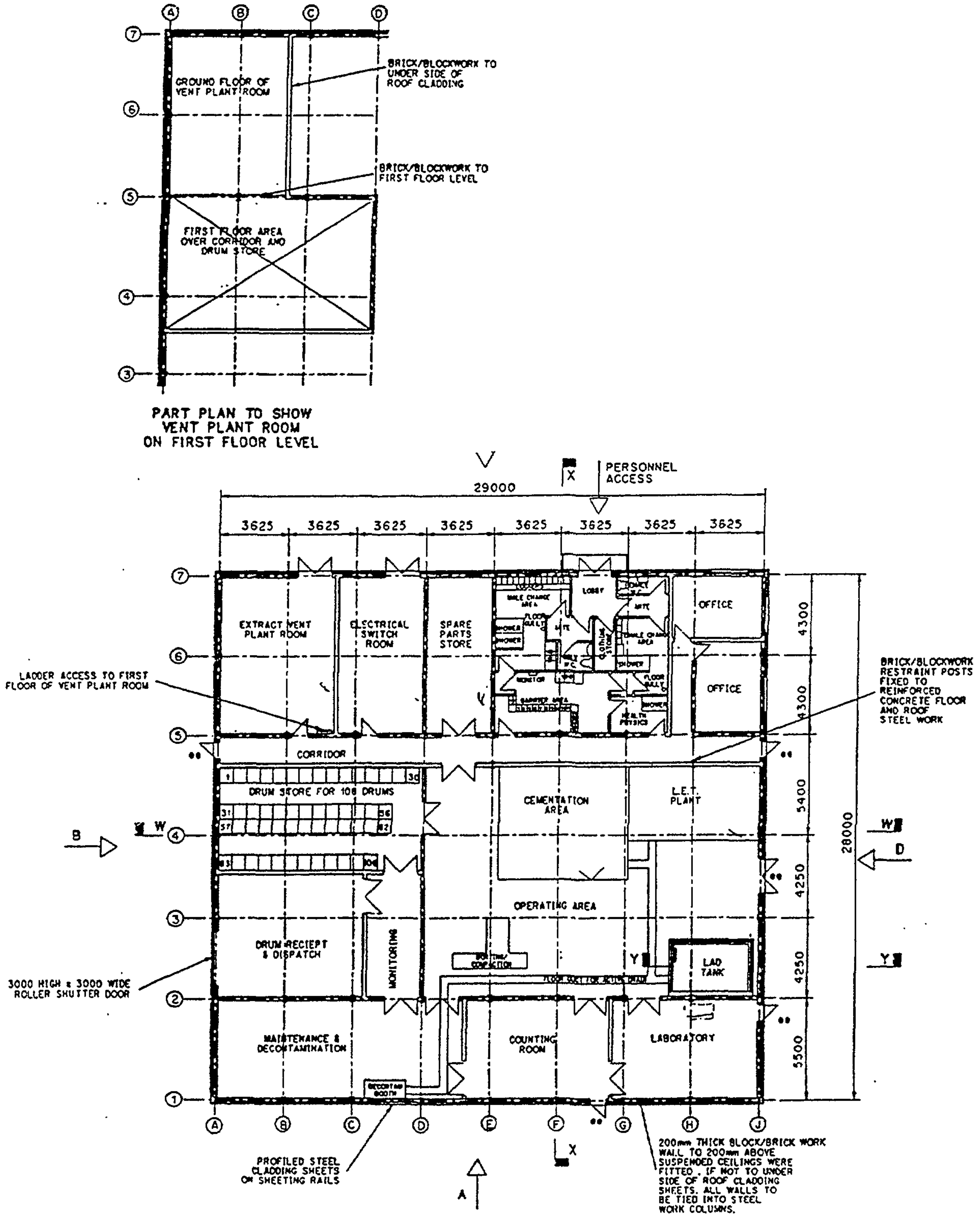


FIG. 8. Waste processing building — Floor plan.

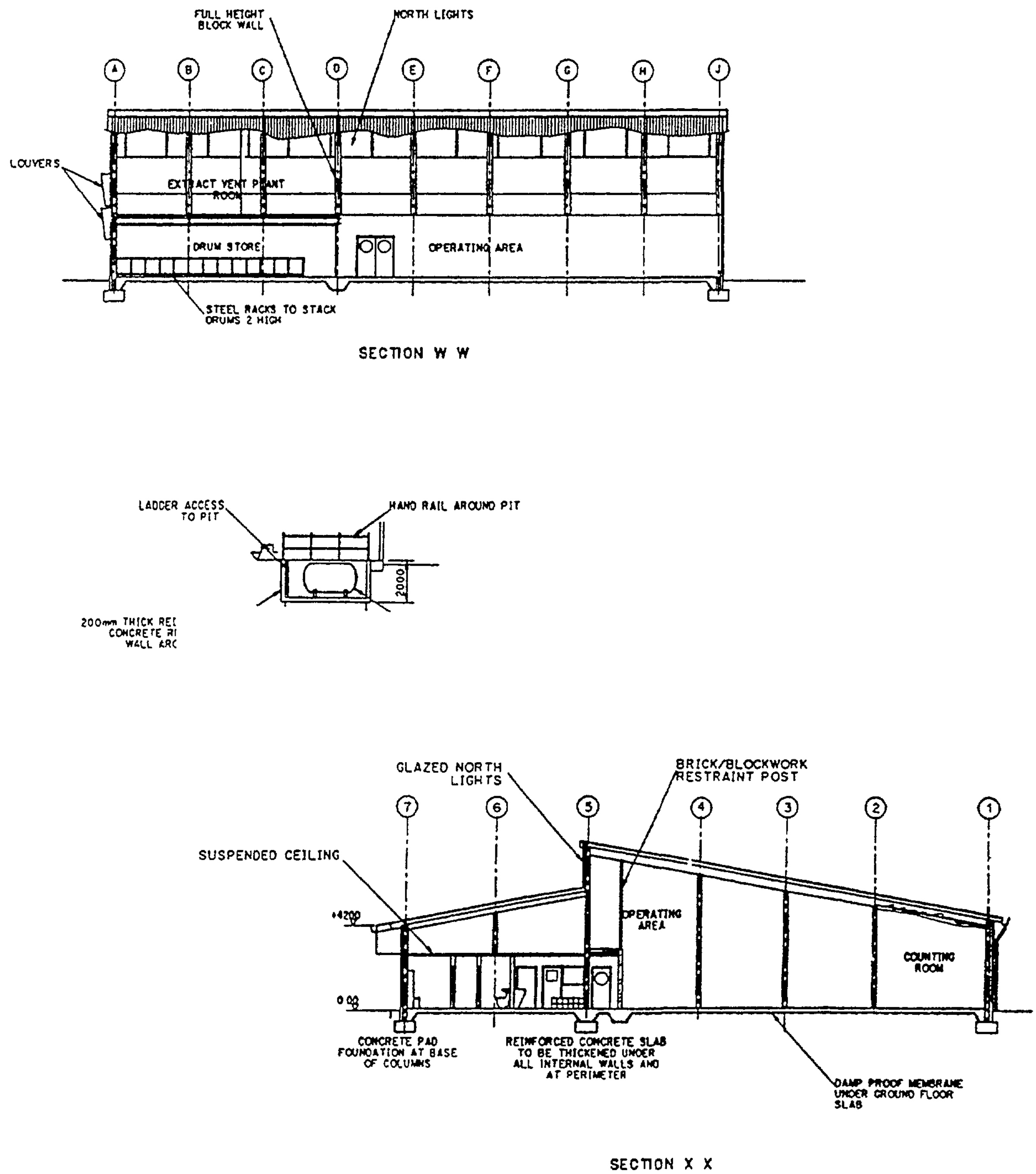


FIG. 9. Waste processing building — Sections.

The external walls comprise commercial insulated metal cladding on steel sheeting rails which span horizontally between the perimeter stanchions. In addition an inner block wall is provided for the full building height. This block wall is located within the depth of the stanchion webs to which it is connected by commercial metal ties.

The internal partitions are of concrete block construction and generally extend to the full height of the building. These partitions are built into the web of the internal steel stanchions to which they are connected by metal ties. The stanchions provide lateral restraint to the wall panels - in some areas additional panel lateral restraint is necessary and this is achieved by the introduction of blockwork restraint posts which span between ground floor and roof framing level and to which the blockwork is tied.

In the office and change areas the internal partitions do not extend to the full height of the building. A suspended ceiling is provided to give a headroom clearance in these areas of approximately 2.5 m and the partitions are terminated at this ceiling level.

The ground floor comprises a steel mesh reinforced concrete ground bearing slab. This slab is thickened all around the building perimeter and locally under all internal partitions and at building stanchions. Resistance to water penetration from the ground is provided by a polyethylene waterproof membrane on the underside of the slab.

In the operating area an open top pit is provided to house a low active drainage (LAD) storage tank. This pit has internal dimensions of approximately 3.9 m × 2.5 m × 2.0 m deep with the top at ground floor level. It is of reinforced concrete construction with 200 mm thick walls and base slab. The external floor and wall faces are protected against ground water penetration by a commercial tanking system. Access to the pit is provided by a ladder and protective handrails are provided around its top. Additionally two concrete ducts are provided which house LAD pipework running from the 'cementation area', 'liquid effluent treatment area' and 'sorting/completion area' to the LAD tank pit. These ducts have approximately internal dimensions of 0.7 m × 0.5 m deep, are open at their top and protected by removable commercial steel duct covers.

Structural steelwork will generally be grit blast cleaned and treated with a zinc rich primer followed by an alkyd undercoat and gloss finish paint system. The roof purloins, sheeting rails, ladder and pit handrail system will be hot dip galvanized. Internal wall finishes will comprise smooth faced block work which may be painted.

The ground floor will be finished with an epoxy paint with the exception of the office, changing room and corridor areas where a commercial linoleum finish will be applied.

2.1.2. Features

Section 1 describes in general the main waste treatment areas and their interactions with other areas and facilities within the waste treatment building. These other areas and facilities are listed here and discussed in more detail below:

- change rooms;
- receipt and dispatch bay;
- monitoring area;
- interim store;
- decontamination room;
- laboratory.

Change rooms

(a) Function

Sufficient change room facilities are provided for approximately 15–20 plant operators and staff (male and female). The change rooms encourage correct personnel contamination protection with boot barrier, overshoe and lab coat/overall changes and personnel monitors.

(b) Description of operation

Entrance to the WPSF is via a lobby area. Personnel then pass into the change areas where lockers are provided for personal belongings. From here, personnel move into the barrier area where they should adopt correct barrier procedures, changing their shoes or adding overshoes as they pass over the boot barrier, and then putting on lab coats or coveralls as appropriate.

When leaving the operating area personnel again go into the barrier area and adopt correct barrier techniques; first removing their lab coat/coveralls and then their overshoes as they pass over the boot barrier. As a minimum, personnel are able to wash their hands and then monitor their hands and feet before passing into the change area to collect personal belongings.

(c) Description of change rooms

The change rooms occupy an area around the personnel entrance to the WPSF. The male change area is provided with lockers, showers, wash basins and WCs sufficient for approximately 12–15 operators, whilst the female area is provided for 4 operators.

Waste receipt and dispatch bay

(a) Function

A bay is provided at the centre of one end of the building for the receipt of waste drums from the transport conveyance, and for dispatch of processed and conditioned wastes to the final store (Fig. 8).

(b) Description of operation

Drums of waste will be delivered to the WPSF by some means of transport vehicle. When the transport arrives at the WPSF, the roller shutter door is opened and the vehicle backed up to, or into, the bay. Drums may then be off-loaded using a manual or powered fork lift truck fitted with drum grab attachments. To speed emptying of the vehicle, waste drums are initially held in the receipt bay before being taken via the monitoring area to the operational store. The bay has sufficient capacity to temporarily store up to 100 drums if required.

The bay also acts as a dispatch area for conditioned wastes. These will be delivered to the store from the operating area via the monitoring area using a manual fork lift truck. After final checks on documentation, the drums will be transported to the final store. If the store is adjacent to the main processing building the drums will be transported by powered fork lift truck as they arise, i.e. approximately one per day. However, if the store is some distance away, several drums will be accumulated in the bay until a sufficient number are available to fill a transport vehicle. Temporary shielding will be erected around particular individual drums, or self shielding by other drums could be used if required.

(c) Description of bay

The bay is rectangular in shape, approximately 7.5 m (ℓ) $\times$ 6.5 m (w). A roller shutter door in the outside wall is sized to allow the largest transport vehicles to back part way into the bay. A double door in the opposite wall allows personnel and manual fork lift access into the monitoring area, and from there into the store, or via the decontamination area into the operating area. If required, part of the adjacent decontamination area would be closed off and opened up to the receipt bay to allow a receipt bay office to be created.

Monitoring area

(a) Function

This is an area where drums of waste either entering or leaving the WPSF can be monitored for contamination and gross radiation levels.

(b) Description of operation

Waste drums are brought into the area one at a time using a manual fork lift truck for monitoring. Gross radiation level measurements at the surface at several points and at a 1 m distance are made. The readings are checked against the documentation for the drum. Particularly high activity level drums are identified and appropriate precautions taken to reduce operator dose rates by providing temporary shielding using a shielding material, or other drums of waste, or distance. Surface contamination checks are also made by swabbing several areas of the drum. Drums with surface contamination are sent to the decontamination area for cleaning.

(c) Description of monitoring area

The monitoring area is located adjacent to the drum store, drum receipt and dispatch bay, and the maintenance and decontamination area, with double personnel doors into each. The area is approximately 2.7 m (w) $\times$ 6.5 m (ℓ).

Operational store

(a) Function

The operational store is provided in the main processing building to provide storage of waste drums after receipt at the WPSF and awaiting processing. The store also has adequate capacity to provide longer decay storage of wastes than might be possible to provide at the waste producer.

(b) Description of operation

The store is located adjacent to the three areas with which it interacts:

- receipt;
- monitoring;
- processing.

On receipt at the WPSF, waste drums will be monitored for radiation levels and contamination, and documentation will be checked. The drums will then be transferred into the interim waste store using a manual fork lift truck fitted with a drum lifting attachment. The drums will be placed on the stacking shelves and the position of each drum in the store recorded along with its documentation to allow quick and simple identification and retrieval.

It is expected that particular types of wastes will be processed in campaigns, i.e. soft wastes for compaction, hard wastes for in-drum grouting, or aqueous wastes for precipitation and encapsulation. The method of storage will allow pre-selected containers of waste to be retrieved as and when required for processing.

The store provides sufficient capacity for 100 drums which corresponds to approximately 4 months of waste processing at the nominal throughput of the WPSF. This capacity is also slightly greater than the largest single load of drums which could be expected to be received at the WPSF by a lorry. Therefore, the WPSF could be kept operating at capacity by only 3–4 single, large deliveries per year.

(c) Description of store

The store is basically a rectangular room approx 10.5 m (d) × 5.5 m (w) with a suspended ceiling at 2.5 m (h). Double doors in one corner give access to personnel and waste drums. The store has sufficient capacity for approx 100 drums (200 L) stacked 2 high on racks. This system allows any single drum to be retrieved without the need to shuffle drums around.

Commercial racking/shelving systems are used for storing drums. Alternatively, it may be appropriate to fabricate the shelves from standard steelwork sections, finishing them with a suitable epoxy paint finish to provide a decontaminable surface.

The width of the aisle between the shelf racks is 1.1 m to allow access for the manual fork lift truck. The architectural finish of the store is similar to the main operating area with smooth, decontaminable surfaces to the floors and walls, and covering to the wall/floor joint.

The store is ventilated, and the exhaust joins that from the other low risk areas. No HEPA filtration is required as the drums remain sealed whilst in store.

Decontamination room

(a) Function

The decontamination room provides an area both for the maintenance and decontamination of equipment and also the decontamination of waste drums. The room is provided with a decontamination cabinet where most decontamination operations will be performed.

(b) Description of operation

Waste drums or items of equipment requiring decontamination will be brought into the room on a pallet truck or manual fork lift truck. The doors of the decontamination cabinet will be opened, and the drum or equipment loaded into the cabinet using a fork lift or small mobile crane. The doors of the cabinet are then closed and decontamination can begin, using gloves fitted to the doors.

This section is not intended to give a full description of the decontamination techniques and chemicals available (see Section 2.4.5). However, it is expected that the cabinet will provide the facility for most simple techniques using washing, swabbing and scouring with hands-on operation.

After adequate decontamination, the drums or equipment may be removed from the front of the cabinet once the doors have been fully opened.

(c) Description of decontamination area

The decontamination area is a room approximately 12.8 m × 5.3 m adjacent to the main operating area. The majority of the area will be used as a workshop, and will also provide storage space for decontamination fluids. The main item of equipment in the area is the decontamination box, is described in Section 2.4.5.

Laboratory

(a) Function

The laboratory provides an area for the preparation of chemicals for the precipitation treatment process, and the analysis of samples of solids and liquids, as well as providing space for performing small research and development projects. In addition, the laboratory houses the fume cupboard and pump used to transfer aqueous waste liquids into the LET plant.

(b) Description of operation

A number of routine operations are performed within the laboratory. However, perhaps the most significant one is the transfer of waste liquids to the LET plant. After receipt, poly bottles or larger containers of liquids will be taken to the laboratory and positioned either adjacent to or in the laboratory fume cupboard. Here, the liquid is first sampled and analyzed before being transferred to the LET plant. A small, air operated, diaphragm pump is provided in the fume cupboard. The flexible suction pipe from this is dipped into the liquid container and the isolation valves on either side of the pump are opened. The pump is then started to empty the container. When the container is empty the valve on the pump delivery side is closed before the pump air supply is turned off, and the suction side valve closed. Any drips from the suction pipe when it is removed should be directed to the fume cupboard drain which is routed to the low active drain tank. Empty containers are taken to the decontamination area for cleaning.

(c) Description of laboratory

The laboratory is located in a corner of the WPSF building and measures 5.5 m (ℓ) × 7.25 m (w). The laboratory will be equipped with a range of standard laboratory furniture, i.e. benches, cupboards, chemical stores and standard laboratory equipment, listed below:

sink
benches and cupboards
fume hood
oven
radiation counter (both personal monitor and sample counter)
solvent and chemical stores
waste bins
fire extinguisher
protective clothing and gloves

appropriate safety and first aid equipment
glassware; beakers; pipettes; standard flasks; etc.
distillation and vacuum filter glassware
pH meter
conductivity meter
clamp stands
balance.

The fume cupboard (Fig. 10) can be purchased commercially. It is connected to the active ventilation system and the low active drain.

An air operated diaphragm pump is located in the fume cupboard. This pump is fitted with plastic ball type isolation valves and a flexible suction pipe.

The laboratory may also contain the cement testing equipment mentioned in Section 2.5.3.

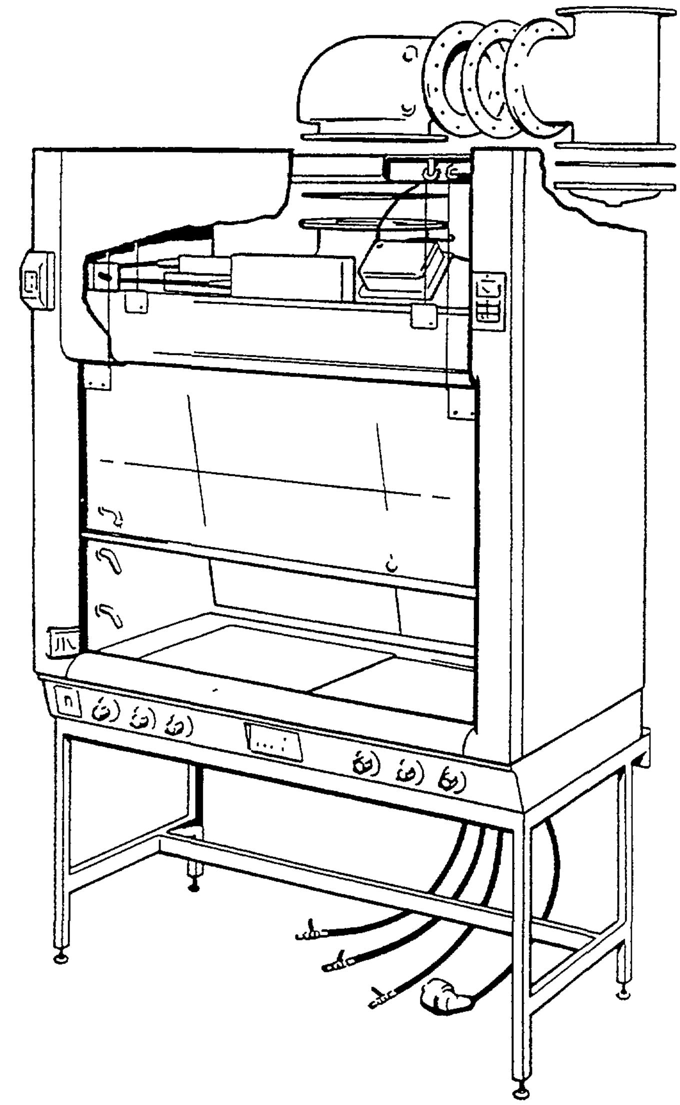


FIG. 10. Typical laboratory fume cupboard.

2.2. LIQUID (AQUEOUS) WASTE TREATMENT

Treatment of aqueous liquid effluents will be by precipitation, with discharge of the supernate, and encapsulation of the settled sludge in cement [5–7].

The major equipment for the precipitation plant will be on skid mounted modules, including tanks, pipework, pumps and valves (Fig. 11). Liquid effluent will be pumped to the plant from either:

- a separate building low active drain tank which will receive potentially active effluents and overflows from several areas within the WPSF;
- a waste receiving station within the laboratory fume cupboard, feeding to a small arisings tank on the module.

Treatment chemicals are prepared in the laboratory and manually transferred to the plant. Alternatively, a simple chemical preparation module (Fig. 12) could be installed adjacent to the precipitation plant and the chemicals pumped into the plant.

2.2.1. Process description

The design throughput of the plant is up to 360 m^3/year of low active liquid effluent based on 1.8 m^3 batches at one batch per day and 200 batches per year. For illustrative purposes the process description below includes values for the quantities of treatment chemicals added based on the example flowsheet illustrated in Fig. 13. The major steps in the treatment process are described below.

Feed transfer and analysis

A 1.8 m^3 batch of liquid effluent is transferred to the precipitation tank from either the low active drain (LAD) tank or the small arisings tank. The batch is sampled using a small peristaltic pump and the sample analysed for pH, iron content and radioactivity. The flowsheet shown in Fig. 13 assumes a pH of 7, and no initial iron content.

Adjustment of pH

The first step of the treatment process is to reduce pH to ≤ 2. This is achieved in two stages by addition of one molar nitric acid (1M HNO_3) to within 10% of the calculated acid requirement. The tank is then stirred and sampled and 0.1M HNO_3 is added slowly with repeated sampling until pH 1.8 to 2.0 is reached. The addition of acid is in two stages in order to avoid overshooting the desired pH.

Rapid stirring will be required during this phase of the treatment. The chemical feed line will then be flushed through with five litres of process water. (This will add to the process inventory.)

Flocculation with iron nitrate

Sufficient iron nitrate is then added in solution to give a final concentration of 100 ppm Fe. In this case 1910g $Fe(NO_3)_3$ is added in 10 L of water. This gives 183.3 g Fe in 1833 kg solution which corresponds to the concentration requirement. Again the line is flushed into the precipitation tank with 5 L of water.

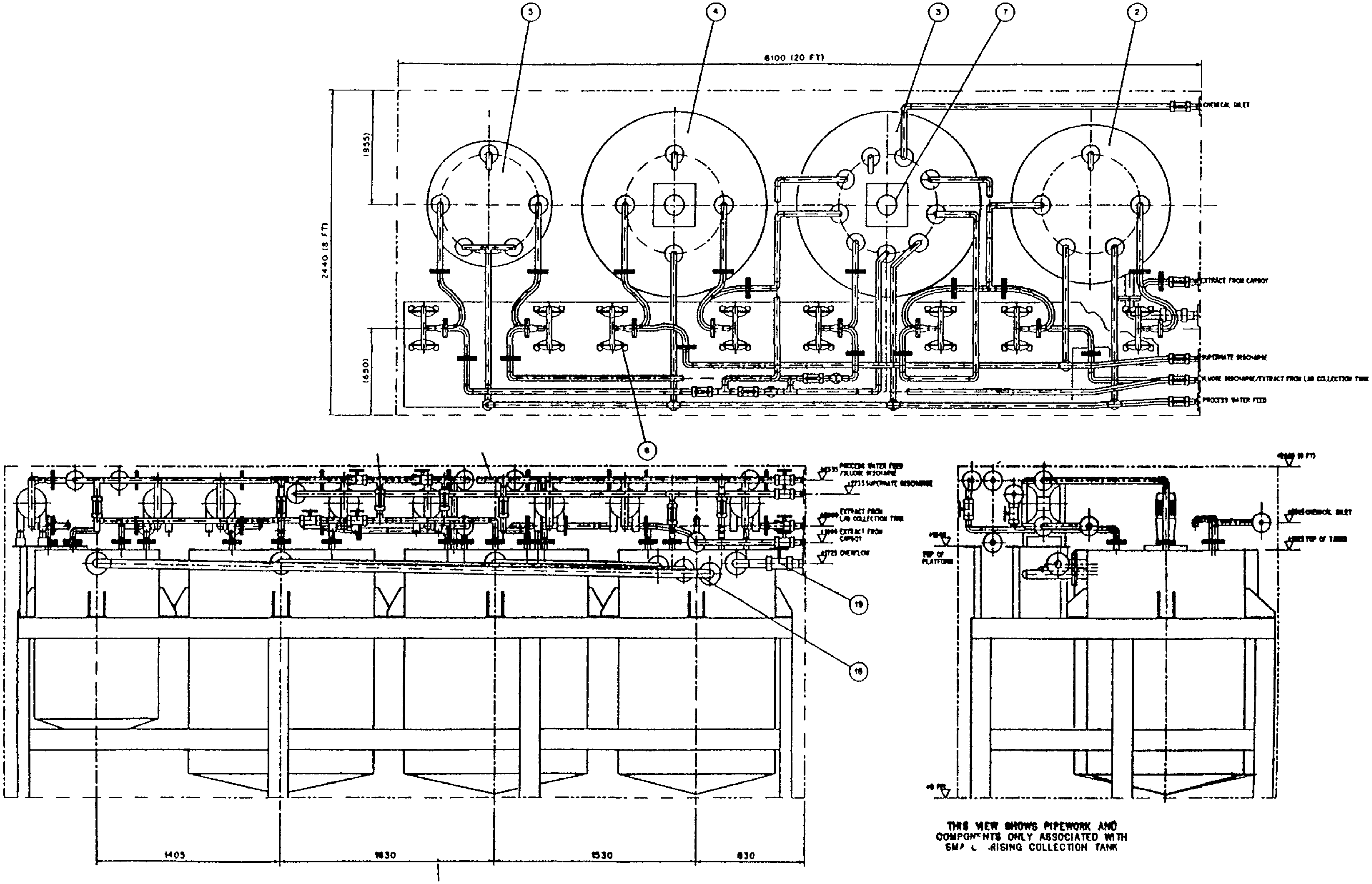


FIG. 11. General arrangement of liquid effluent treatment plant.

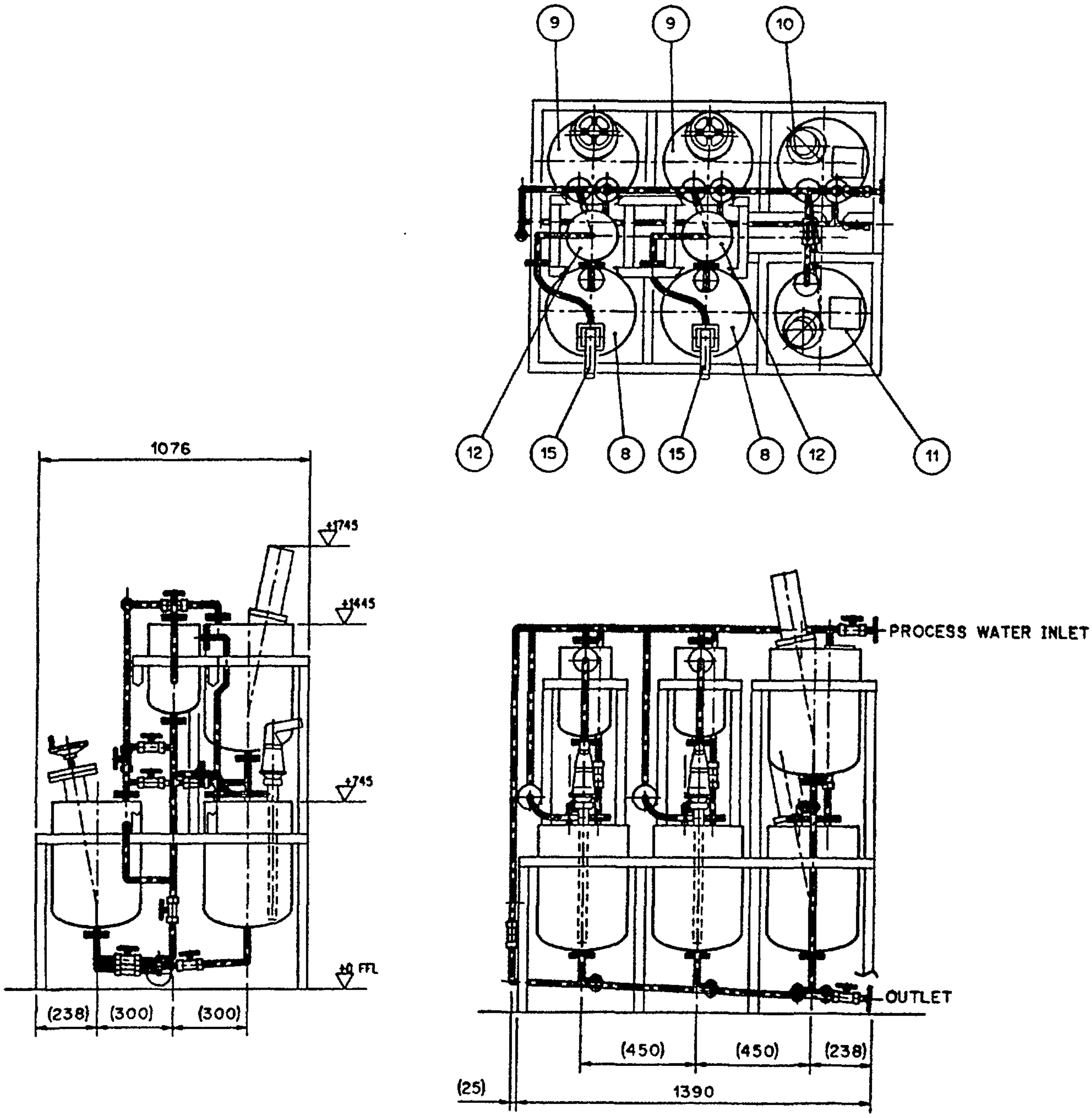


FIG. 12. General arrangement of chemical dosing module.

Adjustment of pH

Caustic soda is added in the same manner as the acid to increase the pH to 9, i.e. alkali added as 1M NaOH and trimmed with 0.1M. $Fe(NO_3)_3$ is insoluble in an environment of pH 9 and flocculation occurs. The agitator speed is reduced to encourage the agglomeration of the precipitate. This treatment removes the majority of the activity. However, additional treatment is required to remove particular radionuclides, for example ^{137}Cs. The pH control is critical as the second precipitation stage for Cs removal is ineffective above pH 11. A premixed $Ni_2Fe(CN)_6$ precipitate is added in sufficient quantity to give a batch analysis of 5 to 10ppm $Fe(CN)_6$. This precipitate is allowed to settle overnight in which time it reduces to a sludge of about 3% of the batch volume.

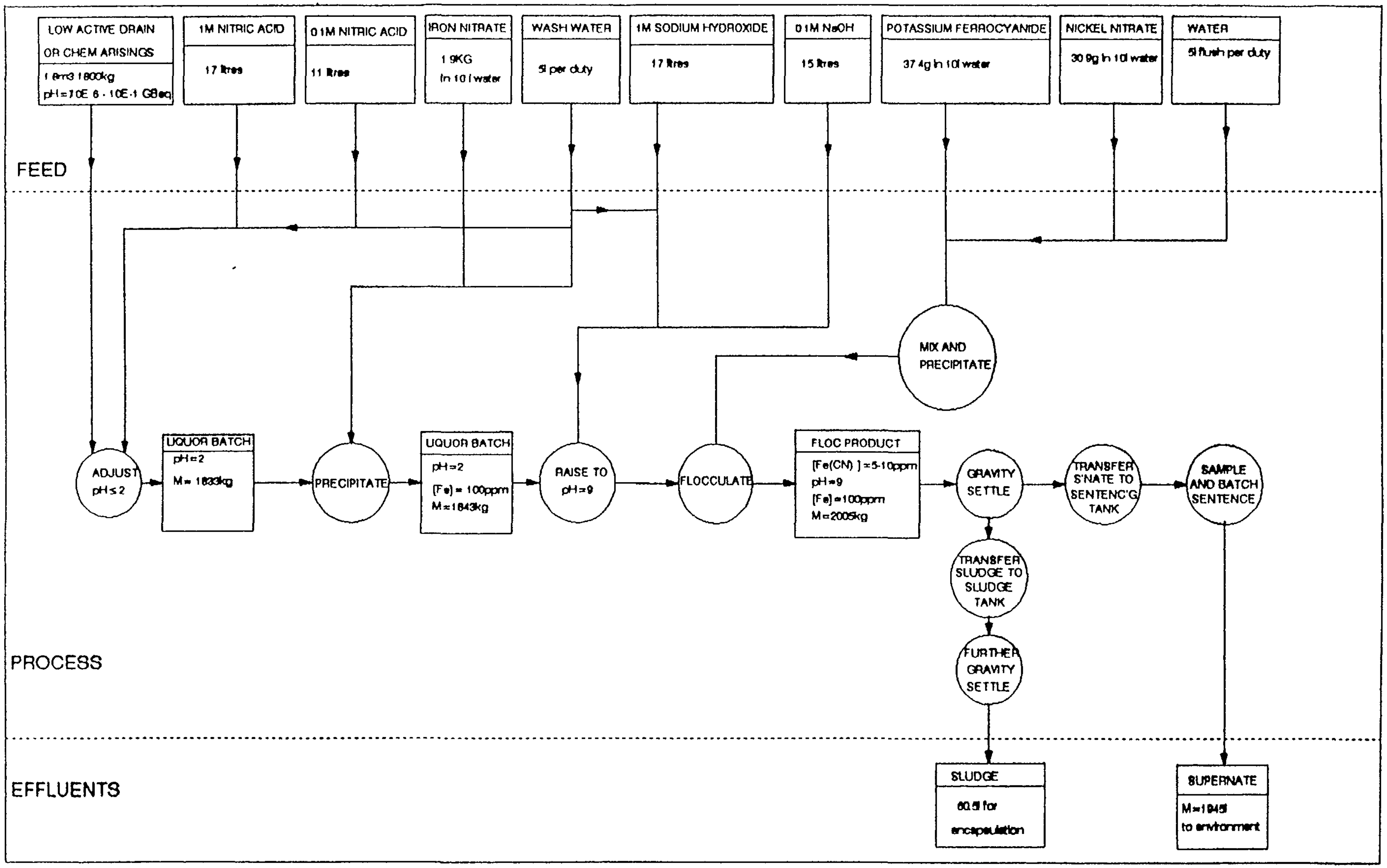


FIG. 13. Liquid waste processing flowsheet.

Separation and downstream processing of waste

The remainder of the plant is associated with storage and sampling of the separated products. The key to achieving a good decontamination factor (DF) is the efficiency with which the sludge is separated from the supernate. A two stage sludge-supernate separation process is used. Firstly the supernate is removed down close to the interface but not sufficiently close to entrain any sludge. The supernate is transferred to the sentencing tank. In the batch sentencing tank the supernate is sampled, its volume noted for regulatory purposes and if the activity is within authorized limits it can be discharged to a municipal or industrial sewer.

The sludge is then drawn out of the precipitation tank and transferred to the sludge de-watering tank. Lines contaminated by sludge will be flushed clean with fresh liquor from the precipitate tank, either with wash water or a portion of the next batch. In the sludge de-watering tank the sludge is allowed to settle further. Additional de-watering of the sludge is performed periodically by pumping the supernate back to the precipitation tank. This time, however, supernate is drawn off right down to the interface. This supernate, and any sludge that is incidentally transferred, will be processed in the next precipitation batch treatment. When encapsulation is required the sludge is transferred to the encapsulation plant.

After each transfer of sludge the de-watering tank will be washed down and liquors recirculated to clean the line.

Chemical preparation

Acid and alkali will be supplied to the plant at 1M. 0.1M solutions will be made up in 50 L batch tanks. Further tanks will be used to prepare batch quantities of ferric nitrate ($Fe(NO_3)_3$), potassium ferrocyanide ($K_4Fe(CN)_6$) and nickel nitrate ($Ni(NO_3)_2$).

For the preparation of 0.1M acid and alkali, 45 L of process water will be fed to the makeup vessel and 5 L of 1M will be measured out and then added. The iron and nickel nitrate and potassium ferrocyanide are supplied in powder form. For each batch, 10 L of water is measured into the make up tank. The required weight of powder is added and the vessel agitated until dissolution is complete. The $Ni(NO_3)_2$ and $K_4Fe(CN)_6$ precipitate forms. These chemicals are then added when necessary.

Washdown

All vessels and pipework are fitted with washdown lines to allow the plant to be washed between batches or between liquor transfers. Wash liquors are eventually transferred to the precipitation tank for treatment as are other liquids prior to discharge.

2.2.2. Plant description

The plant consists of three sections: storage; precipitation process and chemical preparation.

The storage section includes a collection tank for the WPSF low active drains and a carboy feeding system. The process area comes as a self contained skid mounted unit. All required pumps are mounted on the unit. Connections between the unit and services are made via interlocked ball valves and flanges.

Should any leakage occur the liquors will be collected in a containment tray which lies below the process area, and returned via the drains to the low active drain collections tank.

The precipitation process equipment is contained within a 6 m × 2.5 m × 2.5 m module in order that it may be transported on the back of a lorry. All plant connections are made at one end via interlocked ball valves. This prevents transfers of liquor when the connections are not made.

A set of chemical dosing tanks make up the final area of plant. This area is also supplied as a complete unit. This section is also a single unit and is installed either adjacent to the main precipitation module, or within the laboratory.

The LAD collection tank is below ground level in a corner of the operating area. All equipment with potential active liquor arisings gravity drain to this tank. Figs 13 and 14 illustrate process and flow diagrams of the liquid effluent treatment plant.

General description

All tanks, except where otherwise stated, are constructed from natural polypropylene. Volume measurement is effected by a calibrated strip attached to the tank wall. Sampling is performed using a peristaltic pump which draws and returns liquor to the tank. A branch and valve is provided from which a sample is taken.

All tanks are vented to the plant enclosure which is in turn vented by the plant enclosure exhaust system. Overflows and wash down lines are provided for the tanks in the process area.

The following paragraphs list the function, general description, and interconnections (branches) of each process tank. The tank numbers are the same as shown in Figure 14.

Tank 1 – Low active drain (LAD) tank

(a) Function

Tank 1 contains low active drain arisings and also acts as an overflow for tank 2.

(b) Description

The tank has a capacity of 6 m^3. It is of horizontal cylindrical construction, 1.7 m in diameter and 2.8 m in length.

(c) Branches

The tank is provided with a vent and a wash water stub. Other connections include process overflow inlet, low active drain inlet, a submerged suction line to draw liquor out of the vessel and feed it to tank 3, and a drain line from the plant containment tray (Fig. 14).

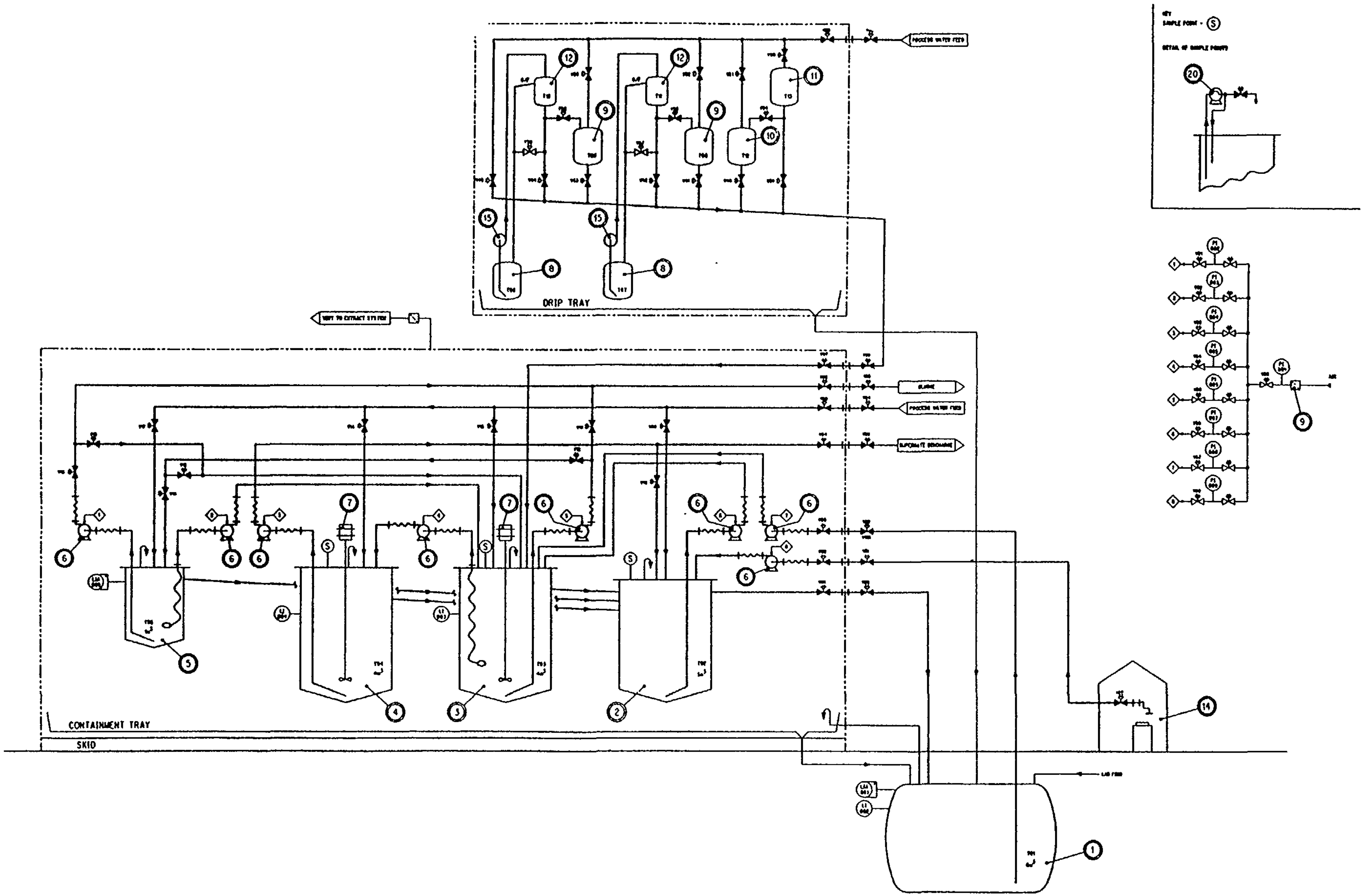


FIG. 14. Liquid effluent treatment plant flow diagram.

Tank 2 – Small arisings collection tank

(a) Function

This holding tank collects the waste that arrives at the WPSF in carboys and polyethelene bottles. It has sufficient volume to store one batch of liquor awaiting treatment.

(b) Description

The tank is 2 m^3 in volume with a maximum operating volume of 1.8 m^3. It is 1.2 m in diameter with a height of 1.8 m. It is of vertical cylindrical construction with a conical base and a flat bolted down lid.

Level measurement and sampling are provided.

(c) Branches

Connections include vent and wash water, feeds from the carboy feed area and the batch sentencing tank for reworking and a line to the precipitation tank 2. An overflow to tank 1 and a sample loop are also supplied.

Tank 3 – Precipitation tank

(a) Function

This is the chemical treatment vessel where a precipitate is formed and allowed to settle leaving a clean supernate and an active sludge precipitate.

(b) Description

The tank is 2.6 m^3 in total volume with a working volume of 2 m^3, which is the final batch volume. The tank is provided with volume measurement and sampling to allow calculations to be made for chemical additions. The vessel is 1.4 m in diameter and 1.8 m in height and of similar geometry to tank 2. Agitation of the vessel is required for two different duties. Rapid stirring is necessary to disperse the chemicals and slow stirring to allow the precipitate to agglomerate.

(c) Branches

The connections to the vessel include a vent, process water feed, inlets from the low active drain and small arisings tanks, an inlet line from the chemical dosing area and a return line of supernate from the sludge de-watering tank. The precipitation tank also acts as a source of wash water for cleaning sludge transfer lines. For this purpose there is a return line from both the sludge transfer lines.

For normal operation there are also two output connections. One is used to draw the supernate off the batch and transfer it to the batch sentencing tank. The in-tank portion of this pipe is a flexible hose attached to a float to draw liquor from the surface.

The second output is through a submerged line to withdraw sludge and pump it to the sludge de-watering tank 1. This line is also used to pump wash water through the sludge lines.

Tank 4 – Batch sentencing tank

(a) Function

This tank is used to temporarily hold a batch of supernate from the precipitation tank until it is sampled and analysed. If the supernate conforms to authorized discharge limits, it is discharged to an industrial or municipal sewage system.

(b) Description

This tank has a volume of 2 m^3, with dimensions 1.2 m diameter and 1.8 m tall. It is of vertical cylindrical construction with a conical base and a flat bolt-down lid.

c) Branches

Corrections are provided for supernate feed from the precipitation tank 1, supernate discharge, sampling and washwater. An overflow is provided back to the small arisings tank.

Tank 5 – Sludge storage

(a) Function

This tank is used to collect and periodically de-water the sludge from the precipitation tank. Once several batches of sludge have accumulated the sludge is pumped to the encapsulation plant.

(b) Description

This tank has a volume of 1 m^3 with dimensions 0.9 m diameter and 1.35 m height. The tank is of similar geometry to tank 2.

(c) Branches

Standard connections include vent, overflow to tank 2 and a wash water feed. Connections for sludge to feed from tank 3 supernate to return there and de-watered sludge to be transferred for encapsulation are also supplied.

Carboy emptying station

(a) Function

This is an area where carboys and polybottles of liquid effluent are opened and emptied by suction pipe and pumped to the small arisings tank.

(b) Description

The station is housed in the laboratory fume cupboard, and comprises an air operated diaphragm pump and a flexible suction hose which is inserted into the carboy or bottle. The pump delivers to the small arisings tank via PVC pipework.

Chemical dosing tank module

(a) Function

The chemical dosing module provides the equipment to store and prepare the chemicals required for the precipitation process.

(b) Description

The chemical dosing module consists of a set of six 50 L translucent polypropylene measuring tanks and two 10 L measuring tanks. The relevant item numbers are:

Tank 6	1M HNO_3	– 50 L, strong acid batch tank
Tank 7	1M NaOH	– 50 L, strong alkali batch tank
Tank 8	0.1M HNO_3	– 50 L, hand operated stirrer
Tank 9	0.1M NaOH	– 50 L, hand operated stirrer
Tank 12	$Fe(NO_3)_3$	– 50 L, mechanical stirrer
Tank 13	K_4 $Fe_3(CN)_6$	– 50 L, mechanical stirrer.

Transfer of chemicals to the precipitation plant can be by gravity (if the dosing module is mounted above the precipitation plant) or by pump.

(c) Branches

All tanks have process water and process feed lines.

With exception of the feedlines between Tanks 6, 10, 7 and 11 liquors are transferred by gravity through 2.5 cm pipes. The process may be flushed with water between additions.

Connections between tanks 6, 8 and 10 include: feed for tank 6 to tank 10 with an overflow and a return line back to tank 6. 1M acid measured into tank 10 may be fed to tank 8 add to a batch of water and make 0.1M HNO_3 or fed directly to the process. Tank 13 has a connection to tank 12. This is to allow mixing of nickel nitrate and potassium ferrocyanate solutions.

Auxiliary equipment

(a) Pumps

There are three types of pump in use on the plant. These include eight 100 L/min air operated double diaphragm pumps, two 10 L/min barrel emptying pumps, and small peristaltic pumps for liquor sampling.

The air operated double diaphragm pumps facilitate liquor transfers in the main process area with the drum emptying pumps being employed on the chemical dosing module. Flexible hosing is required on both the inlet and outlet of the diaphragm pumps to reduce the effect of vibrations caused by the pulsed flow.

(b) Valves

All valves are PVC ball valves.

(c) Pipework

All process lines are 2.5 cm ID PVC with overflow lines of 5 cm.

Flexible piping of 2.5 cm ID is also employed on the inlets and outlets of the double diaphragm pumps to absorb the vibrations set up by the pulsed flow. Flexible hosing with floats attached to the end are used in tanks 3 and 5 to enable clean supernate to be drawn off the top of the batch of liquor.

(d) Agitators

There are six stirrers in the plant, four in the chemical dosing section and two in the process area.

Two of the agitators in the chemical dosing area are simple hand paddles and two are mechanical. These mixers are used for blending and to aid dissolution.

The agitator on the precipitation tank 3 has a dual function. Firstly to blend all chemical additions and secondly to slowly stir the contents to encourage coagulation of the precipitate formed. The duty therefore requires a two speed mixer. Suitable mixers of 0.4 kW are commercially available. The final mixing duty is on the batch sentencing tank 4. This tank must contain a homogeneous mixture in order to ensure that representative samples can be taken. A 0.4 kW mixer is adequate for this duty.

2.3. SOLID WASTE TREATMENT

2.3.1. Process description

The reference solid waste arisings to be handled in the WPSF are:

- ≤ 80 m^3/year of compactable waste;
- ≤ 10 m^3/year of non-compactable waste.

The non-compactable waste includes spent sealed sources. It is expected that these will be individually packaged and marked separately from the more routine non-compactable waste arisings such as scrap metal. The processing of these spent sealed sources is therefore considered separately in Section 2.4.1.

In addition to the above volumes there will be secondary wastes arising from the operation of WPSF itself. Typically these would include:

- gloves and clothing;
- swabs and wipes;
- HEPA filters;
- scrap contaminated equipment.

It is expected that the WPSF would operate an exemplary waste minimization strategy. The typical expected volume of solid waste arising from operation of the WPSF would be < 10 m^3/year.

Solid waste treatment involves a number of processes (see Fig. 15) these are:

- retrieval of a specified drum of waste from temporary storage;
- sorting and segregation;
- in-drum compaction of compactable waste;
- repacking of non-compactable waste, and in-drum grouting;
- consignment of waste to interim storage.

Each of these separate processes are described in more detail below and in Refs [7–10]. The actual equipment used is described in the Section 2.3.2.

Retrieval from temporary storage

Documentation will record the contents of each drum delivered to the WPSF as described by the waste consignor. It is expected that drums will be processed from the interim store on a first-in-first-out basis to avoid the possibility of drums staying in store for lengthy periods. It is also expected that it will be operationally more convenient to process several waste drums of a similar type in one campaign.

A pre-identified drum will be removed from storage using a manual forklift truck and taken first to the monitoring area for radiation level and surface contamination checks. If contamination is found, the drum will be moved to the decontamination area. The WPSF management should be notified immediately and the source of the contamination investigated with appropriate Health Physics support.

Contamination-free drums of waste will be transferred to the sorting cabinet.

Sorting

On delivery to the sorting facility the drum will be placed on the floor adjacent to the drum port in the sorting box. A second manual forklift equipped with a drum grab and tilting mechanism will then lift the drum and tip it horizontally so that the lidded end is facing the drum port. The drum is then moved forward on the truck pushing the lidded end of the drum through the rubber diaphragm sealing ring of the port.

The operator at the front face of the sorting box can then open the inner door of the drum port to reveal the drum lid. The lid clamping ring and lid are then removed and placed to one side in the box. The operator can then pull waste from the drum onto the floor of the sorting box using long reach tools such as a rake or tong unit as necessary.

Operation of the box is via gloves or gauntlets which are fitted in sliding ports.

The waste posting arrangement described would also be used for putting used HEPA filters into the cabinet.

As noted earlier, drums of waste will have been bulk gamma monitored. It is recommended, additionally, that a beta monitor is installed in the sorting box to monitor all waste as it is pulled from the drum.

It is expected that drums will mainly contain sealed bagged waste. Sorting and segregation would not normally involve opening individual bags, but simply visually

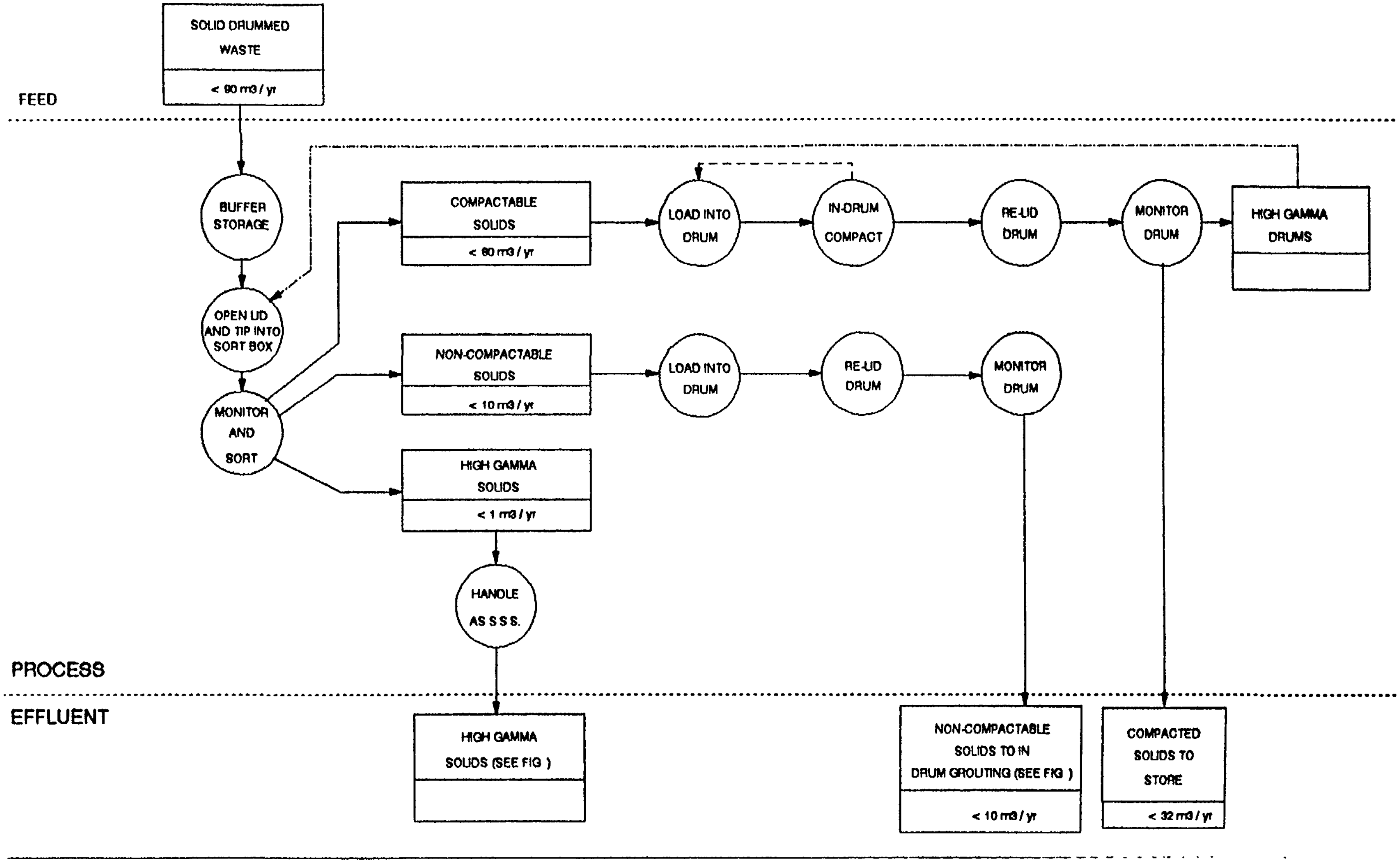


FIG. 15. Solid waste processing flowsheet.

examining them for obvious discrepancies such as containers of liquids, sealed sources or other non-compactable items. Also, waste which has been categorized as non-compactable would be check handled through the box allowing, for example, any extraneous compactable packaging to be removed, e.g. the removal of a large plastic casing from around the small sealed source in a smoke detector.

Waste will be segregated as appropriate and placed in one of the two drums positioned in the floor of the box.

Compaction

Compactable wastes will be placed in the drum served by a low force in-drum compactor [9]. It is expected that this compactor will need to be used 3–4 times to fill a drum with waste. The compactor normally is at rest to one side of the drum allowing unrestricted access into the drum to place waste. When required the compactor is pulled across on rails and positioned above the drum. Interlock safety switches are fitted so that the compactor can only be actuated when in position.

Repacking of non-compactable wastes

Non-compactable waste will be loaded back into a 200 L drum. It is expected that careful repacking could improve the packing efficiency of the drum and thereby reduce the total volume of waste to be stored.

Drum lidding

Once a waste drum is full either at the compaction station or at the non-compactables station, the drum must be removed for lidding. A loose fitting cover is first placed over the drum floor port in the box to minimize the air flow through the port when the drum is removed. Next the drum is lowered and withdrawn from under the box. An operator wearing a respirator as a precaution will then swab around the underside of the box and the top of the drum to check for contamination. The drum can then be lidded and the clamping band fitted. The drum may then be transported using the manual fork lift truck to the dispatch area (compacted waste), or the cementation area (non-compactable waste).

The in-drum compactor would also be used for processing used HEPA filters. Once introduced into the cabinet the filter would be loaded into the drum and crushed together with other soft waste. The use of the large round HEPA filters allows drumming and crushing in this way.

Empty drum removal

Once a drum of waste has been emptied it can be removed from the waste inlet port. Although the drum lid would be refitted whilst the drum is in the port, it is expected to be simpler to replace it once the drum is released from the port. Therefore, the first operation is to close the inner port door. The drum on its tilting/lifting trolley may then be withdrawn and the drum turned upright. The port seal, the outer face of the inner door and the top of the drum can then be swabbed and checked for contamination. Similarly the lid of the drum and clamping ring are checked when they are removed from the cabinet via the sash opening. The empty drum may then be re-lidded, and taken to the decontamination area (see Section 2.4.5).

2.3.2. Plant description

The main item of solid waste treatment equipment is the sorting/compaction box. This is essentially a fume cupboard type containment, fitted with sliding gloveports and gloves for handling waste. A large port at the back of the box allows drums of waste to be emptied into the box and sorted. Two floor mounted ports enable waste to be segregated and posted into new drums. A low force compactor is mounted adjacent to one of these two ports to perform in drum compaction. Smaller items can be introduced into or removed from the box via the sash opening with the appropriate monitoring. Fig. 16 provides a general arrangement of the box. The individual features of the box are now discussed in more detail.

Sorting/compaction box body

The box could be constructed in stainless steel or mild steel with a painted decontaminable surface. The latter will have a lower initial capital cost, but higher future maintenance costs.

The overall dimensions are 4 m (w) × 1 m (d) × 1.5 m (h). There is a fixed sash opening 0.35 m tall the entire width of the box. This sash opening is fitted with runners for sliding gloveports. The runners are recessed to minimize the disruption to the airflow into the box.

Viewing windows are provided to both the front, operating face and the rear face to improve light levels. Clear panels are also fitted in the roof of the box above which are mounted electric lights for additional lighting if required.

The central portion of the box forms the sorting worktable. This area is in the form of a shallow sump between the two port areas. The box slopes to a midpoint in this sump area where a drain is fitted which leads to a removable container below the box. The drain is approximately 20 mm diameter and is fitted with a plug.

The box sits on a mild steel support frame. This steelwork will be grit blasted, degreased and painted with an epoxy paint to provide a decontaminable surface. A tray will be fitted to the bottom of the support frame to catch any falling debris.

Waste inlet port

A single large round port is provided for posting waste from drums into the box. The port comprises an inner hinged door and an outer rubber diaphragm sealing ring. The door is not interlocked although a mechanical interlock could be incorporated. The diaphragm seal is designed to fit around a 200 L drum, minimizing airflows around the drum when it is in the port and preventing small items falling from the drum and out of the back of the box between the drum and port. The seal is replaceable from outside the box.

The port operates in conjunction with a modified manual fork lift truck equipped with a drum tipping mechanism. This truck is used to lift the drum to the required height, tip it, and then push the top of the drum through the lipseal of the port and part way into the box. An example of a typical truck is shown in Fig. 17.

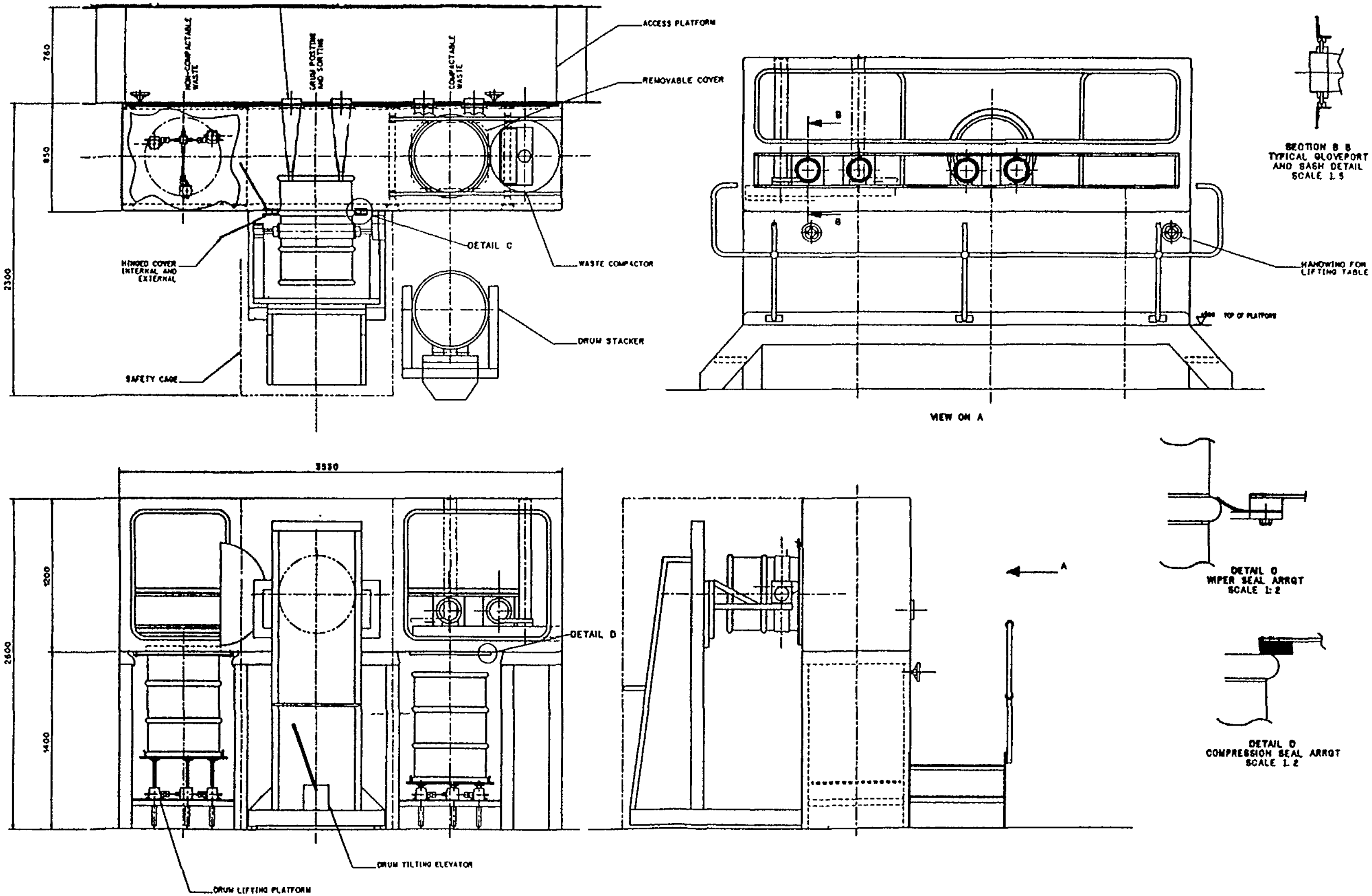


FIG. 16. General arrangement of sorting/compaction box.

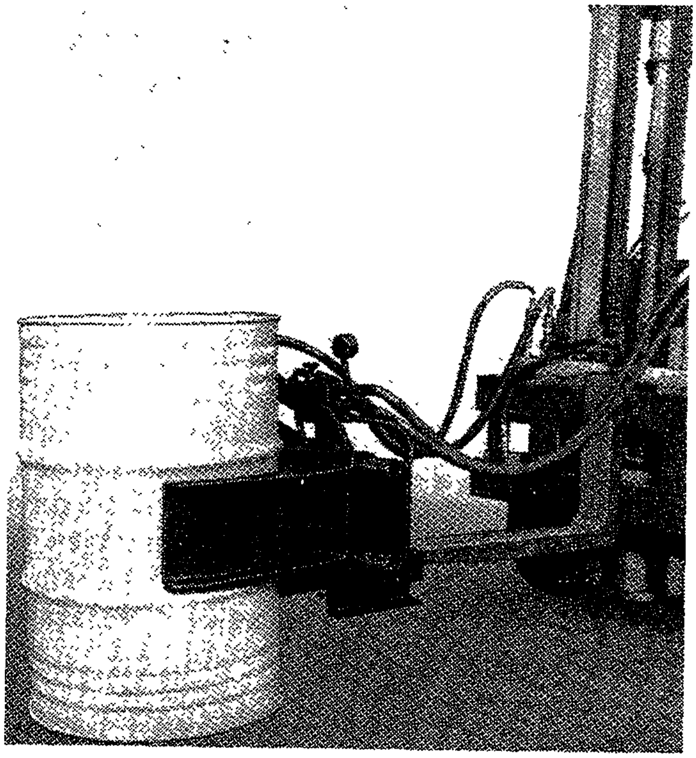


FIG. 17. Typical fork lift truck with drum tipping mechanism.

In-drum compactor

The in-drum compaction facility is built into the waste sorting box. The proposed facility is based on a commercial item supplied by Orwak Linley Ltd of the UK. However, there are numerous equivalent units available which could be used in the same manner. The standard compactor is built into the floor of the box. The actuating cylinder and platen are mounted on a trolley which can traverse across the drum port in the box floor. The compactor is operated by a hydraulic lever mounted on the sliding trolley. Alternatively, a remote solenoid switch could be incorporated, but at extra cost. The hydraulic lines to the cylinder exit the box through bulkhead fittings in the side of the box to the locally mounted hydraulic power pack.

The compaction forces are not restrained by the box floor but are taken back through the jacking table on which the drum sits. The height of the compactor unit determines the box internal height.

Drum jacking tables

Jacking tables are provided beneath each drum port in the box floor. These tables raise the drums up into position, closing off the ports, and allowing waste to be placed into the drums.

The table beneath the non-compactables drum port will only be slightly loaded. It can be raised manually using a hand crank.

The table beneath the compactables drum port takes the full 3 tonne compaction force and is therefore significantly more robust. Raising and lowering are again still by manual hand crank.

The raising and lowering of both tables could be automated using an electric motor and gearbox, together with sensors for detecting the limits of movement. This would add substantially to the cost of the tables without offering any significant operational benefits. Automation is therefore not considered further.

Cabinet floor drum ports

The box is fitted with two drum ports to allow compactable and non-compactable waste to be segregated and posted into separate drums. The ports are simple 510 mm diameter openings in the floor of the box. A compressible seal is fitted to each port, maintainable from outside and beneath the cabinet. Inside the cabinet the port has a loose fitting piano-hinged lid. This is normally open when a drum is in position during operation. However, it is closed across the port when a drum is removed from a port. This reduces the size of the opening to allow adequate ventilation through the front sash opening to be maintained. It also prevents waste from falling through the bottom of the box.

Around the edge of each port is a continuous vertical lip which prevents small loose debris falling inadvertently through the port.

Cabinet services

The main services required in the cabinet are lighting, ventilation and hydraulics to the compaction unit.

(a) Lighting

As noted earlier, the box is fitted with large windows to provide a good view of its contents as well as light from the room. However, if required, strip fluorescent lights can be mounted on top of the box, to shine through the roof windows and enhance the lighting levels.

(b) Ventilation

The box is fitted with two ventilation exhaust ducts, which join adjacent to the cabinet and run to the contaminated air duct in the operating area. This duct itself then runs to the vent room where it is HEPA filtered. No primary HEPA filters are fitted in the cabinet itself, although spark arrestors are fitted to the entrances to the ducts.

(c) Hydraulics

The in-drum compactor comes complete with an electrically driven hydraulic power pack. The power pack will be mounted beneath the box with feed and return hydraulic lines running to the compactor cylinder via bulkhead fittings in the side of the box.

(d) Fire protection

Two smoke detectors will be fitted in the box which will activate local alarms. Hand operated fire extinguishers will be mounted adjacent to the cabinet. Consideration should be given to the installation of a fire suppression system in the cabinet. A halon or carbon dioxide system would be the most appropriate, and this could be either automatically or manually triggered.

2.4. TREATMENT OF OTHER WASTES

2.4.1. Spent sealed sources

The treatment/conditioning of spent sealed sources involves the packaging of the source within a Type A package [11]. The source in its cask and container is placed in the centre of a 200 L drum and the drum filled with cement mortar (Fig. 18). This conditioning procedure is suitable for any type of source, assuming its size (including casket and container) allows it to be conveniently accommodated in the centre of a 200 L drum. Because the source remains in its casket it is not necessary to rely upon the shielding properties of the cement mortar matrix. The activity in the package must however conform to A1/A2 levels as set out in IAEA transport regulations [11].

Conditioning in this way prevents unauthorized removal of the source because of the bulk, weight and robust nature of the package and it also provides a barrier against loss of containment of radioactive material. The adoption of this method will depend upon a number of factors, including:

- the number of spent sealed sources;
- the half life and activity of the sources;
- the toxicity of the radionuclides in the sources;
- the final disposal scheme for the sources.

Such packages would have a weight of about 450 kg and removal and transportation would require mechanical equipment, i.e. a fork lift truck.

Further information on the conditioning of spent sealed sources is available in another IAEA report [12].

2.4.2. Organic liquids

The small quantities of organic liquids expected to be received at the WPSF or to arise at the WPSF from liquid scintillation counting or other laboratory work will be treated by absorption on vermiculite followed by direct encapsulation.

Containers of organic liquids will be taken to the laboratory fume cupboard where a suitably sized large diameter container with sealable lid, and adequate amount of vermiculite will be available. In the fume cupboard, the large diameter container is opened and several centimetres depth of vermiculite added. The organic liquid container is then opened, and organic liquid poured slowly to evenly distribute the liquid over the surface of the vermiculite. More vermiculite is added as required so that there is no free liquid.

When full the large container of vermiculite is lidded, the outside of the container is swabbed and checked for contamination. If contamination is found and simple wiping is unable to remove it, the container should be taken to the decontamination area where mild detergent cleaning should be sufficient to remove any contamination. The container is then

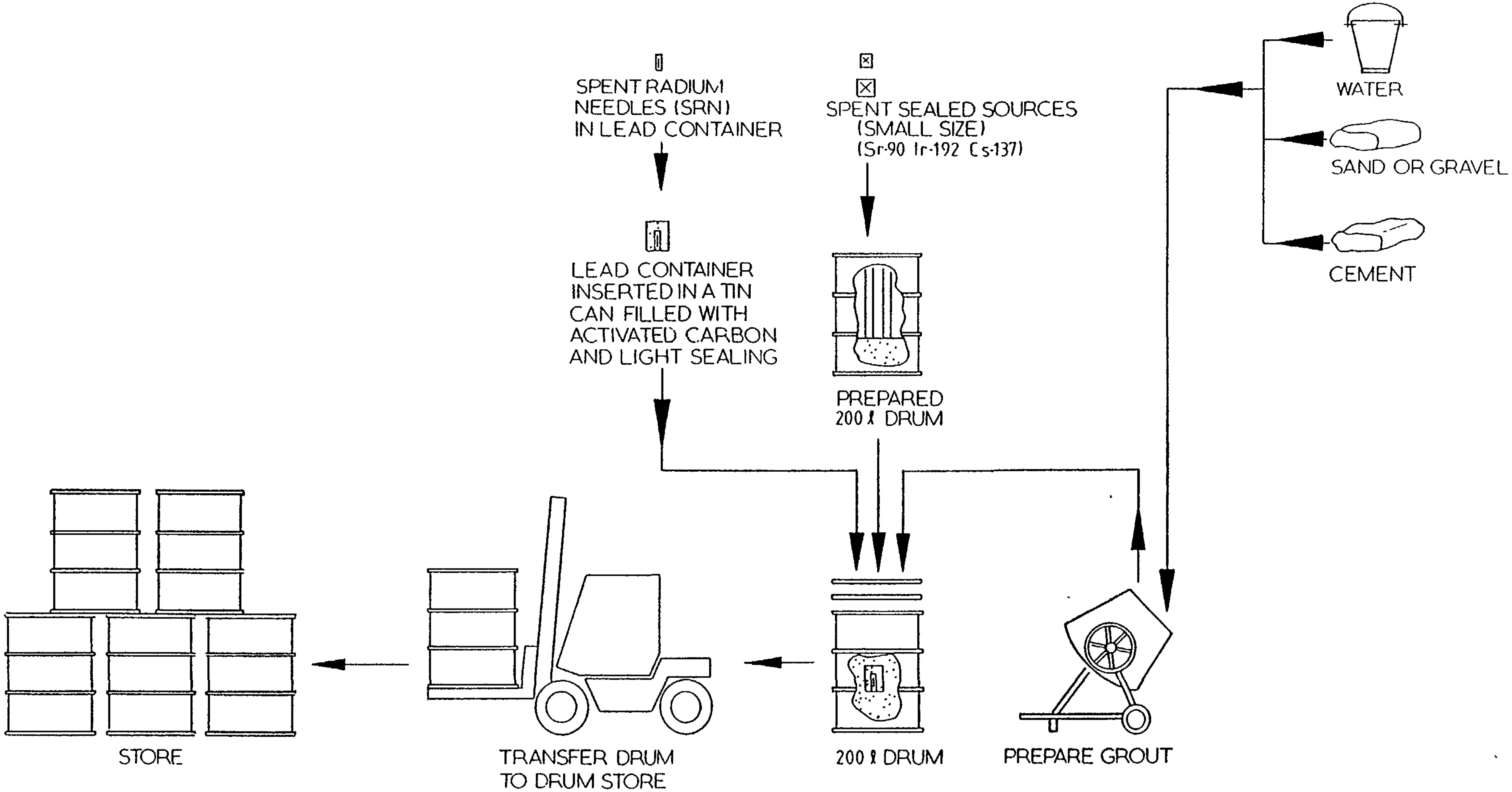


FIG. 18. Pictorial flowsheet of spent sealed source conditioning.

taken to the cementation area. Encapsulation in cement can be either by in-drum grouting of the container of liquid soaked vermiculite (as for non-compactable waste), or by emptying the container of vermiculite into a drum prior to the in-drum mixing and encapsulation of sludge from the precipitation process. Encapsulation in cement is discussed further in Section 2.5. Further information for treating and conditioning organic liquids is given in Ref. [13].

2.4.3. Ion exchange resins

The small quantities of ion exchange resins expected to be received at the WPSF will be treated by direct encapsulation.

Ion exchange resins may come to the WPSF either held in fixed beds in cartridges/canisters or loose within a variety of sizes of bottles, carboys or drums. After appropriate sampling and analysis, the containers will be taken to the cementation area. Cartridges or canisters of fixed beds of resins will be in-drum grouted as for solid non-compactable wastes. Loose resins will be encapsulated by transferring 10 to 20 L of resin into a drum prior to in-drum mixing and cementation of sludge from the precipitation process. Further information for treating and conditioning ion exchange resins is given in Ref. [14].

2.4.4. Animal carcasses

Waste animal carcasses will be encapsulated in cement after a pre-treatment stage.

Animal carcasses will be temporarily stored in a freezer located either in the temporary store or the decontamination area awaiting pre-treatment. Two methods of pre-treatment are possible prior to conditioning, either:

- placing the carcass in a strong polybag and adding lime;
- using formaldehyde to preserve it, draining the solution and placing the carcass along with vermiculite into a strong polybag.

After the pre-treatment, the carcass is transferred in its bag to the cementation area where it is placed in a drum and in-drum grouted as for solid, non-compactable waste. Further information for treating, conditioning and storing animal carcasses and other biological wastes is given in Ref. [15].

2.4.5. Decontamination

A decontamination area is provided within the WPSF for the decontamination of:

- items of equipment prior to maintenance and re-use;
- the outside of drums and other containers to allow handling and/or transfer to store;
- the inside of empty 200 L drums to allow re-use.

The main item of equipment is the decontamination box (see Fig. 19). This is a large enclosure, approximately 1 m (d) × 1.5 m (h) × 2 m (w) fabricated in stainless steel and located on a strong platform framework capable of supporting a drum of cemented waste. The front of the enclosure has two clear plastic (i.e. perspex) doors, hinged at the side which overlap in the middle by approximately 40 mm. Each door is fitted with four glove ports and long gauntlet type gloves.

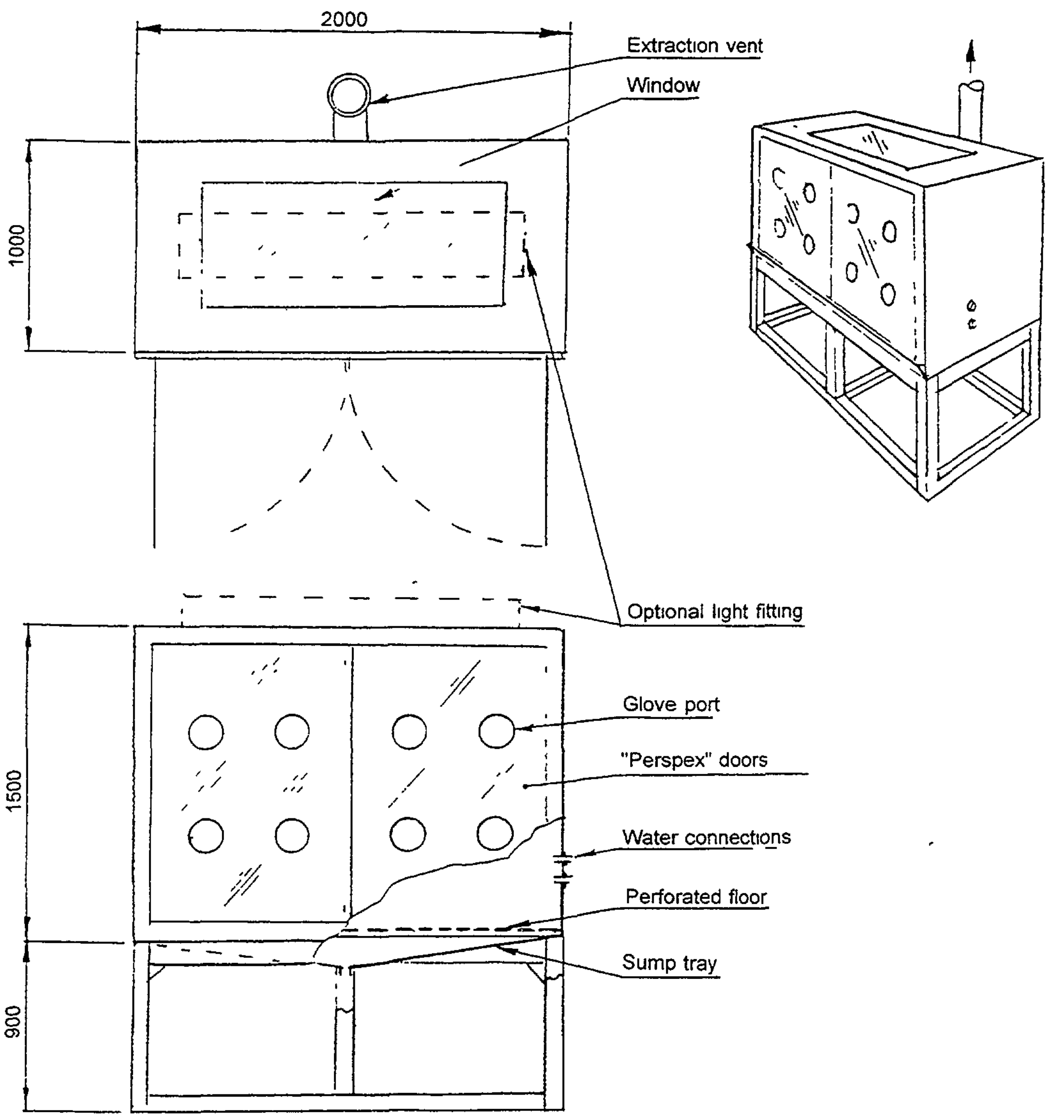


FIG. 19. Schematic arrangement of decontamination box.

The box is served by the ventilation exhaust system, a gravity drum to the low active drain tank, and hot and cold water connections via bulkhead fittings in one side of the box. A guttering lip in the front box wall below the window doors directs liquids dripping from the doors back into the box. A fixed window in the roof of the box improves natural lighting levels, and allows fitting an externally mounted strip light if required. The box support framework will provide room for a manual forklift truck to be used to place drums straight into the box. The floor of the box will slope to a sump which is served by the drain. A selection of trays and baths will be provided to contain cleaning solutions and items requiring decontamination. As noted earlier, the box may also contain the hose and spray head of a pressure jet washer. The IAEA has prepared a manual on the decontamination of surfaces [16].

2.5. CEMENTATION AREA

The cementation area contains equipment for the encapsulation of a variety of wastes in cement [10, 14, 17 and 18]. The area is enclosed by half-glazed panelling, with personnel and manual forklift truck entry and exit. The area is ventilated direct to the exhaust system to prevent the spread of cement dust.

There are two basic items of cementation equipment:

- an in-drum mixer for the cementation of liquid wastes, sludges and ion-exchange resins;
- a grout batch mixer for the immobilization of solid wastes and for grout capping prior to lidding.

Illustrations of typical equipment are shown in Fig. 20.

2.5.1. Process description

In-drum mixing

The in-drum mixing equipment will principally be used for the encapsulation of sludges arising from liquid effluent treatment by precipitation. Other liquid wastes and ion-exchange resins will arise occasionally for encapsulation, but these will be added in small quantities to a drum of sludge. An empty drum will be placed in the in-drum mixer, and the mixer head lowered into position. A clear plastic anti-splash guard can be fitted to the top of the drum as a precaution. This shield fits around the stirrer shaft, and has holes cut for the sludge and cement powder feed.

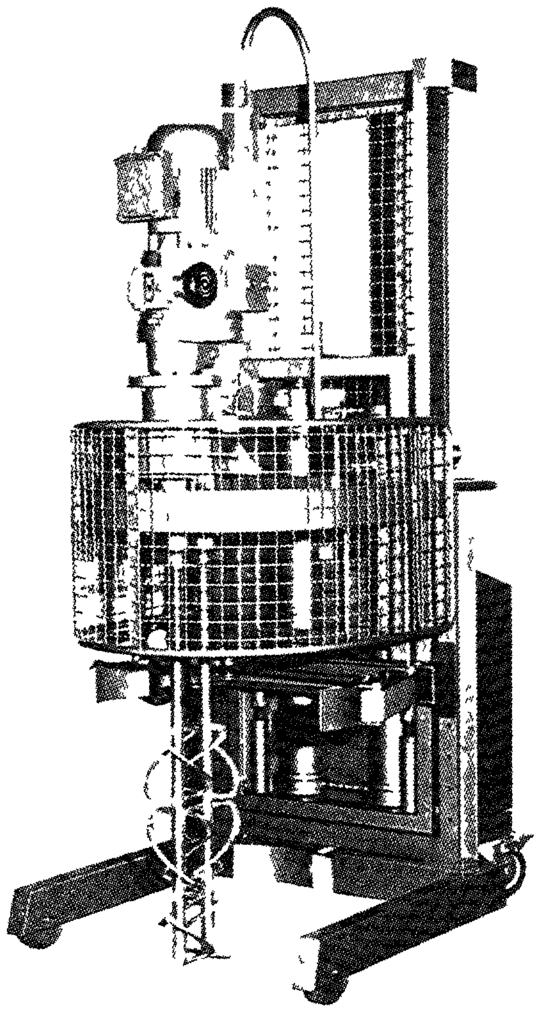
Sludge is pumped from the sludge tank to the sludge hopper using a diaphragm pump (see Fig. 21). The sludge tank is calibrated, with an overflow back to the sludge tank at a height equivalent to one single batch of sludge held in the hopper. When this height is reached, or the hopper begins to overflow, the pump is stopped. Having ensured that the hopper delivery pipe is in the drum, the hopper discharge ball valve is opened and sludge is transferred into the drum.

The stirrer of the mixer is then started, and a pre-measured batch of cement is then slowly added to the sludge, stirring continuously.

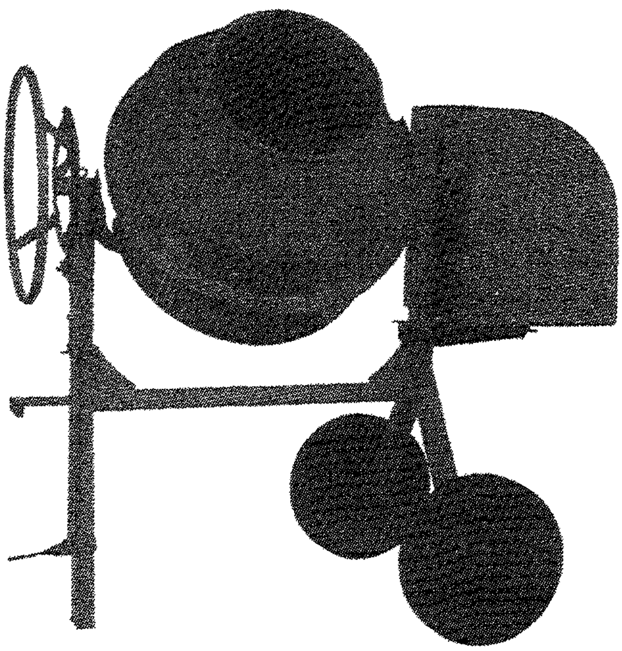
When mixing has finished, the cement and sludge feed lines are removed, and the splash guard lifted. The stirrer is then raised and left for five minutes to drip. After this time the mixer equipment is moved away from the cemented sludge drum and positioned around a previously prepared drum of water. The mixer head is lowered and the mixer operated for two minutes to wash the stirrer free of cement.

After mixing, the cemented sludge drum is temporarily lidded and left to stand without moving for 24 hours, to allow the mix to set.

The next day the drum contents are tested for set by using a penetrometer, and any bleed water is removed by pumping to a small container. Bleed water is then transferred to the small arisings tank of the liquid effluent treatment plant. A small batch of grout is prepared and pumped or poured onto each drum until the surface is within 2.5 cm of the drum lip. The grout cap is allowed to set 24 hours, tested for set, and then the drum lid is finally fitted.



Typical in-drum mixer



Typical tilted drum mixer

FIG. 20 Typical cement mixers for WPSF application.

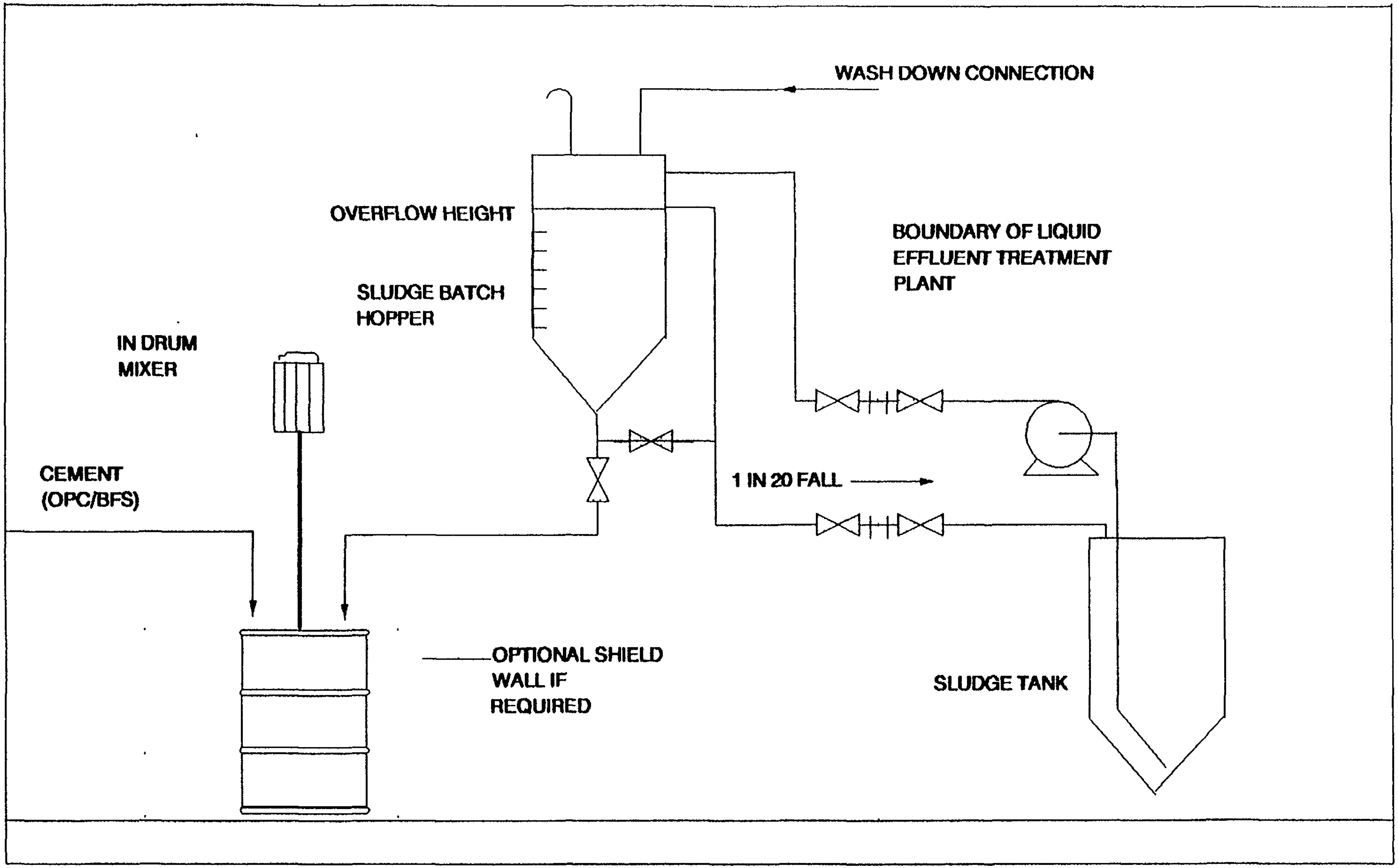


FIG. 21. Schematic flow diagram of sludge transfer.

The sludge transfer and overflow lines and the hopper should be washed out with small batches of water at the end of the process. Wash water to the sludge lines will drain to the sludge tank from where it can be pumped back to the precipitation tank for treatment. Wash water to the sludge hopper should be collected in a carboy and taken to the laboratory for transfer to the small arisings tank as for other small quantities of aqueous liquids.

In-drum grouting

The in-drum grouting equipment will be principally used for encapsulating non-compactable solid wastes and spent sealed sources. Drums of solid non-compactable waste will be moved from the sorting cabinet into the cementation area using a manual fork lift truck, and placed adjacent to the grout batch mixer. A batch of grout will be prepared in the mixer. Grout will then be transferred using a pump or by pouring into the drum. The grout should be introduced at three or four positions around the drum to ensure filling of all voids.

2.5.2. Plant description

The main items of equipment used in the cementation area are:

(a) the in-drum mixer;
(b) the grout batch mixer;
(c) the sludge batch hopper and transfer pipework.

This equipment is housed in the cementation area within the main operating area. The cementation area is enclosed by half glazed partition walls and a roof, with personnel and manual fork lift access via double doors and separate extract ventilation.

Other items of equipment within the area will include weigh scales for measuring quantities of cement, a water supply and shielding blocks which may be required to be assembled around a drum of higher activity sludge prior to cementation. Consideration should also be given to providing a small, separate enclosure in which bags of cement can be opened, to limit the spread of cement dust. The main items of cementation equipment are now discussed below.

In-drum mixer

A simple in-drum mixer is required for the cementation of sludges, loose ion-exchange resins and aqueous liquids in 200 L drums. Fig. 20 (top) illustrates a stand-alone machine suitable for use in the WPSF. The mixer unit can be raised and lowered into the drum, and is electrically driven. The drum itself is restrained by side clamps to prevent movement during mixing. A splash guard should be incorporated onto the mixer, which raises and lowers with the mixer, and covers the drum when in the lowered position. This guard features cut outs for the sludge feed pipe, and for cement feed via a chute/funnel.

Grout batch mixer

A simple grout batch mixer is required for the preparation of grout for in-drum grouting and grout capping. The mixer should be electrically driven and mobile, and capable of producing batches of up to 200 L. These are commercial items and numerous examples are available. Fig. 20 (bottom) illustrates a typical tilted drum mixer. Batches of grout would be poured from such a mixer either direct into a drum or via another container.

Sludge batch hopper

The sludge batch hopper is a calibrated translucent polypropylene vessel on an epoxy painted mild steel framework mounted on the wall in the cementation area and adjacent to the liquid effluent treatment plant. The hopper has a nominal working capacity of approximately 150 L, and is approximately 0.6 m in diameter by 0.8 m tall.

Sludge is pumped into the hopper from the sludge tank on the liquid effluent treatment plant via a 2.5 cm PVC line, entering the hopper through the top lid. A 5 cm PVC overflow line is set at a level corresponding to one batch of sludge. Pipework and valves exist to allow the hopper either to be discharged to a drum for cementation, or to be returned to the sludge tank (see Fig. 21).

2.5.3. Test equipment

The types of test normally required on cement include tests on the starting materials, tests carried out on the mix and tests on the final product [17 and 19]. Table III lists the basic tests which would be required, and typical prices (UK, 1992) of the equipment. A budget of approximately £10 000 would be sufficient for this basic equipment.

TABLE III. BASIC CEMENT TEST METHODS AND EQUIPMENT

Test method	Uses	Main equipment	Cost
Starting materials Fineness	To test specific surface of cements and powder additives. This influences setting exotherm.	Rigdens flow meter kit Accessories Waterbath (temp. control)	About £500 £200 £650
Fluid properties Flow tests (various)	Tests ability to infill small gaps in solid wastes	Slump test (for concrete) Flow table (for grout) Flow channel (commercial)	£50 £200 Not known
Setting tests Consistency and setting	Measures time to initial and final set	VICAT needle	£200
Bleed test	Measures per cent bleed water after 24 hours setting	Measuring cylinder	
Exotherm temperature	Adiabatic temperature measurement using thermometer in vacuum flask - mimics drum centre temperature	Thermometers vacuum flasks	
Tests on final product Compressive strength	100 mm cubes normally used. 100 kN frame probably sufficient for most encapsulating grouts	Compression machine Cube moulds Curing (controlled T)	From £2600 £35 each From £200
Density	Useful to check entrainment of air bubbles, etc.	Balance water tank	£1000-2000

This equipment will allow the WPSF operators to develop and qualify cement waste recipes for particular waste types and for particular cements used, and to assure the quality of cemented waste prepared in the WPSF.

2.6. MECHANICAL SERVICES

2.6.1. Ventilation design

The following require controlled ventilation to provide contamination control: laboratory fume cupboard, cementation enclosure, liquid treatment module, decontamination box and filter enclosure. It is not required in other areas.

Where air movement is required for contamination control minimum velocities through all permanent openings or design breaches in containment are 0.5 m/s. Design velocities are 0.5 m/s to ensure that this criteria is fully met. Average velocities through doorways into high hazard enclosures that are normally closed are 0.2 m/s.

In the event of any failure of the ventilation system, or on sounding of a high air borne activity alarm, it is assumed that the plant will be stopped and operators withdrawn until the problem has been identified and corrected. It is therefore not necessary to enhance the reliability of the ventilation services — diesel backed, or uninterrupted power supplies are not required, nor are standby fans.

The outline designs are shown in Figs 22 and 23. The design is for a fully mechanically ventilated building with two ventilation system branches [20, 21]. The first serves the change room and general areas and discharges without filtration. The second serves the working areas and is filtered before discharge. It is expected that this design would be acceptable in other countries with a temperate climate. If the climate of the location that this facility is to be located in were not temperate the need for increased ventilation, mechanical cooling or additional heating would need to be assessed.

General area ventilation

Supply is drawn in from the gable end of the building before being treated and industrially filtered before supply to the areas served. The supply air temperature is modulated to maintain comfortable temperatures in the change room areas. The two offices have small supplementary electric heaters to ensure comfort at all times. The outline flow diagram is shown on Fig. 22.

The highest demand for ventilation air is in the change room complex. Much of this air is unsuitable for re-circulation so it is convenient, and economical, to discharge all of the air extracted from the general areas without re-circulation but using a run around coil for recovery of heat from the exhaust air.

Although no radioactive contamination of the exhaust air is anticipated, provision is made for sampling this air flow before discharge at the gable end of the building.

Main area ventilation

The main area ventilation is also a full fresh air system, with heat recovery, drawing in and discharging air from the gable end of the building. Rates are suitable for summer cooling in the UK.

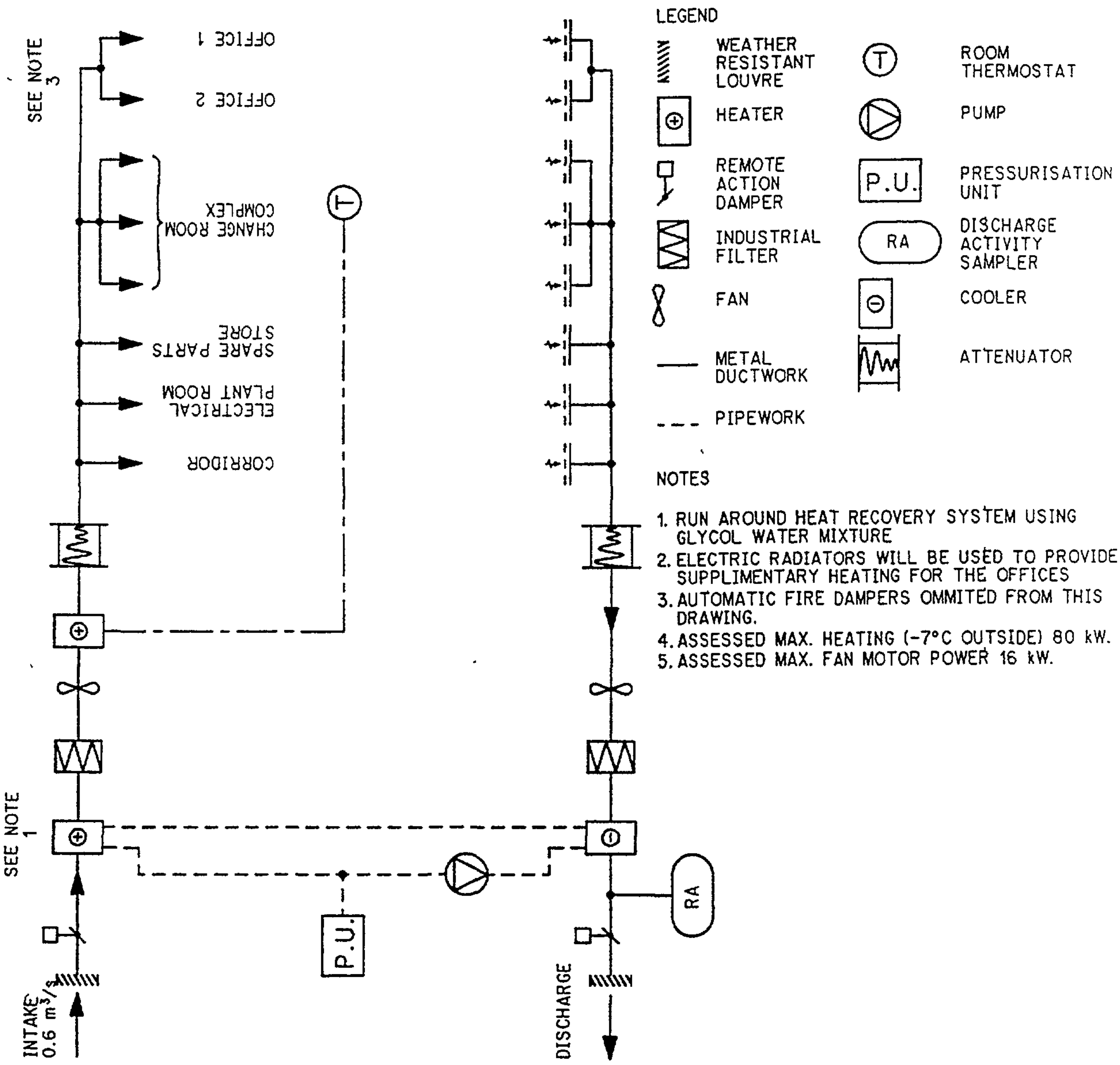


FIG. 22. Ventilation flow diagram — General areas.

The fresh air is pre-heated and industrially filtered before dividing to serve two branches each with its own re-heater.

The ventilation rates vary — they meet the minimum requirements of [20] but are often higher to provide the necessary air flow rate from enclosures, booths and fume cupboards.

Not all of these areas have a high hazard classification. The exhaust from those that do have a single stage of HEPA filtration before discharge. For convenience, in a small facility, those extract flows not requiring filtration bypass the filters rejoining the main flow upstream of the exhaust fan. The cementation enclosure exhaust is provided with a local industrial grade filter to stop dust entering the extract ductwork. The waste sorting cabinet exhaust is provided with a spark arrestor to limit the fire hazard.

The exhaust filtration is provided by two high capacity circular filter housings. They are both required to be in service for normal operation. The system capacity will be reduced

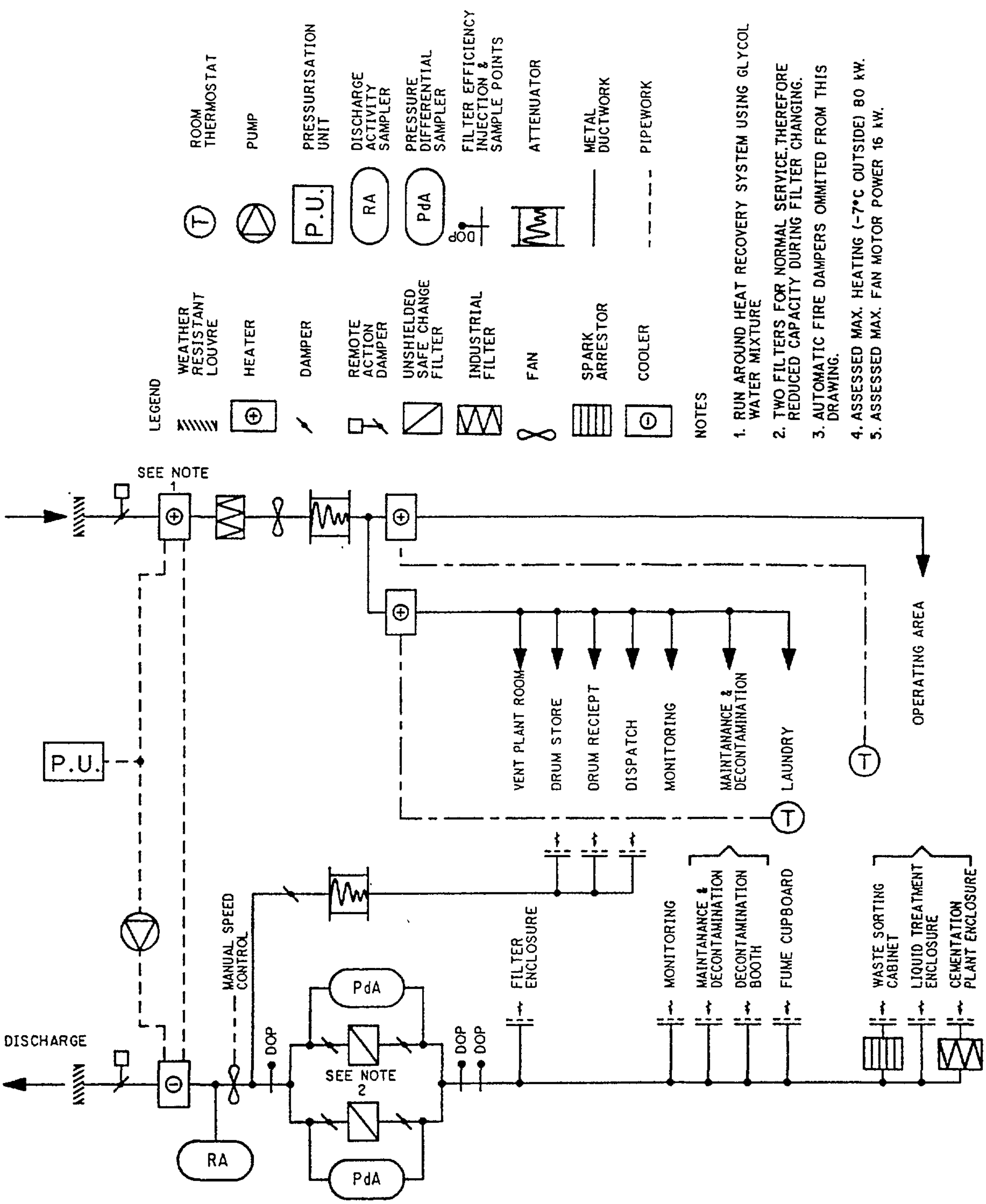


FIG. 23. Ventilation flow diagram — Working areas.

during filter change operations which must therefore be undertaken when the facility is not otherwise in use. Provision has been made to manually regulate the fan speed to correct for increasing filter resistance in service.

Provision has been made for sampling the exhaust air before discharge.

Fire safety

The ventilation plant must conform to fire safety requirements. These requirements are likely to include the provision of automatic fire dampers and provision for fire fighters to control the ventilation fans. These requirements cannot be determined until detailed design is undertaken.

Service requirements

The assessed maximum heat demand is 80 kW with the assessed electric power requirements 17 kW.

2.6.2. Heating and hot water

The outline flow diagram for heating and hot water is shown on Fig. 24. The heat source is assumed to be low temperature hot water.

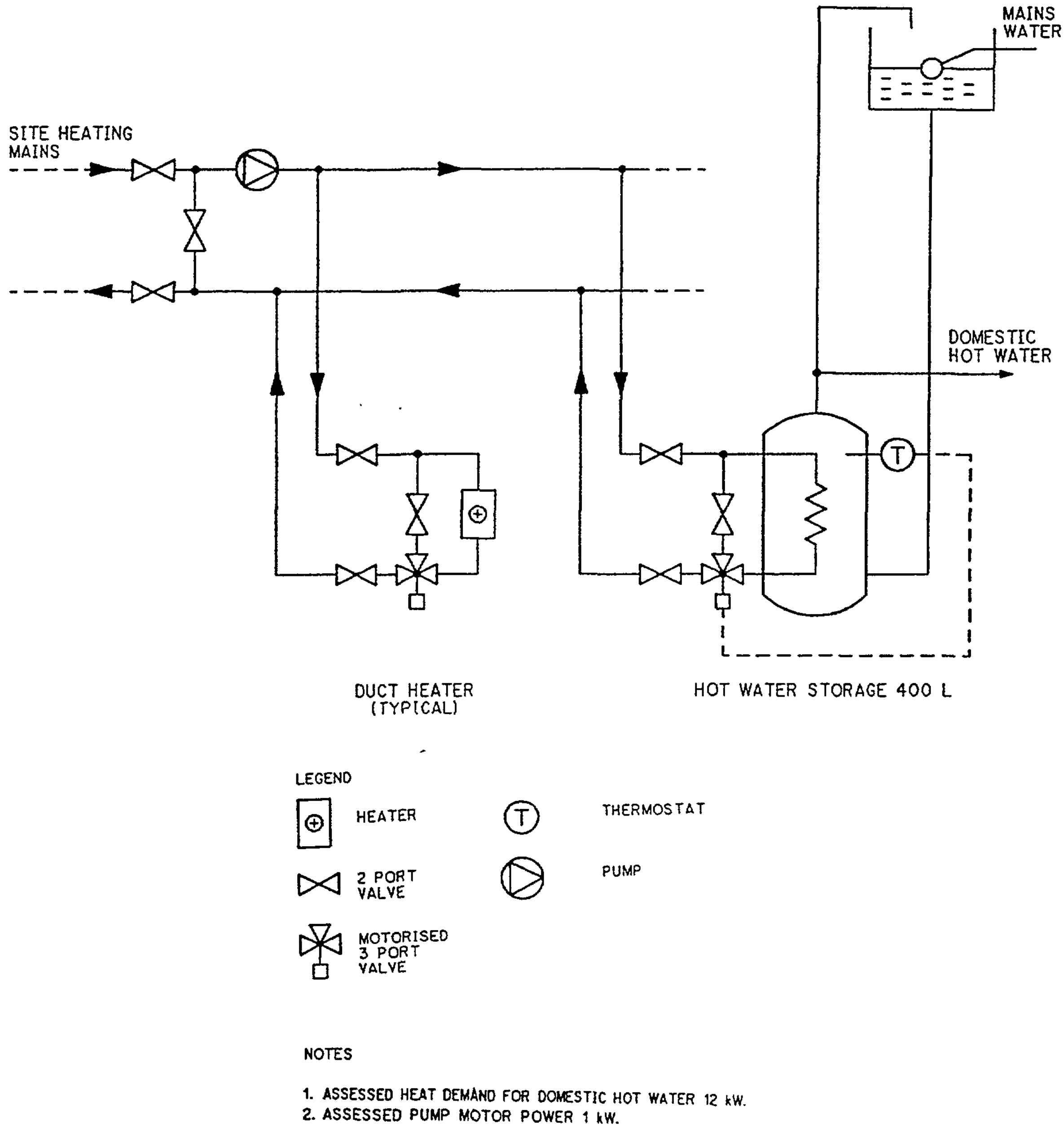


FIG. 24. Flow diagram — Heating and hot water.

A secondary pump circulates hot water to the heater batteries and to a hot water storage calorifier.

Hot and cold water services will be provided as required to the general area as required. Cold water services to the working areas will be provided from a high level break tank.

The peak heat demand for domestic hot water is assessed at 12 kW with electric power demand estimated at 1.0 kW.

2.6.3. Other services

The other two main services required in the WPSF are steam, electrical and compressed air. Generally, these service requirements are not specialized and so have not been considered in any detail. Brief discussion is given below.

Steam

Unless steam is already available on the site on which the WPSF is sited, a small steam generator will be required. This will serve mainly space and hot water heating requirements.

Electrical

Incoming electrical supplies will go to the electrical room which will house switchgear, etc. There are no single large electrical loads required by any of the process equipment. It is not expected that guaranteed supplies will be required to any item of equipment. The major loads are:

- ventilation system fan
- hot water system pump
- lighting
- compactor unit
- in-drum mixer
- drum grout batch mixer.

Compressed air

A small air compressor and receiver will be required to provide compressed air for driving the diaphragm pumps. If automation of any of the ball valves on the liquid effluent treatment plant were required, then this supply could be extended to provide pneumatic actuation.

3. WASTE STORAGE FACILITY

3.1. FUNCTION OF STORAGE

The function of the storage facility is to provide safe housing of the waste packages such that the operators and the general public are adequately protected from radiological hazards which could arise during normal storage and accident scenarios [22]. Containment of the waste is required to be maintained over the storage period. Therefore it is important to ensure that deterioration of the waste package which is providing primary containment of the waste, does not occur. Package deterioration also needs to be prevented to avoid problems when the waste is ultimately retrieved from the store and dispatched to the disposal facility.

Degradation of the inner surface of the package is dependent on the waste and the containers themselves, whilst that of the outer surface will depend on the environmental conditions in which the package is held. The ability to visually inspect the outer surface of the container will be a requirement for arranging containers that will be stored over a period in which, or in conditions in which, deterioration of the waste container might be expected.

Since storage is temporary by definition it should be as easy to remove the waste containers as it was to put them into the store. This should preferably be done by the equipment used for loading and without the need for repackaging. Adoption of this approach negates those designs which utilize a backfill or permanent closure for storage purposes.

3.2. REQUIREMENTS AND FEATURES

The defined function of the WPSF store is to provide storage for 10 years of the expected annual waste quantities after treatment and immobilization. From Table I in Section 1.4, this equates, to about 600 m^3 or 3000 (200 L) drums. No period of storage is defined, as it depends on the development and construction of a low level radioactive waste disposal facility [23, 24]. The store design is generic and not tailored to any one location.

It is expected that the radiation level on the vast majority of drums will be sufficiently low to allow manual handling without additional shielding.

A separate review of store designs found the following amongst its conclusions [22]:

(a) The cheapest stores in terms of capital cost/m^3 of waste stored are those which:

- use drums or fairly large boxes to contain the waste;
- use fork lift trucks to move and stack the waste containers;
- adopt a low stacking height for waste containers, e.g. avoid the need to use costly and space consuming supports.

(b) Stores should be as large as possible if the cost economies of scale are to be achieved, i.e. one large store is cheaper than two half-size stores.

From these conclusions, and from the preceding discussion sections, the WPSF store design is based on the following:

(a) The standard waste container will be a 200 L drum [25]. No shielding of the drum is expected to be necessary in the majority of cases.

(b) A fork lift truck will be used for transporting the drums to the store and for placing them in position. In view of the small number of drums to be handled, the fork lift will only need to handle the drums singularly.

(c) Drums will be stacked up to 3 high in rows 2 wide with narrow aisles between. The aisles will allow personnel (but not fork lift truck) access to allow inspection of the outer surface of the drums as required over the period of storage. A central corridor should be left in the middle of the store to allow the fork lift truck access (Fig. 25).

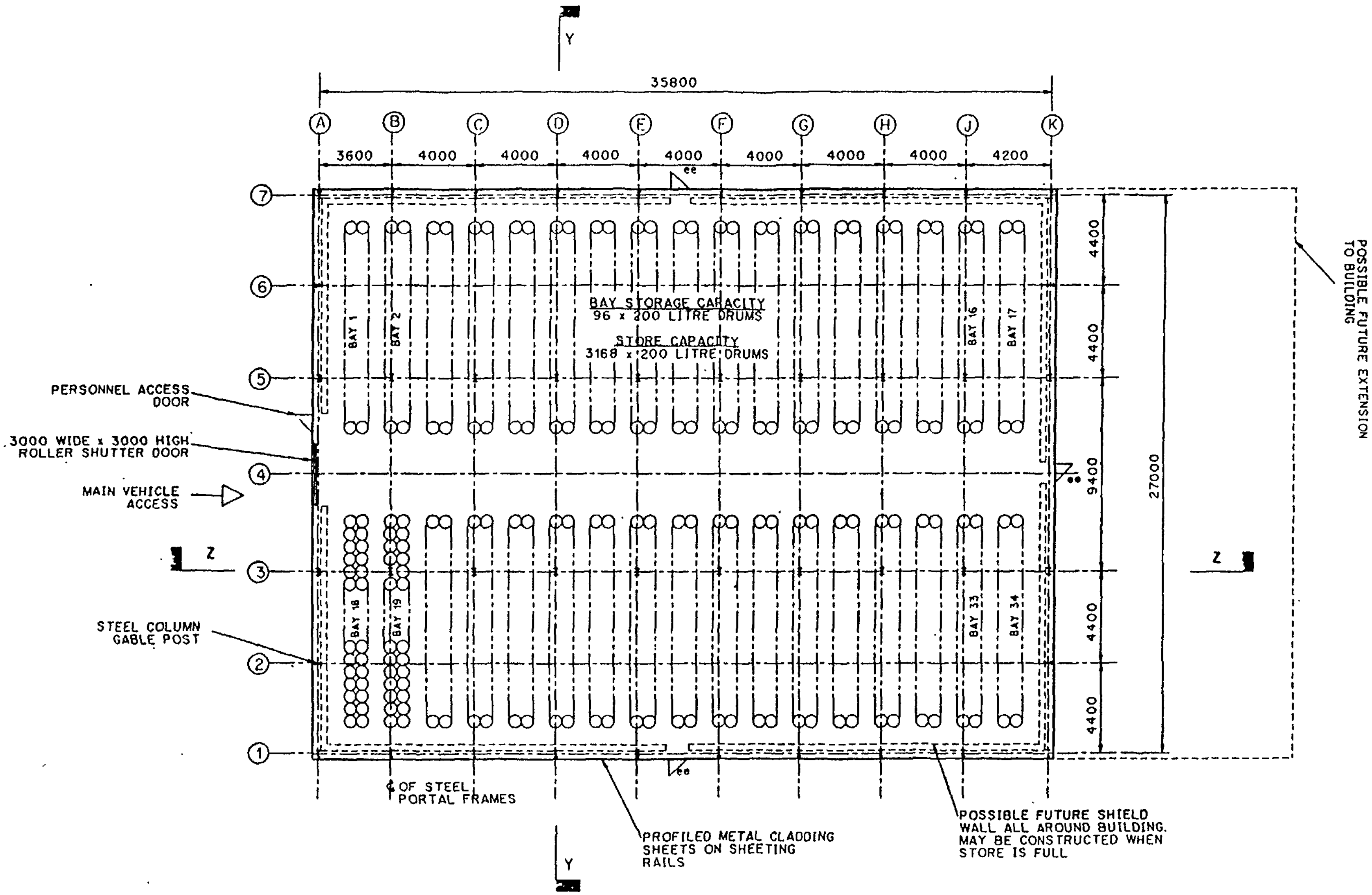


FIG. 25. Storage building — Floor plan.

(d) It is expected that the construction of the store will be simple such that standard industrial building designs will be sufficient. The store will be separate from the main waste processing building. Locating the store near the process facility will be convenient, but not necessary.

(e) Active ventilation will not be required because the store is not expected to contain a significant amount of TRU waste. Radon generation from radium sources is expected, but the quantities are expected to be low compared to natural radon levels. The store will not be sealed and natural circulation of air through the store will be adequate to prevent accumulation of radon.

(f) The requirement for any conditioning e.g. heating, cooling or dehumidifying of the store atmosphere will be a function of the climatic region in which the store is situated. A number of waste stores in the UK have no ventilation and no heating.

Capacity

The store is designed to accommodate up to 3000 drums expected to arise over a 10 year period of operation of the WPSF. At the end of that 10 year period the store contents can be readily retrieved and transferred to a disposal site. Alternatively, prolonged storage is possible.

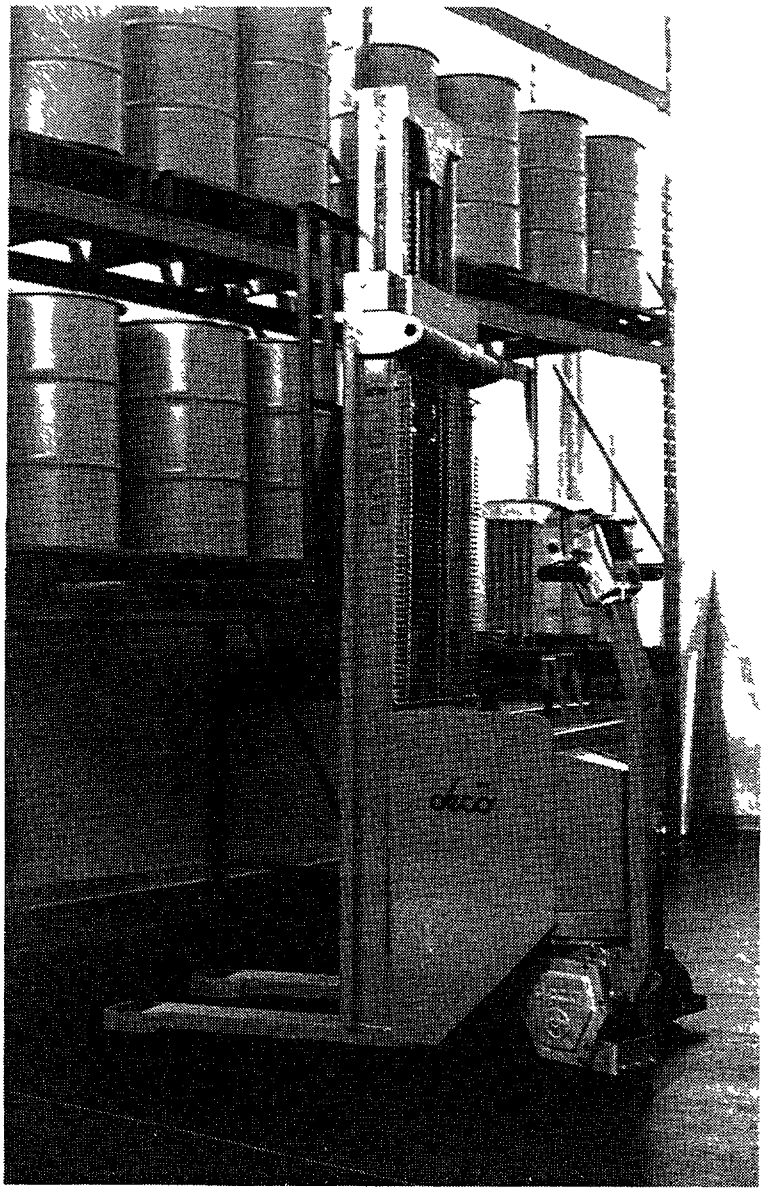
When the store is finally emptied it should be straightforward to decommission. It could however, also be reused for another industrial purpose.

Store operation

The operations in the store are limited to the delivery, placement and periodic, i.e. visual inspection of waste drums.

Drums of waste, at an average of approximately one per day will be transported to the store using a powered fork lift truck. It is expected that the combination of low radiation levels in the store, and minimal time spent in placing a drum will mean that the fork lift truck cab will not need to be shielded. Drums will be stacked 3 high in rows 2 wide in a half-offset stacking pattern (see Figs 25 and 26). A central corridor 4 m wide will be left in the middle of the store to enable the fork lift truck to manoeuvre. The rows of drums will be run to a depth of 15 drums either side of this corridor. Narrow aisles 0.8 m wide will be left between each double row. These aisles are not intended to allow fork lift truck access, but they will allow personnel access so that any drum can be visually inspected periodically. It is expected that this provision will meet the requirements of most regulatory authorities.

It should be noted that in the proposed stacking arrangement if the least accessible drum had to be retrieved from the store for inspection, then this could involve moving up to approximately 90 drums. If any need for removing individual drums is expected, for example for occasional thorough inspections of selected containers, then the planned drum arrangement should be modified [26]. This will probably decrease the number of drums that can be stored per square metre of store area, and thus increase storage costs (note Section 3.4).



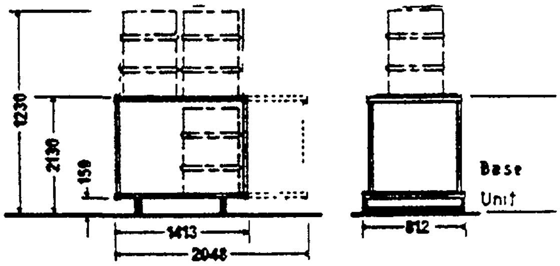


FIG. 26. Example of drum rack system.

3.3. STORE CONSTRUCTION

The store is a single storey rectangular building with overall plan dimensions of approximately 39 m × 26 m, rising to an eaves height of approximately 4.5 m. The roof is of symmetrical double pitch form. The building size and form is designed to facilitate the storage of 3000 waste drums and to ensure that it may be extended in the future, to increase its drum storage capacity, without the need for structural modifications to the original building. The general arrangement of the building is indicated in Fig. 6 shown in Section 1.5 and in Fig. 25.

The building is of steel framed construction. Unbraced, three bay, partial frames are provided at approximately 4.3 m centres along the length of the building. These portals provide support to the roof structure and lateral stability to the building in the transverse direction. Internal partitions are not provided.

Stability to the building in the longitudinal direction is provided by a system of roof bracing and bracing to the longitudinal external building elevations which will ensure that all lateral loads at roof level are transmitted to the foundations. The stanchions are founded on individual mass concrete bases which are taken down to a suitable soil bearing station. Structural steelwork will generally be grit blast cleaned and treated with a zinc rich primer followed by a alkyd undercoat and gloss finish paint system. All sheeting rails and purloins will be hot dip galvanized.

The roof comprises commercial uninsulated metal cladding on steel purloins which span between the portal beams. Roof draining is achieved by pressed metal gutters to the eaves which discharge into downspouts to the exterior of the building envelope.

The exterior walls comprise commercial uninsulated metal cladding on steel sheeting rails which span horizontally between the perimeter stanchions. Although not required at present, consideration has been given to the possible future option of providing an inner shield wall. This has been assumed to be of concrete block or reinforced concrete construction and to be located between the perimeter stanchions to which it would be mechanically tied. The overall building width has taken account of the space requirements for the construction of such a wall, assuming the waste drums are in place and adequate wall foundations have been provided.

The ground floor comprises a reinforced concrete ground bearing slab. This slab is thickened locally all around the building perimeter, (to support the future shield wall) and locally around all internal stanchions. Resistance to water penetration from the ground is provided by a polyethylene damp proof membrane to the underside of the slab. The ground floor slab will be finished with an epoxy paint.

Future extension of the building may be achieved by the addition of further panel bay frames thus increasing the length of the building in 4.3 m modules. The only modifications to the existing building made necessary by such an extension will be the removal of sheeting, sheeting rails and sheeting posts to the end gable to enable access between the existing and extension areas.

3.4. OPTIONS FOR SPECIFIC NEEDS

A wide variety of storage needs exist throughout Member States. Store design is influenced by a number of factors including, but not limited to:

- waste activity;
- waste packaging;
- national regulations;
- store location;
- volume to be stored;
- anticipated period of storage;
- climatic conditions.

Despite the large variety of needs there are basically only two main store concepts or types for packaged wastes. These are:

- the open vault store, with differing numbers of trays in the vault;
- stores where the package stack height is generally tall and each stack is constrained/contained in tubes, lattices or posts, for example.

Additionally, the needs can be addressed by three fundamental considerations in storage design. There are the need for:

- large or small scale storage;
- remote or manual handling systems;
- surface or sub-surface location.

These options are discussed in the following paragraphs.

Large/small scale storage

Total capacity of the storage facility is likely to be dictated by the overall waste management strategy as opposed to considerations within the store itself. In particular, the timing of disposal routes becoming available will dictate the size of the pre-disposal store. The size of a buffer store will on the other hand depend upon the regularity of waste receipts as compared with dispatches for disposal [22].

The usual economies of scale mean that storage costs, per unit volume of waste, will depend upon the size of the facility. These economies will only be realized in the case of bulk storage configurations such as, in the extreme, large vaults containing waste packages closely stacked. This tends to require some uniformity of waste package size/shape, since common handling facilities are implied and efficient stacking is most easily achieved with regular forms. Depending upon the stacking arrangements such bulk storage concepts may suffer from retrieval limitations, in that access to certain packages may depend upon others being removed.

Bulk storage of unshielded packages would tend to offer distinct advantages for shielding, in that the inner packages are shielded by those placed towards the edges. As with the volume/surface area economics, building length-breadth-height ratios close to unity represent the optimum configuration. In practice the extent to which such an optimum is approached depends on various constraints including package stacking and strength considerations.

For a given capacity of facility, the next step down from the one large vault extreme is by provision of a number of smaller vaults or modules. This may have advantages in terms of separation of different waste package shapes/sizes or waste types. Handling and stacking of different waste packages may for example be most easily achieved if these are segregated into discrete regions of the store. Different types of waste may require different storage conditions (i.e. combustible waste requires provision of fire suppression systems, the lower activity waste is less demanding in terms of handling and shielding). These may be most economically achieved by segregation. Such an arrangement may also offer the advantages of flexibility to cater for unplanned situations such as may result from an accident requiring the affected area to be cleaned up. A modular facility could well continue to operate in such circumstances, for example by closing off the affected section.

Limiting concepts of storage modules, dedicated to individual or small groups, of waste packages, are likely to be uneconomic except for very small quantities of unusual (in terms of size, shape or activity level) packages. Such a storage concept could for example be included as a special sub-facility within what is otherwise a bulk store of the vault type.

Remote/manual handling system

The decision on which type of handling system is employed depends on whether or note the waste packages being handled require or incorporate shielding. Any need for shielding is derived from the specific activity of the waste stream, which is controlled primarily by the waste generator (Appendix I). Member States using the reference WPSF store will probably not produce wastes that require shielding, but this possibility cannot be excluded [27].

The use of self-shielded packages has far reaching implications throughout a waste management strategy. This important aspect not only affects handling arrangements but also dictates the physical size of the store and influences the relative advantages of surface or sub-surface location. Implications go beyond the store itself; the external transportation systems and the disposal facility are similarly affected.

Unshielded packages will in general enable a higher waste storage density to be achieved within the facility. This has obvious economic benefits which may be partially offset by the need for the building itself to provide shielding. On the other hand remote handling does introduce costs and complexities in terms of the equipment and these are by no means insignificant: apart from the requirement for remote positioning capability, remote systems are often slower than simple manual systems (due to the requirements for spatial checks and interlocks). In a large store waste package movements would consume considerable effort. Remote systems have to be provided with back-up facilities in case of breakdown since direct personnel access is by definition excluded.

The advantage of manual handling extend beyond the associated simplicity of equipment; it may be possible to treat the store almost as a non-nuclear facility so long as the packages are sufficiently shielded and mechanically protected. Manual handling systems could comprise standard stacker-trucks, for example, but weight limitations might be important in relation to self-shielded waste packages.

Sub-surface storage

Stores can be constructed either above or below ground. Underground stores, which could be new excavations or developed from existing mines, should ideally be located in dry ground. In arid regions of the world sub-surface stores can be excavated above the water table and dry conditions can be virtually guaranteed. The overburden provides shielding and a high degree of security. Sub-surface stores have much to commend them particularly where the cost of underground space is less than suitable surface structure. This may be true in desert areas subjected to high winds and dust.

4. GLOBAL COST ESTIMATE

To provide Member States with a general perspective of the cost for the reference WPSF a global project cost estimate has been prepared for design, construction and installation. This estimate based on UK suppliers in 1992 is presented below:

	£k
Building and civil work	930
Mechanical plant and equipment	200
Mechanical installation	175
Electrical plant and equipment including installation	100
	1405
Contingency on capital estimate (~25%)	340
TOTAL CAPITAL	1745
Design and engineering (D&E) costs including project management	450
Contingency on D&E (~25%)	105
TOTAL DESIGN	555
TOTAL PROJECT COST	2300

A number of assumptions have been made in compiling this estimate and these are discussed below:

(a) UK costs are used throughout.

(b) Costs are for the WPSF building and equipment, and for the store building only. The extension of any incoming or outgoing services beyond the building boundaries is excluded. The costs of roads, paths to serve the buildings, and landscaping are excluded.

(c) Site surveys prior to construction are excluded.

(d) Preparation for special ground conditions, i.e. piling or vibrocompaction is excluded.

(e) Costs for some items, i.e. the liquid effluent treatment plant are presented in detail based on budget quotations. Costs for other items are based on established unit rates whilst costs for other items, i.e. the waste store, are based on the scaling of costs for similar specification items.

(f) Design and engineering including project management costs are included as an allowance, based on 35% of capital from experience of similar types of project.

(g) The intention is for the WPSF to be a generic design. A large proportion of the design costs could therefore be expected to be a one time cost, incurred only on the first WPSF. Second and subsequent WPSFs would have lower design costs. These reduced costs would cover tailoring of the previous designs to a specific application (i.e. particular waste feeds, geological and climatic conditions) and general items such as project management.

(h) Contingencies are allowed on both the capital and design estimates because of the preliminary nature of these estimates.

The estimated phasing of these costs is illustrated below. The programme should be referred to for the activities during each year.

Year	Capital	D&E	Total
1	-	250	250
2	870	165	1035
3	700	110	810
4	175	30	205
TOTALS	1745	555	2300

It should be emphasized, however, that the costs discussed in this section are based on estimated costs in the UK. Use of local labour and locally available construction materials in developing countries should reduce these costs in a manner that reflects the relative cost differential for living and construction costs in the developing country versus in the UK.

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Appendix I

WASTE MANAGEMENT ACTIVITIES AT THE WASTE PRODUCER

The complexities of operating a waste processing facility require that the waste management process begins at the source of where the waste is produced. Activities at the waste producer involve the preparation of the waste for subsequent transport to the WPSF and processing and may include:

- Administrative measures;
- Sorting and segregation into categories such as:
  - exempt waste;
  - items suitable for decontamination and re-use/re-cycle;
  - waste suitable for decay storage;
  - compactable and non-compactable waste;
- Packaging;
- Temporary storage awaiting transport.

Administrative measures fix the rules for the very first steps of the solid-waste management, i.e. collection, sorting, segregation and packaging for transport to buffer storage areas, or directly to the treatment facilities. Emphasis must be placed on an as informative-as-possible description of the waste, stating origin, nature, activity (isotopes, radiation level), package volume, weight and all further information relevant to the safe execution of the subsequent treatment steps. It is imperative that this information is also provided to meet accountability and operational purposes. This, in turn, leads to the need to use adequate measuring techniques to obtain the above information. Indeed, the establishment has to keep a detailed record system that integrates and documents the information obtained in all phases of the waste management system. In addition to this, and for the sake of safety and efficiency, a strong responsive administration and control system must oblige all parties within the waste management system to comply with operational and safety rules [I.1].

Classifying the wastes into the different categories handled in the integral waste management system is achieved in the sorting and segregation steps [I.2, I.3]. Whenever possible, these operations should be done at the source where the waste is produced, and they should be combined with the packaging into appropriate containers (usually plastic bags and/or 200 litre drums) bearing adequate indication (for instance, colour codes) for transport to the corresponding waste treatment step.

Experience shows that even at sites where waste treatment facilities are not yet available, it is highly recommended to start to store the waste in segregated categories from the beginning. Non-segregated bulk storage makes final waste treatment inevitably more complicated [I.4].

Size reduction will normally be achieved in the treatment facility. It can, however, be advantageous to start already at the source, whenever this is possible [I.5].

Decontamination could be considered as a pre-treatment step whenever the degree and/or the kind of contamination would prohibit treatment of the wastes in an existing facility. In the same context, intermediate storage allowing decay of short-lived isotopes can be a rather effective pretreatment method, considerably facilitating subsequent treatment steps. Fig. I.1 summarizes a typical expected overall work management strategy.

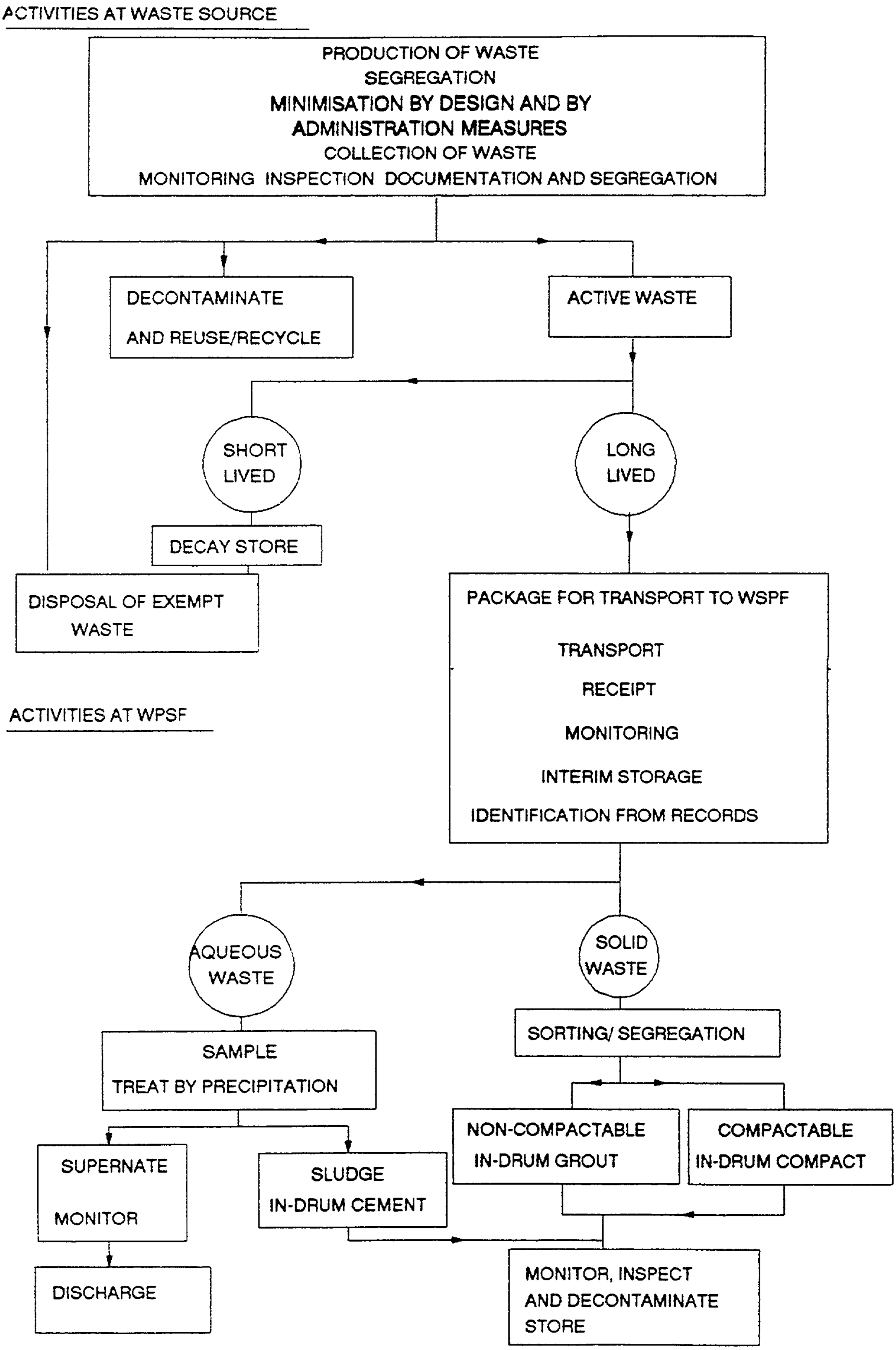

FIG I.1. Waste processing strategy

The result of such a strategy, based on previous IAEA experience, will result in waste arisings from various generators as summarized in Table I.1. The following sections discuss the waste management strategy in more detail.

TABLE I.1. SOURCES AND QUANTITIES OF RADIOACTIVE WASTES IN NON-NUCLEAR FUEL CYCLE ESTABLISHMENTS OF GROUP C MEMBER STATES[a]

Origins, types of wastes	Untreated waste		Typical isotopes
	m^3/year (containers)	Bq/m^3	
1. Nuclear research centre			
aqueous effluents	100-500	4×10^4-4×10^9	Corrosion product ^{55}Fe, ^{59}Fe, ^{58}Co, ^{134}Cs, ^{137}Cs, $^{121}Te^m$
organic effluents	0.1-1	approx. 10^4	^{32}P, ^{35}S, ^{51}Cr, ^{59}Fe, $^{99}Tc^m$, ^{111}In, ^{131}I, U_{nat}, Th_{nat}, ^{125}I, ^{90}Sr, ^{90}Y, ^{3}H, ^{14}C
ion exchange	0.5-1.5	2×10^4-4×10^{10}	
compactable solid waste	50-100	0.01 R/h	
non-compactable solid waste	5-10	<0.01 R/h	
2. Hospitals			^{111}In, ^{99}Mo, $^{99}Tc^m$, ^{125}I
aqueous effluents	2-5	4×10^4-4×10^7	^{35}S, ^{24}Na, ^{32}P, ^{3}H, ^{14}C, ^{60}Co, ^{137}Cs
compactable solid waste			
sealed sources	(2-5)	<0.01 R/h	^{152}Ir, ^{226}Ra
Ra-needles	(1-2)	10^2-10^3 R/h	^{60}Co, ^{137}Cs, ^{192}Ir
3. Industries			^{239}Pu, ^{241}Am
sealed sources	(1-2)	10^2-10^3 R/h	
smoke detectors	(1-2)	<0.001 R/h	
4. Universities and research institutes			^{14}C, ^{3}H, ^{32}P, ^{35}S
aqueous effluents	2-5	4×10^4-4×10^7	
compactable solid wastes	205	<0.01 R/h	

[a]Group C designates IAEA Member States having multiple users of radioisotopes and a nuclear research centre capable of producing those isotopes. Other developing Member States (Groups A and B) use radioistopes to a lesser extent and will produce lower quantities of wastes.

I.1. MINIMIZATION OF WASTE ARISINGS

Although minimization of waste arisings can be considered as a management principle rather than a pre-treatment technique, its importance justifies a brief description of the major features.

The objectives of minimizing waste arisings and, in a further stage, volume reduction of the actual waste arisings have become more and more straightforward in the past five years, because:

- Disposal costs have increased rapidly,
- Acceptance criteria for disposal have become more restrictive,
- Costs of processing to meet these requirements have increased accordingly,
- The availability and capacity of disposal sites are limited.

Therefore, in the management of a nuclear facility a number of organizational and technical actions have to be considered, such as the establishment and implementation of procedures for routine operations, the re-evaluation of controlled areas and radiation zones, the application of quality assurance programmes to waste generation, the training of personnel and improvement of discipline. In the design of new facilities or modification of existing facilities, special attention should be paid to the technical factors affecting waste management during both plant operation and decommissioning.

Also, for general trash, which usually comprises the dominant volume of low level wastes (LLW), a number of practical measures are being undertaken to implement the principle of minimization. Typical examples are the prevention of the entrance of materials in controlled area (i.e. packaging materials) and the use of warm air hand dryers instead of paper towels.

Another IAEA Technical Document [I.3] discusses waste minimization in more detail. However, a number of steps which would be taken are summarized below as an example of the "good housekeeping" practices which should be encouraged:

(a) Keep all unnecessary 'inactive' materials out of 'active' areas. Staff must be organized to significantly help reduce the amount of inactive material entering active areas not only by removing unnecessary packaging, but by being flexible with regard to the amount of material released, i.e. when only three items are required these should be supplied rather than a box of twelve. Tools and other components for radioactive areas will be issued without packaging, wrapping or pallets. Any surplus material should be segregated once in the active areas to avoid becoming contaminated.

(b) Use strong plastic bags to prevent double bagging of waste materials for transfer.

(c) Minimize the use of single use protective clothing, i.e. plastic shoe covers and laboratory costs. Re-use rubber gloves if non-contaminated.

(d) When counting liquid scintillation samples one way to minimize waste is through the use of mini-vials instead of the maxi vials. Three times as many samples can be counted using the same quantity of liquid using those smaller vials, bringing a substantial savings in the volume of waste for disposal.

(e) Keep the amount of inactive materials including liquids, which are put into enclosures, fume hoods, glove boxes, cells etc to a minimum. Reduce water leaks into process systems and regulate indiscriminate flushing/cleaning operations.

(f) Re-use decontamination solutions and recycle clarified liquors within a process to reduce fresh water additions and volumes of effluent for treatment.

(g) Use floor materials that can be easily decontaminated in areas where frequent maintenance is required.

(h) Staff collecting active wastes from laboratories and other facilities must be encouraged to also assist by reporting waste not properly packaged or not accompanied by the correct documentation.

(i) Segregate long-lived nuclides from short-lived materials.

(j) Segregate low level waste from higher level waste.

I.2. SEGREGATION AND SORTING

Classification requirements

In most countries, the management of radioactive wastes must be conducted within an extensive framework of regulations and requirements set by national and/or state authorities, national waste management organizations and centralized waste processing facilities [I.1]. The national regulations often relate to transport and disposal requirements, whereas specifications for treatment and conditioning are imposed by waste processing facilities or waste management organizations. The latter specifications are derived from typical process characteristics and limitations (handling, incineration, compaction, etc.) and also include acceptance criteria for disposal of the process residues.

Transport regulations are in many countries based upon IAEA Safety Series No.6 [I.5]. The IAEA regulations specify the requirements for packaging and labelling, define shipping categories of radioactive materials according to their radioactivity content (i.e. solid materials) and determine acceptable radiation dose levels.

In those countries where the concept of centralized waste processing facilities is applied to most LLW and ILW, a set of requirements is imposed on the waste generator with respect to the segregation and packaging of wastes, depending upon size and physico-chemical and radiological composition. These specifications take into account the subsequent volume reduction process and the operational need for segregation at source. The same concept applies to large nuclear facilities with on-site centralized waste management.

The objective for sorting or segregating wastes is to produce different grouping of materials according to distinct physico-chemical properties and the degree and kind of contamination for ease of subsequent treatment. This segregation will produce a number of direct benefits, eg segregation of non-radioactive waste from radioactive waste at the source will significantly reduce the volume of radioactive waste requiring storage or further treatment, segregation of different types of radioactive wastes will also lead to more efficient waste processing and packaging. Whenever possible, segregation must be at the source of generation of waste into appropriately marked containers. Where space allows wastes should be kept in small bags or containers in hold areas within the ventilated hoods. Use could be made of marked different sized and coloured containers to aid segregation at the workplace.

Materials which may cause significant hazard in the WPSF if available must be set aside. These will include unstable explosive compounds, strong oxidizing agents, sodium, phosphorus, metal hydrides and asbestos.

It is desirable to segregate wastes having long half lives from short half-lives, or combustible from non-combustible. It is important to note that the waste producer may be better placed to segregate wastes contaminated with particular short-lived radionuclides than the WPSF operator, i.e. he will know that wastes originating from a laboratory which only uses ^{35}S will only be contaminated with ^{35}S.

Application of exemption concept

Numerous organizations have recognised the need for criteria governing the disposal of extremely low level radioactive wastes by means less restrictive then those in use at conventional LLW disposal sites [I.6, I.7]. In this approach, referred to as exempt or 'below regulatory concern', the wastes below threshold levels of radioactivity could be disposed of in a manner consistent with the materials' non-radiological characteristics. The task of defining such threshold levels is a practical question of applying the basic radiological protection standards to a specific case.

The application of such a concept would drastically reduce the volumes of LLW, since in most nuclear facilities the origin of the wastes is the determining factor in the subsequent routing and in general the waste arisings increase with decreasing radioactivity content. Especially in view of large decommissioning programmes, there is an international consensus on the key role of the exemption concept in waste management.

The types of solid wastes that national authorities may consider under the exemption concept could arise from many categories, notably:

- Combustible solid wastes having very low concentrations of a wide range of radioisotopes of various half-lives;

- Combustible solid wastes contaminated with beta/gamma emitters of low activity or half-lives of a few months or less;

- Non-combustible solid wastes in which the contained radioactivity is characterised by low leachability, a short half-life, low radiotoxicity or a combination of these.

These waste categories arise in industries using or manufacturing radioisotopes, in hospitals with radiopharmaceutical and nuclear medicine departments, in universities and research centres, and from all components of the nuclear fuel cycles. The wastes may have diverse forms, ranging from disposable syringes, animal carcasses and contaminated hardware though to large volumes of soil or concrete arising from land reclamation and decommissioning of a nuclear plant.

In spite of the consensus on the need for exemption regulations, very few practical applications on a routine basis are known. The current limit in the United Kingdom for uncontrolled disposal is 0.37 Bq/g (10^{-5} μCi/g), whereas 0.37 MBq (10 μCi) in 0.1 m^3 and 37 kBq (1 μCi) per item, excluding alpha emitters and ^{90}Sr, are accepted for local refuse tips.

The example for local refuse tips can be considered as an application of quantities that under certain conditions the competent national authorities may exempt from notification on the assumption that the waste materials involved are disposed of in a specific manner. This practice is often applied for very low level solid wastes from nuclear medicine.

These wastes can be managed as non-radioactive materials, depending upon special licence approval for specific radionuclides (^{3}H, ^{14}C) or after sufficient decay storage for short-lived radionuclides (half-lives less than a few months). Such practices are known for the USA, France, the Federal Republic of Germany and the UK. The implementation of these special licence approvals assumes a thorough segregation of the wastes at source according to the half-lives of the radioactive contaminants.

I.3. DECAY STORAGE

Decay storage is commonly applied to institutional wastes that contain short-lived radionuclides. In many countries, radioisotope producers, hospitals, universities and research laboratories practice on a routine basis segregation of LLW according to the half-lives of the radioactive contaminants. Typical LLW constituents are ^{99}Mo (66.0 h), ^{131}I (8.0 d), ^{125}I (60.1 d) and ^{192}Ir (72.8 d).

At the current radioactivity concentrations in newly generated LLW (of the order of 3.7–37 MBq (0.1–1 mCi/m^3)), decay storage for ten half-lives or more can reduce the residual radioactivity content below the limits for further treatment as non-radioactive materials. Therefore, decay storage for one or two years is an advantageous option. It requires the availability of protected storage capacity on-site in which selective storage can be realized. Adequate procedures and identification, administrative controls and reliable segregation of the wastes are important criteria in meeting these objectives.

For radioactive wastes that also contain longer lived activation and/or fission products, decay storage can offer interesting possibilities with respect to transport and treatment. Waste packages with contact dose rates exceeding the operational handling limits for LLW (1–2 mSv/h (100–200 mrem/h)) require costly shielding provisions and treatment. For example, ^{58}Co (half-life: 70.9 d) is a major radioactive contaminant in wastes from light water reactors, especially during the first five years of operation (until equilibrium between ^{60}Co and ^{58}Co is reached). Decay storage can substantially reduce the radiation levels within a period of one year, resulting in LLW.

The practice of decay storage at the waste producer has a number of advantages compared to the alternative of storage at the WPSF:

(a) if a suitable disposal route exists from the producer once the waste has been decayed to below "exemption" levels, then it avoids double handling of the waste and reduces the volumes of waste to be packaged, monitored and transported to the WPSF;

(b) it is expected that the waste producer would be able to identify the point of origin of the waste, allowing him to better segregate wastes by particular radionuclide content without complex monitoring.

I.4. PACKAGING

Packaging of solid radioactive wastes by the waste generator for handling, transportation, further treatment and conditioning, and disposal is an important pretreatment operation. It has to comply with transport regulations, acceptance criteria for treatment and/or disposal, and general occupational radiological protection standards [I.8].

It is expected that combustible low level solid wastes would be collected at the origin in transparent plastic bags (polyethylene or PVC) with sheet thicknesses between 0.1 and 0.2 mm and volumes of 15–50 L, and which are often marked with the radioactivity label. This primary package is generally adapted to the collection system, which may be pedal bins for laboratories and small waste generators or larger bins, i.e. 100 L drums at larger waste generators. After filling, the plastic bags are removed from the bins and closed with adhesive tape.

The size reduction of wastes at the waste producer will probably be limited to either:

- reduction in physical size, where possible, to allow the waste to be packaged for transport, i.e. cutting lengths of pipe work to allow them to be placed in 200 L drums;

- the removal of uncontaminated extraneous packaging or material from waste to reduce volumes, i.e. removal of sealed sources from smoke detectors.

Non-combustible small size LLW are usually collected as compressible and non-compressible materials in metal or cardboard boxes of 20–50 L for small generators and metal drums of 100–200 L for larger generators.

Deep freezing of animal carcasses or similar types of waste is used to allow convenient accumulation and storage. Carcasses are packed in plastic bags before freezing.

For direct disposal of LLW, 200 L drums, cardboard boxes and larger wooden crates (1.2m × 1.2m × 2.1m) are normally used. The latter allow for packaging of large items. Very large containers are being designed for packaging of dismantled equipment.

Standard HEPA filters are often packed in welded plastic bags, especially when alpha contamination is suspected. Cardboard boxes may be used as an overpack. The technique of double or triple PVC welding is widely applied for removing TRU wastes from glove boxes.

The current transport regulations specify requirements for packaging of solid radioactive wastes, depending upon their radiological characteristics. The main shipping categories, applicable to low and intermediate level wastes, comprise [I.5]:

- Materials with low specific activity (LSA)
- Low level solid materials (LLS)
- Type A category
- Type B category
- Special arrangements.

I.5. TEMPORARY STORAGE

The need for interim storage capacity at the site of the waste generator, before wastes are ready for off-site shipment for treatment or disposal, is obvious. The storage buildings or rooms are operated according to local radiological protection standards and the capacity should meet the requirement of operational independence.

Further guidance on the design of interim stores at waste consignors is available in another IAEA publication [I.9].

I.6. COLLECTION AND TRANSPORT

Radioactive wastes require transport from their points of origin to the WPSF. The safety of these operations (i.e. protection of persons, property and the environment from radiation and other hazards) is the primary concern in the transportation of radioactive wastes. Thus, transportation must be considered as an integral part of the waste management system.

The radiation levels of the various types of radioactive waste have a significant impact on the methods and equipment used for transportation. The low levels of penetrating radiation characteristic of low-level wastes permit their transport without shielding and with direct handling operations. However, the higher levels of penetrating radiation associated with intermediate-level wastes require the use of shielding during their transport and indirect or remote-handling operations; thus, the equipment aspects are more demanding. It is expected that the wastes sent to the WPSF will not require additional shielding for transport. In principle, three modes of transportation can be used: road, rail or water transport.

Five of the main objectives of the IAEA regulations for the safe transport of radioactive material are:

(i) To limit radiation doses to transport and handling workers and members of the general public to acceptable levels under normal conditions of transport;

(ii) To limit the risks from accidents to acceptable levels for transport and handling workers and members of the general public;

(iii) To limit the activity content and specific activity in connection with different transport packages;

(iv) To specify labels for the packages and vehicles;

(v) To set the classification and test requirements for transport packages.

The regulations specify the requirements for packaging and conditions of transport for all types of radioactive material, including radioactive wastes [I.5].

For the transport of waste to the WPSF it is expected that the 200 L drum will be the preferred container. The 200 L drum fulfills the requirements of the IAEA Transport Regulations for the transport of the types of waste materials which are being considered for treatment at the WPSF. In addition, the 200 L drum has advantages of low cost, simplicity, and availability of handling equipment.

Prior to collection and transport, the waste producer will transfer waste from the bins etc which it has been accumulated in at source to 200 L drums. As noted earlier, it is expected that the bins would be lined with polybags, and sealed and taped when full. Transfer of bagged waste to the 200 L drum should therefore be a clean operation.

It is expected that the waste producer will have documentation and records for each of the bags of waste which goes in to a drum. These will need to be transferred to the documentation for the drum, and filed under the unique drum identification number. The details to be recorded are:

- the activity and type of radionuclides present;
- the chemical and physical nature of the waste;
- the name of the person responsible for that waste;
- the drum weight;
- the dose rate at the surface of the drum;
- the maximum drum contamination level;
- the unique drum identification number.

Prior to loading a drum onto the transport vehicle the drum outside surface should be checked for contamination. If outside the limits set in the IAEA Transport Regulations, the surface should be decontaminated and remonitored until satisfactory.

The frequency of transport movements between individual waste producers and the WPSF will depend on the rate of waste arisings and the size of the transport vehicle. At one extreme, single drums may be transported by a small vehicle. At the other, consignments of 70–100 drums may occur.

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Appendix II

WPSF PROCESS OPTIONS

II.1. OPTIONS FOR TREATMENT OF AQUEOUS LIQUID WASTES

The following section describes low level liquid waste treatment processes giving their advantages and limitations [II.1–II.5]. The processes detailed include: evaporation, precipitation, ion exchange and ultrafiltration.

II.1.1. Evaporation

Concentration by evaporation is a well established process, widely used in the nuclear industry worldwide. It is capable of giving high decontamination and large volume reductions and is currently being used in the treatment of high-, medium- and low-level waste effluents. On cost considerations, evaporation is a relatively expensive process and is therefore more attractive for the treatment of small volumes of highly active effluents than for the treatment of large volumes of low-level wastes; although it is used for low-level waste concentration at some sites.

Description of the process

When compared with other effluent treatment processes, the evaporation process is in principle relatively simple. Essentially it involves distillation of the waste effluent, leaving a smaller volume of residue containing both the radionuclides and the inactive salts. In practice, evaporation gives very good decontamination for all non-volatile radionuclides (up to 10^4 in a single stage evaporator) and can result in very large volume reductions provided that the inactive salt content of the stream is relatively low.

The condensate resulting from evaporation is an almost salt-free solution of very low activity which may be subsequently 'polished' by ion exchange, before it is discharged or recycled for use in the nuclear plant.

The concentrate containing the radionuclides can either be dried to produce a salt cake or be incorporated into a suitable matrix (i.e. cement) for disposal. Secondary wastes produced by evaporation are fairly small, arising only from off-gas clean-up when volatiles are present and the decontamination and cleaning reagents used in the routine maintenance of the evaporator.

Evaporation processes are prone to three quite serious problems; corrosion, scaling and foaming. Most effluents treated could give rise to at least one of these problems and it is often necessary to pre-treat the feed.

All of those problems should be considered as potential limitations of the process. The performance of evaporators is strongly influenced by these factors, in terms of decontamination factor, costs and the lifetime of the facility. From these points of view, the process designer requires a good knowledge of the chemical and physical properties of the waste requiring treatment. In addition, in order to ensure efficient running of the evaporator, it is important to have regular maintenance of the facility.

Such problems can be reduced by appropriate preliminary waste treatments in order to remove substances which cause trouble and also condition the effluent itself, e.g.:

(a) filter to remove solid particles, which can cause trouble;
(b) adjust the pH value to reduce corrosion;
(c) remove organics to reduce foaming.

Advantages and limitations of evaporation

The main advantages of evaporation are:

(a) large volume reduction for a range of effluents;

(b) good decontamination for non-volatile radionuclides, DFs of 10^4–10^5 are frequently achieved in a single stage;

(c) it is unaffected by the presence of complexants in a waste effluent, unlike many of the alternative treatment processes.

There are several limitations to the application of evaporation processes:

(a) they are unsuitable for waste effluents containing large concentrations of inactive salts, since the extent of volume reduction is determined by the dissolved solids content;

(b) they are expensive compared to other treatment processes (i.e. 20–50 $\times$ cost of a floc process) due to their large energy requirement. Recently, the increasing cost of energy has actually led to the investigation of alternative processes to replace evaporation for the treatment of large volumes of effluents.

(c) the problems caused by corrosion, scaling and foam formation may prevent the successful evaporation of some wastes;

(d) the presence of some organics can result in explosions during evaporation, e.g. TBP in nitric acid, and appropriate pretreatment is required, such as steam stripping.

II.1.2. Chemical precipitation

Chemical precipitation processes are well established methods for the removal of radioactivity from low- and medium-active liquid wastes and are in regular use at fuel reprocessing facilities, research establishments and, more recently, at several power stations. A wide range of different precipitates are now in use (i.e. metal hydroxides, oxalates and phosphates). Often small quantities of selected absorbers are added during a floc process to improve or provide decontamination from specific radioelements (i.e. hexacyanoferrates for caesium removal).

Chemical precipitation methods are particularly suitable for the treatment of large volumes of liquid effluents which contain relatively low concentrations of active species. They are fairly versatile and may be used to treat a wide variety of different waste streams, including those containing large amounts of particulates and high concentrations of inactive salts. In addition, they are often used very successfully in conjunction with other techniques such as ion exchange and ultrafiltration. The processes usually use readily available chemical reagents and are therefore relatively cheap when compared to the cost of some alternative processes, e.g. evaporation.

Description of the processes

A typical chemical precipitation method involves four main stages:

(a) the addition of chemicals or adjustment of pH, to form the precipitate;
(b) flocculation and coagulation;
(c) sedimentation;
(d) solid–liquid separation.

Agitation is usually applied during the first stage of a precipitation process, to ensure uniform mixing of added reagents and to disperse the precipitate in the effluent. The length of time used for this initial mixing is a compromise, since long periods favour increased radionuclide absorption onto the floc but can also cause the formation of colloidal suspensions. Flocculation is often achieved by slowly stirring the slurry which helps the floc particles to agglomerate.

The waste volume reduction achieved with a precipitation process is very dependent on the method of solid/liquid separation used. Gravitational settling is usually rather slow, so the resultant volume of floc depends on the settling time. The physical nature of some flocs will limit the extent to which they can settle under gravity, i.e. gelatinous metal hydroxide flocs; in these cases secondary processes are necessary to dewater the floc and make it suitable for immobilization in an appropriate matrix for storage or disposal. Two recently developed methods for floc dewatering are ultrafiltration and an electrokinetic technique. Both processes have been shown to be very effective; for example, a sedimented ferric floc containing 5 wt% solids, can be dewatered to 40 wt% solids.

Parameters such as the temperature, the pH, and the concentration and rate of addition of the precipitation reagents, can all affect the quantity and nature of the precipitate formed.

The decontamination achieved by a floc process will depend both on the particular precipitate and the radionuclide concerned and may also be affected by the presence of other components of the waste effluent such as complexants or particulates. Generally, radionuclides are removed from solution by one or more of the following mechanisms:

(a) co-precipitation or isomorphous precipitation with the carrier, where the radionuclide is incorporated into the crystal structure of the precipitate, e.g. radiostrontium removal by barium sulphate precipitate;

(b) entrainment, which occurs when the radionuclide itself precipitates under the conditions of the process and is subsequently swept out of solution by the bulk (or scavenging) precipitate;

(c) removal of radionuclides already absorbed onto particulates present in the waste effluent, which will be scavenged from solution;

(d) adsorption onto the floc, i.e. by ion exchange, chemisorption, physical absorption, etc;

(e) removal can also be achieved or improved by the absorption of radionuclides onto small amounts of finely divided additives added during the floc process, i.e. hydrous titanium oxide for actinides.

Advantages and limitations of precipitation processes

The experience gained with precipitation processes for effluent treatment has shown they have several advantages over some of the alternative processes which have been examined:

(a) they are simpler to carry out on a plant scale and employ well proven equipment for use both in batch or continuous processes;

(b) they generally achieve good DFs (>100) for the actinides and useful DFs for some fission products;

(c) they can be used for treating a wide variety of waste effluents, including those with high inactive salts content, particulates and even organic liquids in solution, although these could affect the floc settling properties and final volume;

(d) they can provide reasonable volume reduction which can be further increased by a sludge dewatering stage;

(e) they are flexible and can involve several different precipitates together to achieve the required decontamination. The addition of inorganic absorbers to improve decontamination, is also possible and enables radionuclides to be removed which would not otherwise be removed by a floc process;

(f) they are relatively inexpensive using low cost chemical reagents and simple plant equipment.

There are also a number of limitations on the use of precipitation processes:

(a) the DFs achieved are very dependent on the efficiency of the solid/liquid separation method employed. Small particle or colloidal carryover with the supernate will reduce the decontamination obtained but may be overcome by subsequent polishing of the supernate, i.e. by ultrafiltration;

(b) the sludges arising from precipitation processes usually have low solids content and require further dewatering to reduce the volume of immobilized waste produced;

(c) the DFs achieved are dependent to some extent on the chemical nature of the waste effluent: the presence of complexants in particular could reduce the efficiency of the process. Further research is still required to assess the extent of this problem and develop suitable pretreatments if necessary. Likewise it may be necessary to pretreat, to stabilize the actinides in the oxidation states required for the process;

(d) precipitation processes may be used for effluents with a high salt content. However, the resultant waste effluents will contain even higher levels of inactive salts and in some cases these could prove problematic for the effluent's subsequent discharge;

(e) the flocs formed may need to be washed to remove entrained salts prior to their storage or encapsulation. At present the effects of washing are relatively unknown, particularly when added inorganic absorbers are also present in the floc.

Selection of sludge dewatering process

Sludges arising from the precipitation process may need some dewatering in order to reduce their volume thereby reducing the volume of final encapsulated waste. Dewatering can be achieved by evaporation, centrifugation, freeze-thaw, or filtration. Dewatering raises the solids content of the sludge and also the specific activity. Typical figures for the solids content achievable with different processes are given below:

Treatment	Solids content (%)
Centrifugation	5–90
Freeze-thaw	12
Filtration	20–40
Two-stage evaporation	30–40
Drying	95–99
Gravity settling	0.5–10

Gravity settling

Gravity settling provides, perhaps, the simplest method of increasing the solids concentration of the sludge, although a sludge/supernate separation stage is required to realize this increase. The 'performance' of gravity settling is time related.

Two to three hours after the precipitation process has been completed, the solids content of the sludge could be expected to be around 1/2–1% by weight. After a few days settling, however, the content could rise to 1/2–5% by weight. Long term storage of the sludge allows more settling to take place, and solids concentration greater than 6% by weight can be achieved.

The cost of gravity settling is therefore in providing adequate storage capacity for the sludge.

Filtration

Filtration is applicable to chemical sludges, obtained from flocculation and co-precipitation of liquid effluents, as well as to suspensions originating from backwash cleaning of larger filter units. The process aims at volume reduction, by dewatering before any further treatment or immobilization, and is based on the separation of solids on a porous material through which the liquid phase passes.

Two main filtration techniques are considered — vacuum filtration and pressure filtration:

(a) Vacuum filtration is the most common type of filtration. Continuous units are commercially available and based on horizontally rotating cylinders with filter cloth or porous metal, on which the filter cake is accumulated during the slow rotation. The filter cake is scraped off. The capacity is limited by the filtration characteristics of the sludge and the equipment size is large compared with pressure filtration units.

Owing to its design and principle of operation, vacuum filtration is compatible with radiological safety requirements and allows for treating low-level as well as intermediate-level sludges, with low exposure to personnel and low potential for spread of contamination.

Dewatering up to 20–40 wt% solids can be obtained for wastes with initial 1 to 10 wt% solids content.

(b) Pressure filtration offers the advantage of increased filtration rate and compact equipment, but the risk of leaks, owing to its operation under pressure, is a disadvantage.

The commercially suitable units consist of filter cartridges or horizontal and vertical multilayer plate configurations. Semi- continuous operation is obtained in the vertical one by centrifugal cleaning of the discs.

Combined systems of pressure filtration with additional hot air or steam drying are also operated at some nuclear power stations, for example in the Federal Republic of Germany.

In general, the filtration technique has the disadvantage that in the case of poor filterability of the sludges (colloidal) filter aids as precoat have to be used, resulting in an increase of the final waste volume.

In the application of any one of these processes considered above in the WPSF several points are worth noting:

- Dewatering the sludge raises the sludge specific activity. It is expected that there will be a point where the sludge could be dewatered to the extent that shielding of the dewatering plant became necessary. The costs of shielding and remote handling may outweigh the minor savings made in reduced volumes for encapsulation, storage and disposal.

- The sludge will ultimately go to cementation. A typical maximum solids concentration of the sludge for straight forward cementation is around 8% by weight. If the sludge solids concentration is raised above this by dewatering, then water may need to be re-added for cementation.

- It is preferable for the sludge to remain pumpable. Significant dewatering will make this difficult.

In addition to these above points, account is also taken of the general philosophy for the WPSF, e.g. simple, rugged, well proven, and the relatively small volumes of sludge to be dewatered. From this it is concluded that simple gravity settling is the preferred sludge dewatering process for the WPSF.

II.1.3. Ion exchange

Ion exchange processes basically involve the exchange of ionic species between a liquid feed phase and a solid matrix (resin) containing ionisable exchange sites. Organic exchange resins have been well developed and wide range of both anion and cation exchangers are available. The resins are usually based on polystyrene or phenol formaldehyde polymers with incorporated 'active groups' forming the exchange sites.

Description of the process

Organic ion exchangers are used either in a bead form in a fixed bed arrangement or as a powder in conjunction with a filter. Organic ion- exchangers are prone to both thermal and radiolytic degradation which may limit their application. In addition, it must be remembered that organic resins are themselves quite complex organic chemicals and certain chemical conditions can degrade them. For example, there have been several incidents where their use with concentrated solutions of nitric acid have caused explosions.

Processes employing packed beds of ion exchangers usually consist of three main stages:

(a) absorption of radionuclides from feed solution onto exchanger;
(b) elution of radionuclides into a small volume of solution;
(c) re-conditioning of the exchanger.

Typically DFs between 10^2 and 10^3 can be achieved by ion exchange processes, often with volume reductions of several orders of magnitude. However, the process is restricted to feeds of low total solutes concentration ($< 1g/L$) except when selective exchangers are used.

The operation of fixed bed ion exchange processes nearly always requires prefiltration of the feed liquor to remove suspended material which could block the column or coat the resin beads and hinder access to exchange sites.

Advantages and limitations of ion exchange processes

Based on the experience gained from existing organic ion exchange processes and the more recent results from development studies, the application of such processes to the removal of activity from waste effluents would seem to offer a number of advantages:

(a) good decontamination factors ($> 10^2$) and large volume reduction factors (up to 10^3) can be achieved;

(b) organic resins are very suitable for use in columns; they possess good mechanical strength and are fairly easy to handle;

(c) resins can have high exchange capacities and in most cases they can be regenerated following elution of the absorbed activity. Hence, they are very suitable for the concentration of activity from a dilute solution. The concentrated effluent can provide the opportunity to recover the radionuclides or alternatively be routed with the intermediate or high level waste streams;

(d) high purity effluents can be achieved using ion exchange processes;

(e) ion exchange process technology is well developed and has been routinely used in the nuclear industry for a number of years.

Limitations to the use of organic ion exchange processes are:

(a) the resins show limited stability to chemical, radiolytic and thermal degradation which can severely restrict the conditions that can be employed in processes;

(b) in some cases particular resins may be used to achieve selective removal of radionuclides, but generally the effects of competing ions are great and processes can only be used for effluents containing low inactive solute concentrations (<1g/L);

(c) the final disposal of the spent ion exchangers may be problematic since restrictions concerning the nature of organic materials permitted in land repositories may necessitate their decomposition prior to disposal;

(d) generally the cost of organic resins is fairly high which makes the processes quite expensive compared to some of the alternative processes such as inorganic ion exchange or floc processes.

TABLE II.1. SUMMARY OF LOW LEVEL WASTE TREATMENT PROCESSES

Process	DF	Volume reduction	Advantages	Disadvantages
Evaporation	10^4-10^5	100-400	Simple process gives complete removal of active and inactive salts. Unaffected by complexants.	Expensive (20-50 × floc treatment). Unsuitable for large salt content streams. Foaming, corrosion and explosion are problems.
Precipitate	10-100 up to $>10^3$	20-50	Cheap. Flexible-chemical treatment. Can vary from batch to batch.	DF dependent on separation efficiency and complexants present. Usually need sludge de-watering pre-filtration required to remove particlates.
Ion exchange	Up to 10^4	10-100	High purity effluent. Well developed technology.	Expensive and may pose secondary waste problems. Organic resins have limited chemical and thermal stability.

II.2. OPTIONS FOR TREATMENT OF SOLID WASTES

The solid wastes at the WPSF which are considered here are:

- soft/combustible wastes;
- hard/non-combustible wastes;
- spent sealed sources;

Treatment processes for low level solid wastes, principally volume reduction processes have become increasingly important in the nuclear industries in Member States in the face of:

- rapidly rising disposal costs;
- more restrictive acceptance criteria for disposal;
- limited availability and capacity of disposal sites.

A number of methods have been employed which may be categorized as:

- thermal destruction, i.e. incineration;
- mechanical reduction, i.e. compaction.

These methods are discussed in this section with reference to the requirements in the WPSF [II.2, II.6–II.9].

The types, volumes and activities of solid waste to be treated in the WPSF were presented in Section 1 of this volume, and are briefly summarized here.

(a) It is expected that initial segregation of solid wastes will be performed at the waste producer as appropriate to the intended volume reduction process to be applied, i.e. compactable/non-compactable, or combustible/non-combustible.

(b) The expected volumes to be processed in these categories are:
compactable 20–80 m^3/year;
non-compactable 5–10 m^3/year.

(c) From experience, it is expected that the packing density of soft compactable waste in 200 L drums will be of the order of 110–160 kg/m^3.

These three points are now taken into account in assessing the solid waste treatment processes available.

II.2.1. Pretreatment

It has been noted earlier that 'good housekeeping' techniques should be actively encouraged at the waste producer. One of the techniques is to ensure that wastes are segregated as they arise, eg in the laboratory, separate bins may exist for compactable, non-compactable and 'sharps' wastes. The waste transfer documentation would record the type of waste in each package to enable it to be readily identified at the WPSF for appropriate treatment.

However, from experience, good housekeeping at the waste producer cannot be relied upon to ensure that no rogue waste packages arrive at the WPSF.

Any waste packages found not to meet the producers description should be reported, and appropriate actions taken to ensure that waste producers are made fully aware of the importance of accurate sorting. It is important to discourage waste producers by applying penalties for example, from relying on the secondary check at the WPSF rather than performing adequate sorting at source.

II.2.2. Thermal destruction

In this context, thermal destruction implies combustion or incineration and these terms will be used extensively in the remainder of the discussion.

Incineration is a state-of-the-art, proven volume reduction method that can make a significant contribution to the long-term management of low level radioactive wastes (LLW). The application of incineration at government, industry, institutional and commercial nuclear power plant facilities has proven to be both technically feasible and efficient and can be an economical part of a complete LLW management programme.

The technology for the incineration of LLW is a specialized and carefully engineered form of incineration developed to ensure essentially complete combustion of the burnable waste and positive retention of the radionuclides. The current technologies range from the common types of excess and controlled air incinerators, including fluidised bed systems to the advanced concepts of high-temperature slagging, molten- salt incineration, pyrolysis, and acid digestion. These LLW incinerators are highly efficient at controlling both radionuclide releases and conventional waste emissions such as acid gases, heavy metal compounds and toxins. In addition, the magnitude of these emissions is far less than the level of similar releases from fossil-fuelled or waste-fuelled power plants because of the relatively small volumes of waste processed in the incinerators.

Most modern incinerator systems have a number of common basic features. These include:

- waste feed system;
- combustor: primary, sealed (or sub-atmospheric) main combustion chamber with auxiliary heaters;
- afterburner: secondary, afterburning combustion chamber with auxiliary heaters. (Note: some systems do not have afterburners);
- ash collection system;
- dry and/or wet off-gas and fly-ash scrubbing/filtering system;
- off-gas release monitoring system.

Incineration systems also have a number of experienced-based limitations on operating parameters and waste input concentrations; although these limitations are not strict design requirements they do represent good practices that can minimize maintenance and monitoring requirements.

Currently accepted practices include:

- minimum primary and secondary combustion chamber temperatures, typically in the 500–1200°C range, to ensure complete combustion;
- maximum allowable input amounts of plastics (such as polyvinyl chloride) and sulphur-bearing wastes to limit the amount of chlorine to about 5–10 wt% and sulphur to about 1-5 wt% (to limit acid-gas formation to manageable levels);
- maximum allowable amounts of certain radionuclides such as tritium, ^{14}C and ^{35}S, which are weak beta particle emitters difficult to monitor in the off-gas stream.

The primary purpose of the combustion is the volume reduction of waste. At the same time combustion converts the waste to a form which is well suitable for the subsequent management steps, i.e. immobilization, transport, storage or even disposal. Combustion can also be used to reduce the chemical hazard associated with some radioactive wastes.

A large proportion of solid contaminated wastes produced in nuclear facilities is combustible and can be reduced substantially in volume and weight by incineration. Composition of incinerable waste includes paper and other celluloses, polyvinyl chloride, polyethylene and other plastics, latex neoprene and other synthetic rubber, animal carcasses from medical research facilities and incidental organic liquids.

In the past decade incineration technology has moved out of the laboratory and pilot-plant stages and is now being installed in numerous locations as accepted volume- reduction technology. Incinerators were initially employed in the nuclear industry to reduce the volume of low-level radioactive waste and to recover plutonium. Incineration facilities are now being installed in many countries that have nuclear facilities.

Incineration performance and conclusions

Typical incineration volume reduction (VR) ratios that are achievable range from 30:1 to 100:1, although some industry reports indicate that actual values of LLW stream VR ratios are closer to 10:1. These LLW stream VR ratios are very plant specific and may be lower than expected because of ash stabilization and packaging requirements, as well as because of difficulties or inefficiencies in separating combustible from non-combustible waste. By comparison, the competing technologies of compaction and super-compaction generally provide a 3:1 and a 8:1 reduction in volume, respectively. Even after the addition of ash stabilising materials and final packaging (i.e. using the LLW stream definition for the VR ratio), the incineration process is still 2 to 5 times more volumetrically efficient than super-compaction.

The treatment of combustible wastes by incineration to achieve a significant volume reduction has proved to be a safe and efficient operation over the last decade. This fact has been established by the great amount of experience gained by running various incinerators for radioactive waste in many countries and the large-scale use of incineration plants for domestic and other conventional waste. The modern plants tend to be simpler to operate than those built in the early days.

However, incineration has a number of disadvantages when considered in its application in the 'minimum' design for the WPSF principally:

(a) Using the WPSF design flowsheet figures for solid wastes, the net present values of incineration and no-incineration options are very similar. However, the up-front capital cost of incineration is much higher than the no-incineration option. It is expected that this high initial cost could be a major disadvantage to developing Member States.

(b) Other important criteria for the selection of processes are robustness, ease of engineering and safety. Under these criteria, the option not to incinerate is the preferred choice.

However, it is felt that incineration is adequately developed, and that for application in some Group C Member States, which may have larger volumes of waste to be processed, incineration may prove to be cost effective.

II.2.3. Mechanical reduction

Mechanical reduction or compaction of low level solid wastes is widely applied throughout the world. Compaction is a simple mechanical technique that can be used for the volume reduction of certain types of radioactive waste. The most suitable and usual feedstock material for compaction is solid low level waste (LLW).

The available compaction equipment can be divided into three groups depending on the compaction force that is applied. The three groups being low force, medium force and high force. Examples of these are low force in-drum compactors, medium force balers and high force supercompactors. A description of each of these types of compaction is given below together with a discussion of their application in the WPSF.

Low force compaction

The use of simple in-drum compactors is widespread in IAEA Member States.

The operating principle of these units is that a cylindrical drum loaded with suitable waste is placed vertically underneath an hydraulic press. The ram of the press, which is fitted with a circular platen of a size just less than the drum internal diameter, is lowered and this applies a force of a few tonnes to crush the waste. More waste is then put into the drum and the process repeated until the drum is full of compacted waste.

This compaction method is only suitable for soft and brittle waste such as paper, plastics and glass because the compaction force is low. Since the side walls of the drum retain the waste during compaction, hard wastes such as metals must be segregated before compaction to avoid the drum being damaged or punctured. However, some low force compactors use a retractable liner to prevent damage to the drum.

Typically 90% of the solid waste arriving at the WPSF is expected to be compactable, i.e. low force compactable.

Experience with in-drum compactors is that volume reduction factors of 3:1 can be achieved but this does depend on the nature of the waste being compacted and the degree of waste loading in a drum prior to compaction. Typically, final compacted waste densities of 270–480 kg/m^3 can be achieved.

The problems that can be experienced with low pressure in-drum compaction are that the compacted waste can recover or springback when the compaction force is removed thus reducing the volume reduction achieved and sharp or hard waste objects local to the drum wall can penetrate the drum skin. Springback can be prevented by the use of retaining plates placed on top of the waste but this does increase the cost of the process. Compactors are available which include a cylindrical steel sleeve which fits inside a drum and in which the waste is compacted. This sleeve prevents damage to the drum wall by any sharp objects and is withdrawn prior to the final lidding of the drum.

In-drum compactors are inexpensive conventional plant items to purchase and operate (capital cost approximately £6,000 for a basic unit). They can be supplied and operated as free standing units within a safety case and an off-gas cleaning system.

High force compaction

The application and use of low pressure in-drum compaction is well established but the types of wastes that can be processed by this method are limited. To enable a wider range of materials to be processed by compaction and to increase the volume reduction achieved, considerable interest is being shown in the use of high pressure compaction. The types of machine being considered are commonly known as supercompactors and these apply a compaction force of 1000 to 2000 tonne to crush whole drums.

The principles of the operation of a supercompactor are that waste contained with cylindrical drums is placed within a thick walled mould which is a close fit around the drum, a hydraulic ram then crushes the drum within the mould using a high force to produce a cylindrical pellet or 'hockey-puck' of substantially reduced height.

The main advantage of supercompaction is that, with the much higher forces involved, it is possible to achieve useful volume reduction of hard wastes that are not amenable to lower pressure compaction and which are not presently volume reduced. Steel wastes such as pipes and electric motors can be processed by supercompaction. As a general principle, if solid waste is contained within a drum and hence will physically fit within a supercompactor then it is suitable feedstock material.

Volume reduction factors achieved with supercompaction can vary from 2 to 20:1 and can typically be a mean of 8:1 for a mix of wastes, but this does depend on the nature of the material being treated and the degree to which the drum was filled prior to compaction.

The supercompaction process crushes the drum and hence the containment integrity of the drum will be reduced (indeed, the drum is deliberately pierced) leading to potential contamination of the outside of the drum and of the compactor surfaces. Also, with the high forces involved, it is possible to express small quantities of liquid from even seemingly dry wastes (and it is most important that wet wastes are not supercompacted). Supercompactors are fitted with gaseous and liquid effluent provisions and experience indicates that contamination control is not a significant problem. Because the compacted pellets are potentially contaminated externally they have to be handled accordingly and overpacked or packaged to allow further handling, transport and disposal. Any overpacking can have the effect of reducing the volume reduction achieved.

Supercompactors can be operated as either fixed or mobile plants. A unit permanently installed at a fixed location can treat waste transported to it from a number of waste producing sites or a mobile plant can visit and process waste on individual sites.

In comparison with low pressure compactors, supercompactors are substantial and more complex machines and this is reflected in the higher capital and operating costs (i.e. capital cost could be of the order of about 0.75M).

Comparison of compactor performance

The performance of compaction units is often expressed in terms of the volume reduction factor (VRF) that they can achieve, defined as the ratio of:

$$\text{VRF} = \frac{\text{volume of waste before compaction}}{\text{volume of waste after compaction}}$$

This term can sometimes be misleading as the volume reduction that can be achieved for a particular waste depends on the nature of the waste, e.g. paper, wood, rubble, metals, and the packed density of the waste prior to compaction. For example, high force compaction of paper, plastics and wood can achieve final compacted waste densities close to the actual bulk density, i.e. ca 1000 kg/m^3. Therefore, a 200 L drum containing 20 kg of loose paper (i.e. a density of 100 kg/m^3) could be compacted to achieve a VRF of ca 10, whilst another drum containing 100 kg of paper (i.e. a density of 500 kg/m^3, i.e. stacked with phone directories) could be compacted and would only achieve a VRF of ca 2.

The difference between the final waste densities achieved by the three compaction methods is due not only to the different compaction forces used, but also due to the ability of the different compaction processes to resist 'springback' of the waste once the compaction load is removed. With high force compaction of drummed waste, the deformed drum contains the waste and restrains it against springback. However, with in-drum compaction there is usually no restraint of the waste. The waste therefore has a degree of 'springback' after each compaction.

It follows from this that, for high force compaction, better volume reduction factors can be achievable by compacting mixed waste i.e. hard and soft waste together rather than compacting the two types separately. This is because the soft waste will fill the voids which would otherwise occur in the pellet of compacted hard waste, whilst the hard waste will restrain the 'springback' of the soft waste.

Although the actual composition of the waste to be handled in the WPSF is not known, it is possible to estimate the performance of the low and high force compaction processes in dealing with the WPSF waste using assumed typical VRFs of 2.5 for the compactable component by low force compaction, and 6 for all the solid waste using high force compaction. The following results are achieved:

		Vol after compaction (m^3/year)	
Waste type	Vol. (m^3/year)	Low force	High force
Compactable	80	32	13.3
Non-compactable	10	10	1.7
Total	90	42	15.0

These figures, however, do not represent the final outcome. After compaction, the wastes will go to storage. In-drum compacted waste is suitable for direct placement in store. High force compacted drums of waste will be surface contaminated and will require additional packaging/overpacking before storage. The assumed VRF of 6 for high force compaction takes into account this overpacking.

Conclusions on selection of type of compaction process

Three compaction processes employing low, medium or high forces have been examined for application to solid waste treatment in the WPSF.

High force compaction offers superior performance to the other two methods, and substantially removes the need to sort solid waste prior to processing. However, high force compactors are expensive items of equipment, and favourable economics in operation are only obtained by high utilization. The volumes of waste to be processed by the WPSF require only approximately 5 days of operation per year by a high force compactor, based on a typical throughput capacity of 90 drums/day.

Low force in-drum compaction can be performed by a variety of equipment. The common features of this equipment are:

- relative low cost;
- reasonable volume reduction for soft waste only;

- simple and safe operation;
- adequate throughput for WPSF requirements.

The economics of in-drum compaction have been demonstrated to be more favourable than high-force compaction or direct storage. The selection of a particular in-drum compactor type is now considered.

II.2.4. The preferred option of a solid waste treatment process

The table below ranks the volume reduction processes discussed in this section and in Sections AII.2.2 and 2.4 in terms of the scale of operation required for each process to be the most economic.

	Process	Volume of waste at which process is most economic (m^3/year)	
		Soft	Hard
1.	No Volume Reduction	<30	10
2.	In Drum Compaction	>30	10
3.	Supercompaction	>80 and	>25
		or >135	>10
4.	Incineration	1700	>100

These results are not unexpected, and are supported by observation of a general trend within developed Member States in the past 5–10 years in the increasing adoption of supercompaction in preference to incineration for the treatment of solid wastes.

The processes are also ranked in order of robustness, ease of engineering and safety.

For the volumes of solid waste to be processed in the WPSF, in-drum compaction is the preferred process.

An interesting alternative which may be worth pursuing in certain Member States is the possibility of hiring a mobile supercompactor as a service. This alternative has a number of advantages:

(a) There is no large initial capital cost for purchase of equipment.

(b) The responsibility for tackling the criteria of robustness, ease of engineering and safety is held, at least partly, by the service operator.

(c) There is a great deal of flexibility in when the service is performed. Waste drums could be accumulated in the store before they were compacted. As a maximum, probably only one service visit per year would be required. As a minimum, only one visit may be required immediately prior to disposal when the store would be emptied, the waste compacted and then sent to disposal.

II.3. OPTIONS FOR TREATMENT OF OTHER WASTES

The principal waste types which fall into the "other wastes" category in the WPSF are:

- ion exchange resins (0.5 - 1.0 m^3/year);
- animal carcasses (0.1 - 0.2 m^3/year);
- organic liquids (0.1 - 0.3 m^3/year).

These wastes represent only a very small proportion of the total volume of waste to be processed in the WPSF. In Member States with nuclear power programmes the volumes of these types of streams can be significant and specialized waste treatment processes have been developed, e.g. incineration/pyrolysis for ion-exchange resins and carcasses, wet oxidation and electrochemical processes for organic liquids). However, because of the small volumes, specialized treatment processes are not expected to be merited on the grounds of economics and complexity.

Incineration could be considered for treatment of these wastes, although installation of an incinerator for one or more of these streams alone would not be economic. However, if an incinerator were installed for the treatment of all combustible solid waste then this could also be used for these three waste streams. In the absence of an incinerator, the preferred waste treatment process for ion exchange resins, carcasses and organic liquids is direct encapsulation.

II.4. OPTIONS FOR CONDITIONING OF WASTES

After waste materials have been treated to achieve volume reductions and to recover valuable (active or inactive) components, they have to be conditioned for transport, storage and disposal. Conditioning is the waste management step at which radioactive wastes are immobilized and packaged.

Immobilization involves the conversion of wastes to solid forms that reduce the potential for migration or dispersion of radionuclides from the wastes by natural processes during storage, transport and disposal.

The immobilization processes involve the use of various matrices, non- radioactive materials such as cement, bitumen and polymers, to fix the wastes as monoliths, usually directly in the waste containers used for subsequent handling.

The matrix materials must be adapted to:

- the radioactive components in the wastes (types and half-lives of radionuclides, specific activities, radiation levels, etc.);
- the chemical and physical properties of the waste materials (liquids, sludges, ion-exchange resins, solids, etc); and
- the behaviour of the package with regard to disposal conditions.

As the matrix materials and the immobilization processes are selected, careful consideration of safety-related features must be given to identify any constraints or incompatibilities; awareness of these safety features and appropriate counter-measures will enhance the safety of routine operation of the processes and subsequent handling, transport, storage and disposal.

Primary barriers for confinement and limiting the release of radionuclides are formed during the immobilization process. Important properties for these barriers are:

Compatibility with the waste;
Homogeneity;
Low solubility;
Low permeability;
Mechanical strength;
Resistance to external agents (chemical, biological, etc);
Resistance to heat and radiation;
Stability during storage.

In addition, matrix materials should be relatively easy to handle and should not dilute the wastes excessively, resulting in high immobilized waste volumes relative to those of the untreated waste. Finally, the selection of the matrix materials should take into account the local, national or international industrial availability and the relevant economics.

The immobilization options considered here are:

(a) hydraulic cements;
(b) bitumen.

II.4.1. Immobilization in cement

The use of cement for the incorporation of low and intermediate level radioactive wastes in cement and associated materials is widespread.

The main reasons for using cement are:

The relative simplicity of handling;
Extensive experience in civil engineering operations;
The availability of raw material;
The relatively low cost;
The high density (shielding effect) and the mechanical strength of cement products;
The compatibility of water with the matrix material.

The word 'cement' is applied to a broad range of products; the cements referred to in this section are hydraulic cements basically made of calcium silicates and calcium aluminates.

A number of variants of hydraulic cements can be used for waste immobilization.

(a) Ordinary Portland cement (OPC)

Ordinary Portland cement is produced by heating clay minerals at high temperatures (1480°C) with lime. In the correct proportions these minerals form a 'clinker' which when cooled, mixed with gypsum ($CaSO_4.2H_2O$) and pulverised, is termed cement. By adjusting the proportions of raw materials, the cement formulation can be adjusted to influence such properties as strength, time of setting, generation of heat and resistance to shrinkage. OPC is produced by a number of companies in the UK to a specification laid down in BS 12 and BS 6100. This specification is broad enough to cover variations in the processes and raw materials used by various producers.

The cement water reaction is exothermic and proceeds through three stages — a colloidal 'sol', a gel and in the final curing stage the process is characterised by the formulation of a network of interconnected tubular fibrils which impart strength to the concrete.

A variety of materials have been used as additives in cement to facilitate incorporation of certain waste types or to improve waste form properties. Absorptive and ion exchange properties make some suitable for radionuclide retention. Other additives alter the characteristics of the waste or the behaviour of the cement to allow the incorporation of waste which would normally hinder cement solidification.

Blast furnace slag (BFS) and pulverised fuel ash (PFA) are two such additives which are blended with OPC.

(b) Blast furnace slag

Blast furnace slag is a by-product of the manufacture of iron. It is formed by the fusion of limestone (and/or dolomite) and other fluxes with the ash from coke and the siliceous and aluminous residues remaining in the iron ore after reduction and separation of iron. After rapid chilling by water, the granulated blast furnace slag is ground to produce a powder with a similar particle size to OPC.

Although BFS possesses hydraulic properties, its reaction with water is very slow at ambient temperatures. To enable hydration to proceed at an acceptable rate, continued dissolution must be promoted by either chemical or thermal activation. The most popular method is by blending the BFS with OPC.

(c) Pulverised fuel ash

Pulverised fuel ash (PFA) is a waste material produced during the burning of coal in a power station. After combustion the ash is separated from the effluent gases. The finer particle fraction is normally used for concreting and grouting purposes. The main chemical constituents are silica and alumina. PFA is not hydraulic and requires activation by $Ca(OH)_2$.

II.4.2. Incorporation into a bitumen matrix

Bitumen is a mixture of high molecular weight hydrocarbons obtained as a residue in the refining of petroleum or coal tar. Because of the differing source materials and treatments, bitumen is a range of thermoplastic materials and can behave mechanically as either a viscous liquid or a solid depending upon these thermoplastic properties. The incorporation of waste into bitumen relies upon the thermoplastic properties.

The bitumen is heated in the presence of the waste, with the heat serving both to liquify the bitumen sufficiently for mixing and to evaporate the water from the active liquid waste. The waste solids are thus mixed and coated with bitumen in a liquid state and when cooled are mechanically held in a solid bitumen matrix. A process variant is the emulsified bitumen process where a solvent is used to liquify the bitumen at room temperature. The water in the active waste is then removed thermo-mechanically while mixing the waste with bituminous material and the mixture solidifies as the solvent evaporates.

The characteristics of bitumen as matrix material for the incorporation of radioactive wastes present the following advantages:

Insolubility in water;
High resistance against diffusion of water;
High chemical inertness, except oxidation;
High biological inertness;
High plasticity;
Good rheologic properties;
Good behaviour towards ageing;
Rather good stability against radiation;
High incorporation capacity leading to good volume reduction factors; and
Material abundantly available at a reasonable cost.

Nevertheless, as an organic material bitumen has the following disadvantages:

Decrease of viscosity as a function of temperature leading to a softening of the matrix that melts at temperatures > 100°C;
Combustible, although not easily flammable;
Possibility of chemical interactions with certain waste components (i.e. nitrates, nitrites, etc.);
Low heat conductivity; and
Tendency to swelling.

The disadvantages of bitumen can be counterbalanced by appropriate selection of the operational conditions such as:

Incorporation temperatures considerably lower than decomposition temperatures;
Appropriate pretreatment of the concentrates to be incorporated;
Fire-proof installations and provisions of fire-fighting equipment.

Whilst there are a number of waste forms which can be satisfactorily incorporates into bitumen, compatibility with nitrates is poor and some waste forms have given fires. There is also a potential fire hazard associated with bitumen packages during storage on-site, transport and ultimate disposal. Up to 1980 there had been three process fires involving bitumen being used for waste immobilization. In view of the safety considerations when processing intermediate active waste from reprocessing plants at high temperatures or with flammable solvents, those special requirements have to be taken into account.

II.4.3. Discussion of conditioning options

After considering the available immobilization processes, the cementation route was chosen for wastes in the WPSF because of:

(a) The radiological and industrial safety of the proposed cementation process and of the eventual waste form.

(b) The need to choose a process that is as simple as possible, and which is proven by many years of operating experience.

(c) The absence of secondary waste streams generated by the process.

Although the cement process will produce higher waste volumes than some other processes (i.e. bitumen) the lower activity content per container and the higher self shielding reduces the store shielding requirement and the shielding required on any future transport operation. Also, absolute waste volumes are relatively small so this volume difference is not significant.

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