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RESEARCH ESTABLISHMENT

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A CONCEPTUAL DESIGN STUDY OF A LOW THROUGHPUT REPROCESSING FACILITY FOR NUCLEAR FUEL

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ABSTRACT

The idea of reducing fuel reprocessing costs by changing reprocessing plant design philosophy is explained. It is shown how a significant reduction in unit reprocessing costs can lead to earlier recovery of nuclear material. A classification is given of some existing nuclear chemical reprocessing plants as a function of their maintenance philosophies.

The feasibility of the rack concept is discussed for application to a conceptual low throughput reprocessing plant specifically designed for reprocessing fuel from the A.A.E.C.'s Dido-class reactor HIFAR. Laboratory and design development work is described. Preliminary cost estimates are given for a site at the Research Establishment, Lucas Heights, with maximum use of existing facilities, services, and plant.

The study did not reveal any technical difficulties that would make the rack concept impractical. The concept of indirect maintenance for items of equipment which are likely to require frequent attention is technically feasible, and it appears possible to remove racks for repair of equipment by normal direct maintenance techniques.

Additional development followed by plant construction and operation would be necessary to verify these conclusions and to establish any cost advantages. However, the cost estimates deduced at the start of the study did not change substantially during the course of the work.

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1. INTRODUCTION

Since Australia is a comparatively long way from countries that have plants for reprocessing reactor fuel elements, the Australian Atomic Energy Commission has been interested in studying the prospects for establishing such a plant. For reactor systems involving the reclamation and eventual re-use of unused or generated fissile material, fuel reprocessing costs need to be known since this is an essential part of the estimation of fuel cycle costs when determining the cost of nuclear power.

Recently the opportunity was taken to study a design philosophy which might result in lower costs and a preliminary design of a low throughput facility to reprocess fuel from the reactor HIFAR at Lucas Heights was attempted.

This report summarises the work done during a one year study, and outlines some modifications to and development of the new design philosophy. The plant described is of pilot scale compared with existing plants.

2. DESIGN PHILOSOPHIES FOR LOW-THROUGHPUT FACILITIES

The minimum economic size of reprocessing plants has been the subject of much discussion. For the present study it was necessary to consider this subject and understand the reasons why the development of a newer design philosophy for small-throughput facilities has economic significance for power reactor systems.

Excluding considerations such as the desirability of establishing the technology in a new field, the question whether it is worth while to reprocess spent fuel from natural-uranium reactors, to recover the various plutonium isotopes, involves study of three major economic factors:

(a) The cost of alternative nuclear fuels.

(b) The availability and economics of a system in which the recovered plutonium can be used.

(c) The cost of recovery of plutonium.

For example, in the heavy-water moderated natural-uranium reactor system the fuel is stored until one of the above factors is more favourable for reprocessing and recycling. Thus the rising cost of alternative fuel could make recovery and re-use of the plutonium economic or a more efficient system might be developed for using the recovered fissile material (e.g. fast breeders) thereby increasing the market value of the plutonium. Then again the cost of recovery of the plutonium might be reduced.

2.1 Reduction of Cost of Recovery of Plutonium

The importance of reducing the cost of separation and purification of plutonium is illustrated in Figure 1, which gives the predicted costs of processing natural or low enrichment fuels for several conventional plants. As might be expected, some correlation exists between the costs for the various plants. The O.R.N.L. data of Harrington et al. (1964) given in the figure are based on their extrapolation of an earlier Du Pont study (Farrow 1961) but we have used modified capital charges of 15 per cent. The extrapolation of the Du Pont data by Harrington et al. is based on estimated capital and operating data for one plant of 10 short tons U per day capacity adjusted to include facilities for krypton removal, conversion of UNH to UO_3, and a silo system for the storage of UO_3. The extrapolation was done by using a 0.15 power relationship between capital cost and throughput. The Harrington et al. data also include a small correction for a plutonium loss in the plant of 0.25 per cent, with plutonium valued at $U.S.6.70/g Pu. The U.K. data (Franklin et al. 1964) are assumed to be based on actual costs for Magnox fuels in the new Windscale plant. If a 10 year sinking fund depreciation and 7½ per cent interest are assumed then the capital charges included in the U.K. costs would be virtually the same (15 per cent) as the modified Harrington et al. data.

The effect of a reduction by a factor of two in the reprocessing costs of conventional plants for assumed lower throughputs is also shown in Figure 1. This assumes that a more economical design philosophy can be found.

If such a design is feasible, reprocessing facilities could be provided earlier in a power reactor installation programme than commonly believed. A marked reduction in the size of plant and hence reduction in initial capital outlay could be achieved.

For example, Figure 1 indicates that if the plutonium produced from the natural uranium heavy water reactor example given, could be sold, or used, for a value of $A10/g fissile, and if a new philosophy enabled unit costs to be halved, "economic" processing would be possible at a plant throughput of 0.48 tonnes per day. This corresponds to 1300 MWe installed capacity instead of a 1.1 tonne per day throughput and 3000 MWe based on conventional philosophies. However alteration of capital charges used in the calculations would have a considerable effect on these breakeven points.

If all the data were available, Figure 1 could give a graphical solution indicating when reprocessing is truly economical. However, in its present form, which only shows trends, it indicates clearly that there is an incentive for reducing processing costs.

2.2 Maintenance Philosophies of Existing Plants

Reprocessing of power reactor fuels on a large scale has only recently commenced and is carried out in several countries to recover generated plutonium and unburnt fissile uranium. The plants have been expensive and this is a function of their design. The designs that have been used can be classified by plant maintenance philosophy which may be direct or indirect. (See Table 1).

TABLE 1

COMPARISON OF DESIGN PHILOSOPHIES

DIRECT MAINTENANCE	INDIRECT MAINTENANCE
1. Long shutdowns	1. Equipment generously spaced for manipulators
2. Duplication of equipment	2. Shielded volumes large and piping runs long
3. Large cell volumes	3. Equipment costs high due to remote installation requirement
4. Equipment designed for decontamination	4. Equipment and piping nozzles must be accurately located
5. Equipment spaced liberally	5. Special remote manipulators needed
6. Shielding volumes large	
7. Long piping runs	
Examples	Examples
1. Old Windscale Reprocessing Plant	1. Marcoule Pilot Plant
2. New Windscale Reprocessing Plant	2. Hanford Production Facility
3. Dounreay Fast Reactor Reprocessing Plant	3. Savannah River Production Facility
4. Dounreay Materials Test Reactor Reprocessing Plant	4. EBR II Fuel Cycle Facility
5. Indian Plutonium Reprocessing Plant	
6. Eurochemic Reprocessing Plant	
7. Idaho Chemical Reprocessing Plant	
8. Nuclear Fuels Services Inc. Plant	

In direct maintenance the equipment is first decontaminated to reduce radiation levels so that personnel can work on equipment without the need for shielding. The very high radiation levels lead to slow decontamination and long plant shutdowns. To maintain high on-stream usage, whole sections of the plant must be duplicated and equipment must be designed for rapid and efficient decontamination. The equipment must also be well spaced so that personnel can move around the equipment and therefore larger plant volumes have to be shielded and contained, and much greater lengths of piping are required.

In indirect or remote maintenance the equipment is designed so that tools can be used from behind suitable shielding. This limits the need for plant duplication and decontamination. However, because of the very serious limitations imposed by remote manipulations, equipment must be generously spaced. This increases both the shielded volume of the plant and the pipe-work connecting various items of equipment. Equipment and installation costs increase greatly, because the need for remote installation of all items including much of the piping requires accurate location of all equipment and piping nozzles and a complicated system of disconnects and carefully balanced piping jumpers.

2.3 Advantages of the Rack Concept

With the rack concept (Unger et al. 1967) it should be possible to take the advantages of both direct and indirect maintenance with few of their disadvantages. This could be achieved by accepting indirect maintenance for equipment likely to require frequent attention, but allowing removal of racks for repair of major items by normal direct maintenance techniques. Costs predicted for this concept are plotted in Figure 1 and indicate a cost reduction of about a factor of 3 on the extrapolated cost of a plant for the same throughput but designed using a conventional philosophy.

It must be emphasised, however, that verification of this newer idea and the predicted lower costs could only be obtained by actual construction and operation of a plant since capital cost savings might well be offset by increases in operating costs, due to such factors as a lower plant availability than predicted.

In the design study which follows, the rack concept is applied to the specific problem of processing the enriched uranium fuel from the reactor HIFAR.

3. DEVELOPMENT OF A FLOWSHEET FOR A PLANT TO REPROCESS HIFAR FUEL

3.1 Flow Sheet Description

Initial plant throughput was selected as 240 fuel elements per year (32.8 kilograms of uranium) which would be twice HIFAR's expected output if operating at 15 MW.

Early in the study it was decided to use aqueous methods rather than halide volatility methods for recovery and purification of the uranium, mainly because it was concluded that aqueous techniques were further advanced than available volatility techniques. Complete dissolution of the cropped fuel element was selected, giving a feed solution of about 3 grams of uranium per litre, containing about 2M aluminium. This was preferred to mechanical disassembly and then dissolution, to avoid the complications and expense of a mechanical head-end resulting from the variety of designs of fuel elements, used and projected (Figure 2).

The process flowsheet (Figure 3) is very similar to the Dounreay process (Buck et al. 1958), except for lower uranium concentrations due to the greater quantity of aluminium dissolved per element.

The following plant operation was envisaged:

Dissolution:	1 element per day, 5 days per week, 8 hours per day
Solvent Extraction and Product Evaporation:	1 week per month, 24 hours per day

Reconversion: 3 weeks per month, 5 days per week, 8 hours per day.

One element would be charged into the dissolver each week day. After dissolution and analysis, the solution would be transferred to a holding vessel before purification by solvent extraction. This operation would not require shift work. Two-cycle solvent extraction purification, performed continuously one week in four, is necessary because of the type of equipment involved, the time necessary to reach equilibrium conditions, and the need to limit aqueous-solvent contact time in order to minimise radiation damage to the solvent.

All operations after solvent extraction can be performed without shielding in glove-box enclosures. The product solution from solvent extraction would be evaporated to a concentration of about 200 grams per litre, the uranium precipitated with ammonia, and the resultant ammonium diuranate filtered, washed, dried, calcined and reduced to uranium dioxide. The reconversion section of the plant would operate during the three-week period between solvent extraction runs.

An estimate of the active waste arisings for the plant, based on the data given in Figure 3, is as follows:

Type of Waste	Quantity (litres/month)	Approximate Level (Ci/litre)
1. High level liquid	1300	130
2. Intermediate level liquid	2500	1
3. Low level liquid	200	< 0.1

The intermediate level waste would be concentrated by evaporation by a factor of about 10, with an overall decontamination factor of greater than 10^4. The first cycle raffinate and the evaporator concentrate would be stored in high level holding tanks pending development of a suitable waste fixation process. Low level waste would be discharged through an existing low level treatment plant.

Initially it was considered that silicon present in the brazing alloy used to fabricate the fuel elements, and radio-silicon produced by neutron reactions with the aluminium would result in difficulties of clarification of the feed solution to liquid-liquid extraction. However, experimental dissolution work with unirradiated sections of fuel elements, together with nuclear calculations, showed that the total amount of silicon present would be less than ten grams per element. It should be possible to maintain this amount of silicon in solution under the acid deficient conditions of the flowsheet selected. This avoids the problem of a mechanical clarification step before solvent extraction.

3.2 Solvent Extraction Development

Total dissolution having been selected, it was necessary to make a detailed examination of available equilibrium data and operating conditions to reduce the solution volumes handled while ensuring adequate decontamination.

Two major factors influencing the selection of feed concentration are:

(a) A maximum solubility of 3.0M Al is obtainable in a 1.2M acid-deficient solution.

(b) Increased acid deficiency increases the solubility of aluminium. However, the reaction rate of the dissolution reaction falls rapidly with increasing acid deficiency.

Because of the lower uranium to aluminium ratio, McCabe-Thiele calculations were carried out to determine the stage requirements for the extraction system. Since the first cycle extraction –

scrub extract is very similar to the Dounreay flowsheet, the first cycle strip and complete second cycle were not considered. The calculation for the first cycle extraction is given in Figure 4.

3.3 Analytical Requirements

A summary of the results of an assessment of the analytical requirements including process, criticality and accountability controls is given in Table 2.

TABLE 2

SUMMARY OF ANALYTICAL REQUIREMENTS

Type of Determination	Approximate Number Required per Month
Uranium concentration	190
Gross $\beta\gamma$	130
Free acidity or alkalinity	110
Cations other than uranium	100
Miscellaneous determinations (e.g. solvent purity, α or γ spectrometry)	60

This table does not include the requirements for analysis of raw materials, since these are limited in scope and number, nor analyses undertaken during any laboratory developmental work.

3.4 Corrosion

Since corrosion in the plant can lead to expensive maintenance and replacement of equipment the corrosion resistance of proposed construction materials must be evaluated carefully. The selection of a material for an item must take account of the construction materials and conditions in adjacent equipment even if this means in some instances using a higher quality material than is strictly necessary. Furthermore the variety of materials in the whole plant should be limited to reduce chances of galvanic attack, and to simplify manufacture.

The materials considered for the more corrosive regions of the plant included stainless steel types 304L ($<$ 0.03% carbon), 309SCb (0.08% carbon) and 347, titanium, and proprietary alloys similar to Incoloy 825. Both titanium and Incoloy 825 have superior corrosion resistance for many applications but are more expensive than the stainless steels. The use of Incoloy 825 for the dissolver would have permitted the dissolution of other fuels such as Zircaloy clad uranium dioxide. However, for this initial design study the stainless steels were considered to be adequate.

The preliminary selection is given in Table 3. Corrosion tests would be necessary to confirm the materials selected for the more corrosive environments.

4. FACILITY DESIGN

To keep capital costs to a minimum the facility was designed to be adjacent to a new hot cell block at the Lucas Heights Research Establishment. This would enable sharing of such facilities as change rooms and decontamination and maintenance areas, avoid duplication of services such as demineralized water, and simplify the handling of highly active samples requiring analysis which could be done in one of the cells of the new block.

Installation of equipment for active areas of the plant was based on the design study of Unger et al. (1967). The rack concept they described was modified and developed in some detail

TABLE 3

PRELIMINARY MATERIALS SELECTION

Component	Environment	Material	Remarks
Ambient Temperature Regions	Acidic and alkaline solutions and organic compounds at room temperature. Hot decontaminating solutions	Stainless steel types 304L or 347	
Steam Jets and Heaters	HNO_3 and $Al(NO_3)_3$ solutions at temperatures up to 200 °C	Stainless steel types 304L or 347	Used for short periods only
Dissolver and Condenser	HNO_3 and $Al(NO_3)_3$ solutions at temperatures up to 120 °C	Stainless steel type 304L	
Off-gas Scrubber	Nitrogenous gases and warm NaOH solutions	Stainless steel types 304L, 316 or 347	
Product Evaporator	Uranyl nitrate solutions up to 120 °C	Stainless steel types 304L or 347	Contamination of the product may necessitate a more resistant material. Titanium and glass have been used elsewhere (Lindley 1963)
Rework Evaporator	HNO_3, NaOH, $Al(NO_3)_3$ and $UO_2(NO_3)_2$ solutions and organic and sulphur compounds at temperatures up to 120 °C	Stainless steel type 304L	The extent to which this item would be used is not known
Waste Evaporator	$Al(NO_3)_3$, HNO_3 and NaOH solutions and organic and sulphur compounds at temperatures up to 120 °C and higher	Stainless steel type 304L	This item may experience the most severe corrosion conditions in the plant. Corrosion tests may indicate the use of a more resistant material such as titanium or Incoloy 825
Waste Storage Tanks	HNO_3 and NaOH solutions and organic and sulphur compounds at temperatures less than 50 °C	Stainless steel types 304L or 347	

in the present study. It combines the direct and remote maintenance techniques, utilizing the best features of both schemes and very largely eliminating their disadvantages. It is particularly suited to small plants and provides many advantages which show as reduced costs for both the facility and the equipment. Modular racks containing all the necessary equipment, piping and instrumentation are prefabricated in the workshop and lowered into simple shielded cells. Interconnections with services are made by using disconnects placed at the top of each cell. The many lines that must enter the cells come through narrow slits at the top of the cells and they can be replaced simply.

4.1 Building Layout

Figures 5 and 6 show a plan and section of the facility and indicate how it would be integrated with the hot cell block. It is divided into five main areas depending on the degree of possible contamination. The cells containing the process equipment for dissolution, solvent extraction and waste

handling are placed below ground level with removable concrete roof plugs. They are not designed for personnel entry, and access is only via the roof. Obviously the cells could become highly contaminated and each one has a sump to collect spillage. The cells are set out in line to give good crane coverage and to simplify construction.

The second area is the space above the cells and includes the sampling area in a small annexe between the cells and the rear of cell area for the hot cell block. It also would be an area of high potential contamination and is separated from the rest of the facility; controlled personnel access to it is provided either from the control room or through the active change rooms via the rear of cell area in the hot cell block. The risk of contamination in the space above the cells whenever a cell is open is overcome by allowing sufficient space to erect temporary tenting above the open cell in order to control the contamination movement.

In the third area, for reconversion, the chances of contamination are slight, since the operations would be carried out in gloveboxes. However, it is expedient to limit personnel access, and separate it from the fourth or control and cold make-up area. Because of the need for routine monitoring of metering pump operation and solution volumes it is wise to place the cold make-up area adjacent to the main control panel. Stirred heated vessels for solution make-up have been provided for in an alcove off the main control room. There should be no problems with contamination in this fourth area despite the piping leading from the control panel and cold make-up tanks directly to the cells, since particular attention would be paid to the detailed design of interconnections between this area and the cells.

The fifth area is the plant area for the provision of ventilation and services. Apart from the active filters, much of the equipment can be in the open because contamination is not a problem.

Figure 7 gives two views of a 1/12 scale model built during the study. It is an early arrangement of the cold make-up and reconversion areas located in-line with the cells and illustrates the rack concept, with installation below ground level.

4.2 Services and Ventilation

No design work has been done on the provision of services or ventilation, but it is believed that most of the services required can be supplied from existing site supplies with a minimum of new equipment. A new compressor would be required but standby compressed air could be provided from available sources to ensure operation of instruments during emergency shutdown of the main plant compressor. Cooling water would be provided from a separate cooling tower to avoid the possibility of contaminating other site facilities. Demineralized water can be supplied from the unit in the hot cell block and only a new storage tank is required.

The ventilation system would be designed to control the movement of contamination out of potentially high contamination regions, by ensuring that any air movement is towards the area of greatest contamination. This can be achieved by pressure control. The control room, reconversion area and filter room would be at a pressure slightly less than ambient so that any leakage of air is from the outside into these areas. The space above the cells would be at a lower pressure and the cells at an even lower pressure. Piping bulkheads would effectively isolate the cells from each other and the two interconnecting ducts. This means that air movement would be from, say, the control room to the space above the cells and into the cells. Exhaust air from the cells would be filtered before being vented via a high stack. Air coming into the facility would be pre-filtered to reduce the load on the active filters. The exit filters would consist of both roughing and absolute filters. Whether all the air entering the facility would pass out through the cells has not been determined.

Vessel off-gas systems would have to be kept at pressures below that of the cells. This would minimize the chances of contamination escaping from the vessel system and avoid any disturbance to the vessel system as a whole either during transfers from vessel to vessel or during any disturbance in a particular vessel. These are not large capacity systems and it should be possible to maintain them by using jets to vent into the main cell off-gas system.

4.3 Rack Installation

The racks containing the equipment for dissolution, solvent extraction and waste handling have been designed to be very compact to reduce the size of cell needed, and,hence,the volume of shielding and containment, and also the length of interconnecting piping. Such close spacing is made possible by shop fabrication which is also much cheaper than field fabrication. Because of the modular design of the racks it is possible to test the equipment thoroughly before installation.

The installation philosophy envisages two main types of maintenance. Firstly, such items as mixer settler drives, pumps, steam jets and valves can be expected to give trouble in continuous service and would require regular maintenance. They have been so placed on the frame that they can be seen and reached with long tools from the cell top and they would be connected into the plant piping with disconnects. Should one of these items fail in service, it would be possible, following limited decontamination of the equipment in the cell concerned, to lift a section of the roof and replace the item by making and breaking the disconnects with long tongs and suitable tools. It could then be decontaminated and repaired, or disposed of. Most normal maintenance can be handled in this way with only limited plant decontamination and minimum downtime. The need for expensive equipment duplication is thereby eliminated. Secondly, if a major plant failure occurred, the whole rack could be decontaminated and removed from the cell for maintenance and repairs. This would be a major operation involving considerable plant shutdown but would be infrequent if reasonable precautions are taken with equipment design and fabrication.

Figure 8 is a view of the scale model of the second cycle cell rack.

4.3.1 Description of rack

Each of the four racks would be constructed from four inch diameter stainless steel tube in the form of a hollow rectangle 10 ft high and 4½ ft wide.

All process tanks would be welded to the frame through gussets and cross members as shown in the typical rack layout, Figure 9, while mixer settlers, pumps and steam ejectors would be bolted to supports and placed as near the frame top as possible for ease of maintenance. A full size mock-up of the second cycle frame is shown in Figure 10.

A stainless steel tray containing a sump would rest on the cell floor and be high enough to contain all the liquid within the equipment on the rack.

The rack would be suspended, say, four inches above the cell floor at two points near its top with provision for slight longitudinal adjustment. Lifting of the whole rack would be via its corners using eye bolts. A separate lifting sling would be necessary for each frame, each sling adjusted for length so that correct balance could be maintained when removal of the frame was necessary.

4.3.2 Rack removal

After the initial installation and startup each rack should not have to be replaced or repaired during the life of the plant. However if removal for repairs were necessary the interiors of all vessels would first be flushed out and decontaminated using various chemical solutions with live steam as the heating medium. Next, the roof plugs would be removed, and a tent to control contamination erected above the open cell. Then any contamination on the outside of the vessels would be hosed off into the liquid containment tray within the cell and transferred from the cell sump to either the waste cell for concentration and disposal, or if this is the inoperative cell, to the medium level waste tank.

Both sides of the bulkhead disconnects would be accessible once the shielding panels over the ducts and the roof plug above the piping slit had been removed. The compression tube bulkhead unions could then be broken. This operation could be performed directly on the inactive side, since the unions would be shielded from any areas of very high activity. On the active duct side

it may be necessary to keep some distance from the unions due to activity. This would mean that an extension wrench would be required and this should be quite feasible since there would be only one row of disconnects on that side.

Once all the connecting pipes had been disconnected the whole frame and attached pipes could be lifted clear with a sling, then clad in plastic, and transferred by trolley to the decontamination and maintenance area in the hot cell block.

There should be little activity present when the frame is being replaced. Hence the more difficult tasks of aligning the frame, relocating all the pipes in their bulkhead unions and restarting the nuts, could be done directly.

4.3.3 Equipment and piping connections

All tanks would be manufactured with their necessary standpipes welded in situ, the pipes projecting say six inches above the tank top. Connection of all active and inactive pipes to these standpipes would be by welding.

All equipment that would need regular maintenance or replacement would be connected to the process pipework by single disconnects of the same type as designed for the Trans-uranium Facility at Oak Ridge National Laboratory, Figure 11, (Mackey 1963). This equipment would be situated as near as possible to the top of the frame.

4.3.4 Cell top and shielding layout

The cell roofs are designed to prevent radiation shining out of the cells and also to provide ventilation control between the cells, and the above-cell area. The roof consists of major concrete roof plugs running the length of each cell with minor plugs to key the larger plugs together (Figure 12). The longest plug is 10 ft long and would weigh about 6 tons. It could be handled easily by the 10 ton crane installed above the cells.

Active and inactive service ducts for general piping (Figure 5, items 19 and 22) have been provided for on either side of the cell and shielded with roof plugs of a thickness proportional to the expected activity that the duct might have to carry under all circumstances.

The active duct would be next to the active sampling area, Figure 5, item 12, and the inactive duct is next to the control and cold make-up area, Figure 5, item 25. The duct cover area would also be useful for a walkway if for any reason the major roof plugs had been removed from any cell and a tent built over the cell for contamination control.

Both ducts have been designed for personnel access and so limited shielding from the cell is necessary. This is achieved by providing concrete shielding near the top of the cell, by having the top of the frame at least one foot below the "service slit" and by arranging that the pipes run through this "slit" in one horizontal layer to the active duct and two horizontal layers to the inactive duct. Thus the minimum "slit" height would be three inches and if necessary some lead shielding could be incorporated around the pipes within the "slit" to lower the radiation levels in the ducts. Spread of contamination from the cell through the slit is prevented by the bulkheads.

Where the "service slit" enters the ducts the pipes all terminate in a bulkhead via a compression tube fitting so that when the cell frame is to be removed the whole five major roof plugs must be removed and the pipes running in the "slits" must be disconnected from the bulkhead fittings.

4.3.5 Regular equipment maintenance

Cell equipment requiring regular maintenance has been placed near the top of the cell. By removing part of the roof after only limited decontamination, it should be possible to gain access to this equipment. Once sufficient experience has been gained it should be feasible to plan routine replacement of this type of equipment, thereby avoiding non-routine plant shutdowns. However it is hoped that the time required to replace any of the items would be short and not a serious interruption of the production schedule.

Steam jets are typical of this type of equipment. They will erode and corrode but within certain limits this will not affect their operation; eventually they would need to be replaced. A planned maintenance programme could use the 3 weeks in the month downtime in the solvent extraction and waste sections, and the weekends for the dissolver cell, to replace the jets.

As the steam jets would all be placed in the centre of the cell frame in vertical banks, see Figure 13, it would only be necessary to remove the centre major roof plug. Removal of the steam jets would be accomplished by undoing the three ORNL single disconnects associated with each jet using a long right-angled drive socket wrench which has already been successfully tested under inactive conditions.

Should the radiation emanating from the 2 ft wide by 10 ft long opening be excessive, temporary shielding could be used to protect personnel from that part of the opening not in use. Such an operation should be relatively simple to accomplish once the necessary skills have been evolved and would require only limited decontamination of equipment to reduce radiation exposure to personnel.

4.3.6 Equipment decontamination

High levels of radiation are expected in the cells even after the equipment has been thoroughly flushed out. Decontamination would therefore be necessary before equipment could be reached for maintenance. Despite much design effort to make maintenance infrequent, provision must still be made even for these occasions. It must be possible for equipment to be adequately flushed and washed out and special decontamination solutions added when required.

Most equipment can fairly readily be emptied without special design. However special provision must be made for the emptying of each stage of the mixer settlers. This should be possible by siphoning through an extra line to each stage. Where decontamination is required or emptying by normal methods is not feasible due to equipment malfunction, temporary connections could be made to lines in the inactive duct. This can be done by removal of the inactive duct cover without the likelihood of overexposure to personnel. In this way, even under emergency conditions, it would be possible to empty, flush and decontaminate all items before removal of any sections of the cell roof.

5. MAJOR EQUIPMENT DESIGN

The designs proposed for major equipment such as the dissolver, contactors, evaporators, and high level waste tanks are now described.

5.1 Dissolver (See Figure 14)

5.1.1 Material of construction

Stainless steel type 304L, Incoloy 825, and titanium have been considered as materials for the dissolver. The preliminary selection is stainless steel type 304L subject to satisfactory corrosion testing in experimental equipment.

An estimate of the thickness of the body of the dissolver can be made using the following assumptions:

(a) A general corrosion rate, at the boiling point, is 0.04 inches per year. This conservative rate is based on a summary of published corrosion results.

(b) Six hours of boiling is required for each dissolution.

(c) No corrosion occurs if the solution is not boiling.

(d) No pitting occurs.

(e) There is no increase in corrosion rate associated with welds.

With these assumptions 0.07 inches of metal would be consumed in ten years if one element were dissolved on each of 250 days per year. Thus, for a body thickness of ½ inch the safety factor, based on the assumed corrosion rate, would be about seven.

5.1.2 The diplegs

Using the same assumptions as for the body thickness of the dissolver the wall thickness of the diplegs would be 1 inch allowing for corrosion on both sides of the dipleg wall. Such diplegs of non-standard piping would be very expensive and since they would not result in a breach of containment on failure a lower safety factor has been accepted. Enquiries have shown that stainless steel type 304L diplegs can be made from commercially available tube with a wall thickness of 0.59 inches, representing a safety factor of four, based on the assumed corrosion rate.

The instrumentation diplegs were narrowed at their outlets without a reduction in wall thickness. This increases the stability of the manometers by reducing the size of the air bubbles emerging from the dipleg.

The nine submerged diplegs are:

2 exhaust lines, terminating in the dissolution product storage tank and the diverter pot in the waste handling cell

1 air sparger

1 steam sparger

1 sample line

2 level and density probes

2 spares, one being narrowed for use as a level and density probe.

Only one thermocouple well is considered necessary. In contrast with the open diplegs, corrosion of the well should be significant only on the outside. A wall thickness of ½ inch, equal to that of the body of the dissolver vessel, was therefore selected.

The four pipes that open into the top of the vessel consist of:

1 sample return line

1 chemical inlet line from the cold make-up area

2 spares.

5.1.3 Heat transfer rates

High temperature saturated steam, which provides rapid heating rates, (162 °C, 95 p.s.i.a.) would be used to heat the dissolver. Temperatures greater than 130 °C in the dissolver are not considered to be hazardous because there should be no organic compounds in the dissolver cell.

Using some simplifying and conservative assumptions it was estimated that the initial charge of water could be heated to boiling in less than ten minutes. Again with simplifying and conservative assumptions, the time to cool the dissolver contents from boiling to 40 °C was estimated to be about two hours.

5.1.4 The hydrogen hazard

Hydrogen released during the dissolution can be a serious fire and explosion hazard. This is particularly so for acid deficient dissolution because of the large volume of hydrogen released.

Laboratory tests showed that as much as 2.4 litres/minute of hydrogen at S.T.P. may be released during the dissolution. This amount could change markedly depending on the acid deficiency and the dissolution procedure. Further work would be necessary to determine the hydrogen release rate more accurately and to determine what sparge rate of air would be required for safe dilution of the off-gas.

5.1.5 The dissolver off-gas system

The dissolver off-gas system has not been designed. An important factor in its design is the air sparge rate which is not known.

It is expected that the off-gas would be scrubbed with a solution of sodium hydroxide to remove the soluble oxides of nitrogen. This would be done best in a packed tower. The rest of the gases including oxygen, hydrogen, nitrogen, oxides of nitrogen and insoluble fission products, mainly krypton, could probably be exhausted to the atmosphere. Iodine would not be a problem because of the long cooling time of the fuel.

5.2 Mixer Settlers

The choice of contactor type was governed largely by the requirements for reliable remote operation and limited head room. Of the various devices for this type of service only mixer settlers were judged suitable.

5.2.1 Design

In designing mixer settlers for this plant an attempt was made to achieve the following objectives:

(1) Stages capable of handling total flow rates of 3.1 to 11.8 litres/hour without flooding.

(2) High stage efficiencies to reduce the number of stages necessary and hence reduce the contactor size.

(3) Achievement of these high efficiencies in the smallest possible stage size for further reduction of contactor space requirements.

(4) Mechanical and structural reliability of a high order to enable extended periods of remote operation without maintenance.

(5) Hydraulic stability to be automatically maintained in the event of a number of malfunctions occurring, e.g. partial port blockage, stirrer failure, change of flow rates or flow ratios.

Following a survey of mixer settler types, the device considered most promising was the K.A.P.L. pump-mix unit originally described by Caplan and Davidson in 1948 although greatly modified since then. In this design, enhanced interfacial stability was attributed to the "make-and-break" action of the impeller dip tube or suction leg with the liquid interface. This principle would certainly be effective in large mixers where some large variation in interface level can be tolerated. However other workers (for example Baillie and Cairns 1960, Lowes and Williams 1954) did not find the technique satisfactory as the sole means of ensuring interface stability in small scale units. Mixing tests have shown that vortexing of the aqueous phase causes most of this problem and this can be overcome by insertion of a vortex-breaking baffle below the impeller dip tube.

Although not yet applied to box type mixer settlers in plant practice, the idea of using balanced internal aqueous weirs between stages has shown considerable promise in laboratory contactors. Units of this type were successfully operated under hot cell conditions (Klitgaard and Goode 1965) and also in the purification of U233 (Baillie et al. 1967). This technique

reduces the effect of impeller pumping on the level of the aqueous phase in the preceding settler by allowing preferential recirculation of organic phase when the interface falls below the weir. Thus loss of interface due to excess pumping action or reduced aqueous flow rate becomes less likely.

After consideration of the flowsheet requirements it was decided to adopt a pump-mix design following the conventional box-type of construction but incorporating both vortex-breaking baffles and balanced internal aqueous weirs. Sizing of the unit was based on performance data published by Caplan et al. (1951), Lowes and Williams (1954), Klitgaard and Goode (1965) and Baillie and Cairns (1960). The design flow rate was fixed at 5 litres/hour with a phase ratio of O:A = 1:1. A residence time for mixing was selected from the literature as 1.5 minutes, and the settling area was fixed by adopting a minimum design settling rate for complete phase separation of 1.0 in/min. The resulting stage size was 1½ inch wide by 4 inch high by 6 inches long, allowing an increase in length of 1 inch over the calculated 5 inches as an additional safety margin.

In order to test this design in principle, a 10 stage Perspex mixer-settler bank (Figure 15) was constructed and fitted with individual d.c. motors to drive the impellers. A number of impeller designs were examined and three types were tested. These are also shown in Figure 15. The prototype mixer settler was fitted with the Mark II type which gave reasonable mixing and good pumping performance at speeds greater than 1000 r.p.m. but subsequent mixing and pumping tests showed the Mark III unit to be capable of better performance at somewhat lower speeds. The balanced aqueous weirs were constructed in such a way as to simplify their manufacture from Perspex. For this prototype no attempt was made to provide a design which would be free from blocking.

5.2.2 Performance testing

The hydraulic stability of the design was tested using diluent/water feeds and found to be very satisfactory for the present application. Hydraulic stability was maintained up to 6 litres/hour total flow rate at 1000 r.p.m. impeller speed, and to total flows in excess of 9 litres/hour at 1400 r.p.m. Minor modifications to impeller design and port sizes would enable the design objectives to be met.

Considerable latitude was found to exist in the operating range of the mixer settlers. For given speed, annular baffle size, and port size, the limits of operation are set by loss of interface at low flows and flooding at high flow rates. For the current design the stable operating range extended over a ratio of nearly two to one for both flow rate and impeller speed. The actual position of the operating range could be selected by varying the effective pumping rate using different sized annular baffles. The best size for the present application was found to be ⅞ inch dia. and the flooding tests cited above used this value.

In a preliminary test run simulating the extraction section of the second cycle contactor and using a feed containing 10.5 g/l uranium and 5.6 M with respect to nitric acid, an overall stage efficiency of 70 per cent was obtained. Somewhat higher efficiency would be expected using the Mark III impeller design but this has not been tested in the prototype mixer settler.

5.3 Evaporators

Three evaporators are required, a product evaporator to concentrate the decontaminated uranyl nitrate solution from the second extraction cycle, a rework evaporator to concentrate solutions requiring recycle, and an active waste evaporator to concentrate the second cycle aqueous raffinate and the condensate from high level waste fixation.

5.3.1 Product evaporator

The function of the product evaporator is to concentrate the uranyl nitrate solution containing 25 g U/l, 0.2 M HNO_3, 100 μCi/l fission products from the second extraction cycle, to a solution containing approximately 200 g U/l and 1.3 M HNO_3.

The evaporator has to meet the following requirements:

(1) It must be critically safe for enriched uranium at any aqueous concentration.

(2) It must be capable of an evaporation rate of about 4 litres/hour at a steam pressure of not more than 30 p.s.i.g., a limit set by the possibility of an explosive reaction between entrained or dissolved tributyl phosphate solvent and nitric acid at temperatures above 135 °C.

(3) The feed solution must be steam stripped to remove any traces of tributyl phosphate and solvent.

(4) Adequate de-entrainment must be obtained to allow the distillate to be discharged directly to the low level waste stream.

(5) The evaporator control system should be simple and reliable.

A vertical tube, natural circulation type evaporator was selected (Figure 16). One leg of the evaporator is jacketed to allow steam heating and provide rapid circulation of the liquid in the vessel. The liquid level, and specific gravity if required, can be determined by pneumatic dip tubes in the relatively stable, non-boiling, return leg of the evaporator.

The evaporator is designed to allow construction from standard 304L stainless steel pipe sizes. Simple Raschig ring packing is specified for the steam stripping and de-entrainment column. The evaporator would be operated semi-continuously by maintaining a pre-determined liquor depth and evaporating until the required density is obtained.

All components of the evaporator, steam strip and de-entrainment column, and condenser would be fabricated from 304L type stainless steel. Welding would be performed under an argon atmosphere in accordance with specially prepared weld specifications. All welds would be radiographed.

Based on a maximum corrosion rate of 0.004 in./year (Loudry and Ullmann 1960) the concentration of corrosion products in the uranyl nitrate product would not exceed 23.0 p.p.m. iron, 6.0 p.p.m. chromium and 3.5 p.p.m. nickel.

5.3.2 Rework evaporator

The rework evaporator has been included in the reprocessing plant to concentrate aqueous uranyl nitrate solutions from the first and second extraction units which are out-of-specification. The major difference in the operation of this evaporator compared with the product evaporator is the high level of radioactivity associated with the feed solution. For this reason the rework evaporator must be located in a shielded cell and remotely operated.

The need for remote operation necessitates a simple, reliable control system, and operating equipment. The final design for the rework evaporator would be made only after rigorous evaluation of control systems, feed steam stripping methods, de-entrainment devices, sampling procedures, and other equipment, using a prototype of the product evaporator.

5.3.3 Waste evaporator

The waste evaporator is used to concentrate the second cycle aqueous raffinate containing 3.3 mCi/l of fission products in 5 M HNO_3.

The activity of the feed solutions would be such as to require remote operation in a shielded cell. Also, corrosion due to high nitric acid concentrations would be more severe than in the product or rework evaporators.

Published information is sufficient for selection and design of the waste evaporator but the final design would be made only after evaluating the performance of the prototype product evaporator, particularly the control system and vapour de-entrainment device.

5.4 High Level Waste Tanks

The liquid wastes which could not be accepted by the existing site facilities due to excessive activity would be held in tanks until a process was developed to solidify them for permanent storage.

The two types requiring separate storage facilities and processing techniques would be:

(1) First cycle raffinate which would have activity levels about 128 Ci/litre and would generate heat at 0.6 to 0.7 watts per litre, requiring cooling. The annual quantity would be approximately 3,200 gallons.

(2) Evaporator concentrates which would have activity levels about 1 Ci/litre and would not require cooling. The annual quantity would be approximately 600 gallons.

The initial installed tank capacity should be adequate for a minimum of two years plant operation with a spare tank available to hold the contents of any one tank in the event of failure, and for plant flexibility, all the tanks should be identical and of 3,200 gallons capacity.

Two ways of achieving the design requirements were investigated (see Figure 17).

(i) Arrange all tanks in a sealed concrete vault under a suitable depth of earth for shielding. Cooling would be effected by coils inside the tanks, immersed in the liquid. The secondary containment would be a stainless steel lining to the vault sufficient to contain the complete installed tank volume in case of catastrophic failure.

(ii) Encase the tanks in an outer jacket which would form the secondary containment, with cooling water circulated in the jacket space to remove the heat generated in the wastes. The tanks would be placed on a concrete pad laid in the bottom of an excavation and buried under the necessary earth for shielding.

It was decided to proceed with the second concept for the following reasons:

(a) reduced cost,

(b) no problems of sealing a vault against ground water,

(c) difficulty of fabricating and installing cooling coils in a tank-in-vault system,

(d) ease of installation of future extra tanks,

(e) the walls of the jacketed tanks would be kept at a lower temperature than those of tanks in a vault, and this would reduce the corrosion rate.

The possibility and consequences of fire, chemical explosion, seismic activity and criticality were considered and it was concluded that the jacketed tanks could be designed to be safe under any of these conditions.

6. AUXILIARY EQUIPMENT DESIGN

The term auxiliary equipment covers a very wide range of items. At this stage not all have been investigated. Attention was concentrated on items that are crucial to the design philosophy, such as pumps, and those involving large costs, such as instrumentation. Individual items and some of the development work are discussed in the following sections.

6.1 Metering Pumps

Two types of metering pumps would be required; inactive area pumps, and remotely operated pumps which would be installed in the hot cells.

(a) Inactive area metering pumps. These would be required to pump liquids such as dilute and concentrated nitric acid, aluminium nitrate and sodium carbonate. Flow rates range from 2.0 ml/min. to 30.0 ml/min., and outlet pressure requirements are low. The cheapest pumps available which could pump the above solutions and yet give an accuracy of 2½ per cent were found to be piston metering pumps.

(b) Remotely operated and controlled metering pumps. Requirements for these are fairly stringent. Features required are:

- reliability, with maintenance limited to once a year or less,
- absolute leak-tightness, as the solutions being handled would have activities as high as 145 Ci/litre,
- accuracy of at least ± 2–3 per cent,
- facilities for remote disconnection,
- a negative suction head of ten feet.

The pump selected as the most promising was a remote head diaphragm pump. A similar pump was extensively tested and performed most satisfactorily. One problem with this type of pump is the need to keep the head and regulation chamber connected to avoid recalibration problems. This makes pump maintenance and removal from the cell difficult.

6.2 Steam Jet Pumps

Steam jet pumps are the most suitable for parts of the plant where active solutions have to be transferred and not metered, radiation fields are high, and the pump sites inaccessible . Their advantages are:

(i) minimum maintenance required,

(ii) reliable – no moving parts,

(iii) ease of control,

(iv) can be made entirely of metals – materials resistant to radiation.

Their main disadvantages are:

(i) dilution of solution by condensed steam,

(ii) heating of solutions,

(iii) low pressure output.

A steam jet pump was developed which has the characteristics shown in Figure 18. The solution temperature seldom rose by more than 15 °C and this was not considered troublesome. Figure 19 shows the principal dimensions of the steam-jet pump selected. No opportunity was available for corrosion testing of steam jets but it is thought that stainless steel types 304L or 347 should be satisfactory as discussed in Section 3.4.

6.3 Air Motors

To save both space and initial cost the use of air motors to drive the mixers in the contactors was investigated. They have a high torque and power to weight ratio and can be used safely in hazardous environments especially since they can withstand stalling for long times without overheating. Each stage could have an individual motor with air fed through an orifice

in a common manifold in order to reduce the number of air lines entering the cells (Figure 20). Alternatively, one motor could drive a bank of mixer settlers through a gear train but this is an undesirable complication to the equipment in the cells.

Since commercially available air motors need a mist of oil in their supply air for adequate lubrication, the exhaust air from the motors would need to be filtered before venting into the off gas system. Two brands of air motors were tested. Some difficulty was experienced in the testing programme in obtaining a uniform dispersion of oil in the supply air, but both brands performed very well.

6.4 Sampling

Because of the design of the cells and the high activity of some process solutions, the sampling system must be a remotely operated type of great reliability.

Some of the requirements of the sampling system are listed below:

(i) Samples to be lifted a total of approximately 20 ft.

(ii) Adequate shielding to be provided for all sampling points.

(iii) Reliability necessary, since maintenance is limited, and the control and safety of the plant depends on the ability to take samples whenever required. Simplicity of overall design, including safety features, is therefore required.

From a brief literature survey to obtain a cross-section of remote sampling practices in radiochemical plants, it was decided to make a preliminary test of a non-recirculating or single-line system, and a recirculating system.

Figure 21 shows the features of the single-line system which was tested. The liquid being sampled fills the collection pot after passing through the sample bottle. This provides washing of the sampling line. The liquid in the collection pot is then returned to the process vessel. Five or six of these cycles were necessary to ensure representative sampling of the process liquid, and automatic cycling was provided by a synchronous motor driving cam-operated micro-switches. These operated the appropriate solenoid valves.

The recirculating system shown in Figure 22 which was also tested, used an air lift to recirculate liquid up the sampling line, through the sample bottle, and then down a large diameter return pipe, where liquid and air separated. A vacuum applied to the overall loop provided the necessary submergence for the air lift. A five to six minute recirculating period provided a representative sample.

Further development would be required before final selection of the liquid sampling system.

6.5 Instrumentation

Because the cells housing the equipment are behind concrete biological shielding without viewing windows, operators would have to rely on their instruments in order to run the plant successfully. Full information about tank liquid level, the density of the liquid and occasionally its temperature (required in evaporators and heaters) would be essential and in specialized locations other variables such as pressure may need to be measured and indicated to the operator. High accuracy would be required for liquid level and density measurements in order to carry out fissile material accounting satisfactorily.

The most commonly used system for measuring tank liquid level and density in plants of this type is the pneumatic dip tube (see Figure 23) whereby a continuous low-rate purge of gas is kept issuing from the bottom of a tube below the liquid surface and the gas pressure needed to keep the gas bubbling through the liquid is measured. This system or modifications of it were selected for further study and experimentation.

The system is such that the pressure in the tank is automatically subtracted from the gas pressure by the use of a balance line connected to the air space above the liquid in the tank. Density is determined by measuring the pressure difference in two purged dip tubes set so that the purge gas outlets are a set height apart. The system has been modified by various people in attempts to increase accuracy. One method suggested was to place the purge gas inlet to the dip tube in the tank itself close to the dip tube outlet. This modification was designed to reduce the error due to pressure drop in the pneumatic lines. For density systems, increased accuracy has been attained using a "reference" leg which had the effect of restricting the range of the instrument.

A limited testing programme of the various systems has indicated that the basic conventional system would be satisfactory. Better than 1 per cent accuracy was obtained in these tests both for level measurements down to a level of 6 in. and for densities over the range 0.74 to 1.34 g/cm^3. A cheaper system, not having a gas flow in the liquid level "balance" tube, would also be satisfactory provided that the tubes used were not less than ¼ in. i.d.

Some work has been done to ensure that adequate space is provided in the control room for the required instrumentation. Figure 24 shows a typical control panel layout for one of the cells. A semi-graphic type of panel arrangement is used. The differential pressure cells required would be placed on racks adjacent to the control room wall but in the above-cell area. The diaphragms of these differential pressure cells can then act as the barrier between the atmosphere in the process vessel and the clean air in the control room. Should an instrument line from an in-cell tank have to be broken for maintenance, contamination would be confined to the above-cell area.

6.6 Disconnects

As discussed in Section 4.3 disconnects are required to enable equipment to be removed from the cells for replacement or repair. For equipment requiring frequent maintenance, quick acting disconnects like those developed by O.R.N.L. for the Trans-uranium Processing Facility (Mackey 1963) are required. However, for process lines requiring only infrequent breaking, compression tube fittings and other types of ganged and single disconnects can be considered. To ascertain the most suitable design for the HIFAR reprocessing plant, samples of each type were tested under simulated plant operating conditions.

The O.R.N.L. type disconnect ferrules were machined from 18–8 Ti stabilised steel according to the recommended design (Figure 11). These ferrules were then tested either in mated pairs with the O.R.N.L. clamp or in a bank of twelve mated pairs with the O.R.N.L. ganged disconnect. A standard ½ inch union was used to test the compression type of fitting.

The disconnects were leak-tested with air, kerosene and steam at pressures up to 100 p.s.i.g.

6.6.1 Single quick-acting disconnect

Satisfactory sealing of this disconnect was obtained for at least eight consecutive closures with a clamp bolt loading of 30 ft.lb. Although a small air leak of approximately 1 cm^3/hour was observed in the pneumatic tests at 100 p.s.i.g., no discernible leak was apparent with further testing in pressurised kerosene.

Thermal cycling tests with saturated steam at 100 p.s.i.g. had no deleterious effects on the performance of the disconnect ferrules or clamp.

The clamp, mounted either in the vertical or horizontal plane could be operated successfully at vertical distances of approximately six feet, using an extension wrench. Consequently, as no difficulty should be experienced in operating this type of clamp remotely, the design of the minor process equipment and associated pipework can be based on the single O.R.N.L. disconnect.

6.6.2 Multiple ganged disconnect

Six pairs of ferrules were tested in the gang clamp, using a bolt loading of 35 ft. lb. Under these conditions, considerable buckling of the two ¾ in. thick clamp plates occurred and resulted in a slight air leakage from the middle disconnect ferrules. Consequently, incorporation of the gang disconnect in the plant does not appear to be practical because of the excessive cost involved in designing and manufacturing more rigid clamps for this type of disconnect.

6.6.3 Single compression tube disconnect

Perfect sealing with a ½ inch pipe union was obtained for at least twelve consecutive closures with either pressurised air, kerosene or steam. However, as a tension of at least 50 ft. lb. was required to obtain perfect closure with this fitting, remote operation would appear to be very difficult. Consequently, this type of fitting can only be used where ready access to the sealing nut is available.

6.7 Vessels, Piping and Sparging

No detailed design work has been done on the many tanks in the plant although they have all been sized. Most vessels and piping would be made from stainless steels type 304L or 347 as discussed in Section 3. In addition plastic piping would be used in areas such as the cold make-up area in order to reduce costs. Pipe sizes vary from ⅜ in. o.d. for instrument lines up to 1 in. and 2 in. o.d. where large volumes of solution must be transferred in short times.

Where agitation is required, it is proposed to install air spargers. These are less efficient than mechanical mixers but have the important advantage of not requiring much maintenance because of the lack of moving parts.

The high level waste tanks would require agitation and therefore air sparge units or internal air lifts have been suggested. In this application, the agitation must be sufficient to prevent solids settling out. If this were to occur, the temperature of the tank would rise resulting in a greatly increased corrosion rate. It is imperative that the agitation provided be adequate and failure free.

7. SAFETY

Careful consideration must be given to safety aspects during the design of a project of this type. The possibility of fire and explosion in various parts of the plant, the control of radiation, contamination and criticality have to be assessed. This section outlines the early ideas on some of these points but it must be realised that ideas change as design proceeds; sometimes design changes alter the hazard; sometimes a hazard will force changes in design.

7.1 Criticality Control

With the type of flowsheet and operating schedule envisaged it is not practicable to maintain criticality control simply by designing all items of equipment to be geometrically safe. Where feasible, this, of course, has been done. In some parts of the plant it is necessary to rely on mass limitation and for this purpose the plant can be conveniently divided into several sections. When mass limitation is the main method of control, it is very important to allow for possible accumulations of fissile material in the system under consideration. These accumulations show up as a discrepancy between the amount of fissile material entering a section and the amount leaving the section and this can occur by fissile material being left in the system or through errors and uncertainties in measuring volumes of liquids in vessels and the concentration of contained fissile material. When the possible accumulation in a system reaches a predetermined maximum figure it is necessary to carry out an exhaustive cleanout of the system.

7.1.1 Dissolver system

The fissile content of the fuel element under consideration is about 90 grams and one element would be charged per dissolution. As the minimum critical mass of fully enriched U235, fully water

reflected, is about 820 grams, it should not be difficult to maintain control of criticality in the dissolver system by mass limitation. Administrative procedures would control the element charging. Mass balances over the system, allowing for errors in measurement of fissile content, would be made to determine the maximum accumulation.

The reflux condenser is designed to drain automatically into the dissolver and is of geometrically safe dimensions. Nevertheless provision for cleanout would be made. Although the chances of fissile material entering the spent caustic soda tank are remote, it must be considered as part of the dissolver system and exhaustively cleaned out together with the rest of the system.

7.1.2 Dissolution product storage tank

This vessel would not be geometrically safe and it is proposed that the product of up to 20 dissolutions be stored in it (that is, about 1.8 kg of fissile material). Under normal conditions, the solution would be safe owing to its low concentration, which would have been checked both in the dissolver before transfer and in the storage tank after transfer.

Two mechanisms which theoretically could result in concentration of fissile material in this vessel are evaporation and precipitation. The former is not considered credible since there are no means of heating the vessel except fission product decay. Since there is a volume change of the order of a factor of six involved, it would be simple to detect it and provide for an alarm on tank liquid level.

Precipitation could occur if alkalis were added to the tank in sufficient quantities. The amount of alkali required is very large and it is expected that such additions to the tank could be prevented by administrative control. A secondary safeguard would be an efficient sparging of the tank, thereby keeping any precipitate well dispersed. Experimental work is needed on both the conditions for precipitation and the sparging system, to be fully confident of this approach to criticality control.

7.1.3 Solvent extraction

Since there is no accounting point for fissile material between the first and second cycle solvent extraction steps, it is necessary to consider criteria for criticality control for both cycles in conjunction. The two dilute product tanks have been designed to be geometrically safe for all concentrations of fissile material. The rest of the solvent extraction equipment including mixer settlers, raffinate tanks, solvent tanks and the like are treated as one unit for which criticality control is achieved by mass limitation in the same way as the dissolver system.

As the input to the system is very low (about 15 grams of fissile material per hour), it should not be difficult to obtain mass balances across the system. The regular cleanout of the system required by this type of criticality control would be more difficult than the dissolver system because of the greater number of items of equipment. However, as the system only has to operate for one week each month, this should present no serious limitations on plant operation.

7.1.4 Waste handling

All items in the waste handling cell can be considered as belonging to one system and criticality control would be ensured by mass limitation. Similarly the high level waste tanks would use mass limitation. This is feasible because of the very small concentrations of fissile material normally discharged to these tanks.

7.1.5 Reconversion area

This falls into two parts; firstly the product evaporator including its condenser and associated tanks and secondly the remainder of the reconversion system. The product evaporator system is designed to be geometrically safe for all concentrations of fissile material.

The subsequent reconversion operations would be carried out batchwise, the size of the batch being metered in a geometrically safe metering pot. The batch size would be chosen to suit the operating schedule but must be small enough to prevent any problems arising from double batching.

7.2 Fire and Chemical Explosion

Naturally very great care would be taken in the detailed design to minimize the possibility of fire and explosion. The likelihood of a fire occurring in the cell areas, in the absence of a nuclear excursion or chemical explosion, is very small for the following reasons:

(1) In the dissolver and waste cells, no inflammable material would be present during normal operations.

(2) In the solvent extraction cells, where there would be, at any one time, a total of about 40 gallons per cell of organic liquid, no heat source would be present during normal operations. The likelihood of a static buildup in, and discharge from the mixer settlers, causing a fire in the solvent extraction cells, is small, since all equipment components would be grounded through the rack.

Assuming a fire did occur in the solvent extraction cells, and assuming the mixer settlers were open topped, the organic liquid present would burn. This would result in vaporisation of organic as well as the aqueous phase, and fission products would be volatilised. The extent of dispersal to the atmosphere would depend on the performance of the high efficiency filters, the dilution effect of the stack, and the speed with which the fire was extinguished.

However, the mixer settlers would be designed as sealed units and it is difficult to imagine a fire occurring in such sealed vessels, inside the cells. Organic liquid would have to spill from a vessel into the cell and be ignited for a fire to start. The quantity burnt would be that which escaped from a faulty vessel or line by leakage. Fission product vaporisation would be that contained in the organic phase spilt before the fire was extinguished. If this is an accepted mechamism for an in-cell fire, then damage to equipment by fire could probably be slight.

Design and installation of fire-proof absolute filters is feasible and has been accomplished elsewhere. A fire in a cell should not result in loss of the absolute filters in the system. A dry CO_2 system appears to be the most appropriate method for extinguishing in-cell fires. However, depending on the design of the system, a fire extinguishing system may be a greater hazard than the fire itself, and one point of major concern with a CO_2 system is the possible over-pressurisation of the cells, causing fission product release from the cells.

A fire in the reconversion area is unlikely except in the event of inadvertent production of pyrophoric uranium dioxide powder. This area could be handled in the usual way by having available in the glove box, quantities of inert powder for extinguishing any fire, or if considered necessary, by having a CO_2 extinguishing system available.

Explosion is possible, but highly unlikely, in both the dissolver cell and the waste cell. No conceivable mechanism exists for explosion in the solvent extraction cells. Because of the use of hydrogen in the reconversion area, it must be considered that an explosion is possible in this area.

Nicholls (1959) considered that an in-cell chemical detonation equivalent to 3 lb of TNT would be credible in this type of plant and could be used as a conservative approach for design of cells. Such an explosion would result in severe damage and destruction of equipment in the cells. The cell roof plugs would lift, but these could be restrained if required. Depending on the efficiency of the sealing around the roof plugs, fission product release to the secondary containment above the cells can be minimised. However, it has yet to be established whether absolute filters could be designed and installed to prevent rupture by explosion, or whether venting into adjacent cells or another pressure relief volume would be more appropriate.

8. COSTS

Preliminary cost estimates have been prepared for the plant. These were made in sufficient detail to be confident that no major item was omitted but they are not based on detailed design of any equipment. Further, they were made before developmental work began. Capital costs are given in Table 4.

TABLE 4

CAPITAL COST ESTIMATE

		$A	
1. Building and Cells			
Conventional building and cells		95,000	
Ventilation		58,000	
Services		51,000	
Contingency (20%)		41,000	
Design fee (11%)		27,000	
	Sub-Total		272,000
Sampling cell and system		22,000	
Service plugs		35,000	
Element transport flask		10,000	
Contingency (25%)		17,000	
	Sub-Total		84,000
2. Equipment			
Delivered Equipment			
Dissolution		29,100	
Cycle 1 solvent extraction		23,950	
Cycle 2 solvent extraction		25,300	
Waste handling		19,650	
Cold make-up area		22,300	
Reconversion		11,600	
	Sub-Total		131,900
Rack construction and equipment installation			
Dissolution		17,600	
Cycle 1 solvent extraction		18,900	
Cycle 2 solvent extraction		20,100	
Waste handling		11,000	
Cold make-up area		17,700	
Reconversion		14,300	
Rack installation		4,000	
	Sub-Total		103,600

	$A
Additional piping costs	52,500
Instrumentation (30% of delivered equipment)	40,000
Special equipment	20,000
Contingency for item 2, (25%)	87,000
3. High Level Waste Storage Costs	
Cost of 2 cooled 5000 gal. tanks and 1 uncooled 5000 gal. tank	80,800
Contingency for item 3, (25%)	20,200
Capital cost total	$892,000

These capital costs are based on early design ideas but do not appear to have changed markedly as design has progressed. Where there has been some obvious reduction in cost during the year's study, as for example by the removal of service plugs from the design, these have been largely offset by increases elsewhere, for example in the instrumentation area. Similarly, costs were included in the rack construction and equipment installation section for about 400 remote disconnects. While this number may be expected to increase as the design proceeds, a large number of these disconnects can be of a much simpler and cheaper design than originally proposed.

It should be noted that a design fee has been included for the design of the building and cells but not for the equipment design, nor is there any cost allowance for the research and development necessary to complete the design. This is because it was intended that equipment design and the research and development required would be done by Research Establishment staff. These costs would not therefore appear as an item of new capital which must be raised for completion of the project.

Sharing of as much as possible of the existing facilities was a requirement of this study to minimise capital costs. This sharing extends beyond that which might normally be expected when building a new plant on an already developed site. For instance no costs have been included for analytical facilities, it being assumed that existing services would be sufficient. Workshop, maintenance and stores facilities have also been assumed to require no further extensions because of this new plant.

Direct operating costs for the plant are shown below.

TABLE 5

DIRECT OPERATING COST ESTIMATE

	$A	
Waste Storage	26,100	
Chemicals	9,000	
Services	3,400	
Labour (not including overheads)	89,500	
Total Annual Direct Operating Cost		$128,000

This estimate provides labour for operation, health physics coverage, analytical services and accountability, cleaning and supervision but it does not include any labour for maintenance or general administration. Nor do the labour charges include any of the normal site overheads since the appropriate figure for this cost would vary from site to site and in any case, some of the costs

would be shared with the reactor in an on-site reprocessing facility. The costs shown are only direct costs; no attempt has been made to include capital charges since these also vary with ground rules selected.

9. CONCLUSION

This study has treated an application of the rack design philosophy to a low throughput reprocessing facility, suitable for processing HIFAR fuels. During the year's development work no difficulties were revealed which would render this philosophy impractical or could not be accommodated by the design. The study and experimental development work extends beyond that previously published and illustrates the feasibility of the rack philosophy for small reprocessing plants.

Because cost data for conventional plants for this application are not available, and since the cost data generated here are peculiar to the presence of existing facilities at the site selected, it is not possible to prove whether unit reprocessing costs have been reduced substantially. To show this, another design study would be necessary on a conventional plant for this application. However, no technical problems were encountered in the study which would render invalid the concept of each major section of the active plant being built on self contained and separate racks operated without master slave manipulators or viewing.

It appears that the concept of indirect maintenance for items of equipment which are likely to require frequent attention is technically feasible, and that rack removal for major equipment repair by normal direct maintenance approaches is possible. However, further development followed by actual plant construction and operation would be needed to verify these conclusions and to establish any cost advantages.

The cost estimates deduced at the start of the study have not changed substantially during the course of the work.

10. ACKNOWLEDGEMENTS

Grateful acknowledgement is given for major contributions made by many people during the development programme and preparation of this report. In particular the authors would like to thank the following staff for their assistance: B.J. Fox, F.R. Carter, R.W. Hubery, R.K. Ryan, F.D. Nicholson, K.C. Parkes, J.M. Devine, K. Nicholson, E.J. Lee and J. Tovey.

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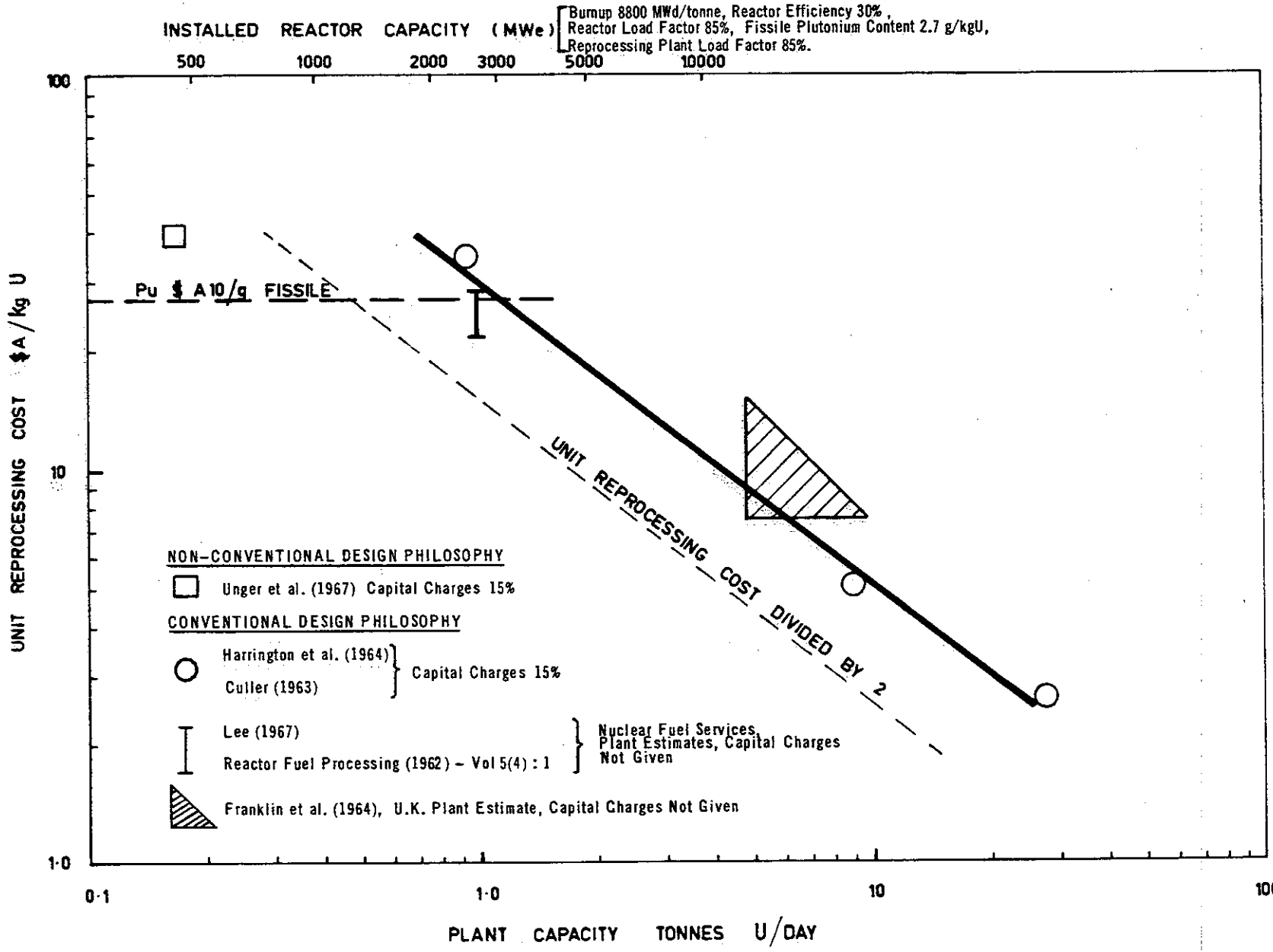
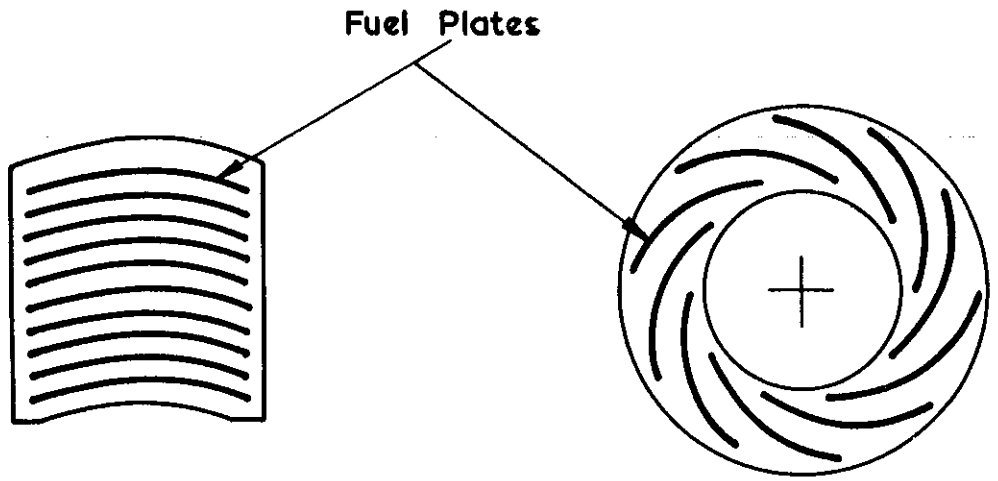
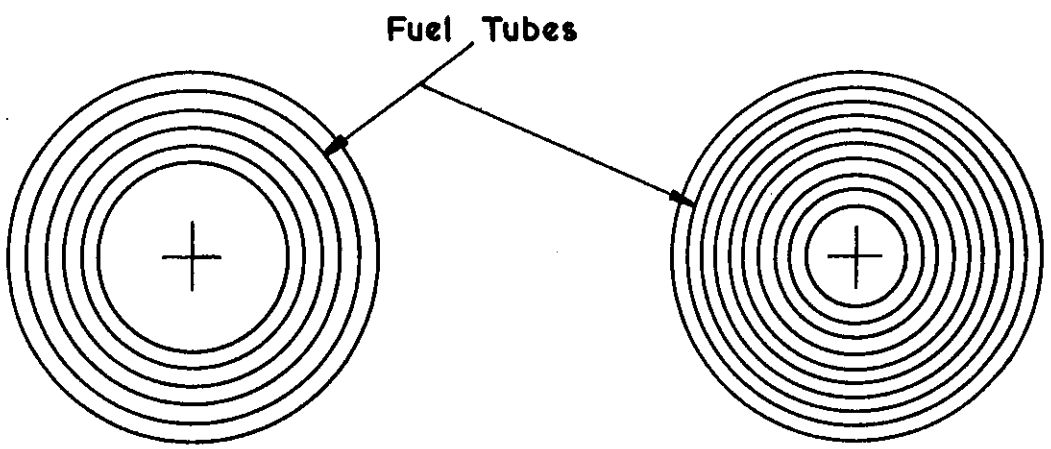


FIGURE 1. UNIT COST OF REPROCESSING NATURAL AND LOW ENRICHMENT FUELS AS A FUNCTION OF PLANT CAPACITY



EXISTING TYPES



POSSIBLE FUTURE TYPES

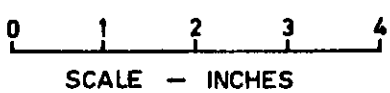


FIGURE 2. HIFAR FUEL ELEMENTS — CROSS SECTION

P860

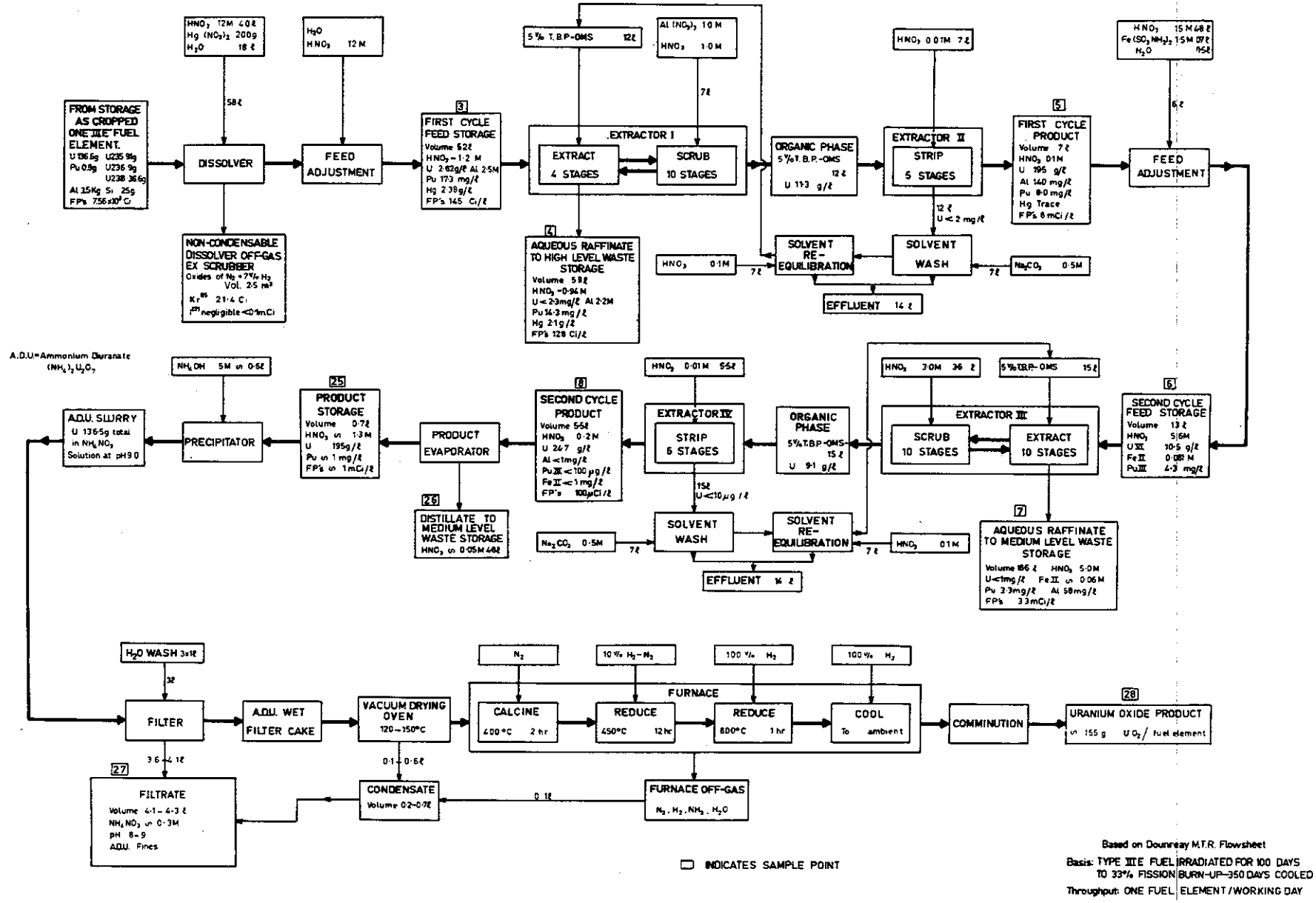


FIGURE 3. CHEMICAL FLOWSHEET FOR REPROCESSING HIFAR FUEL

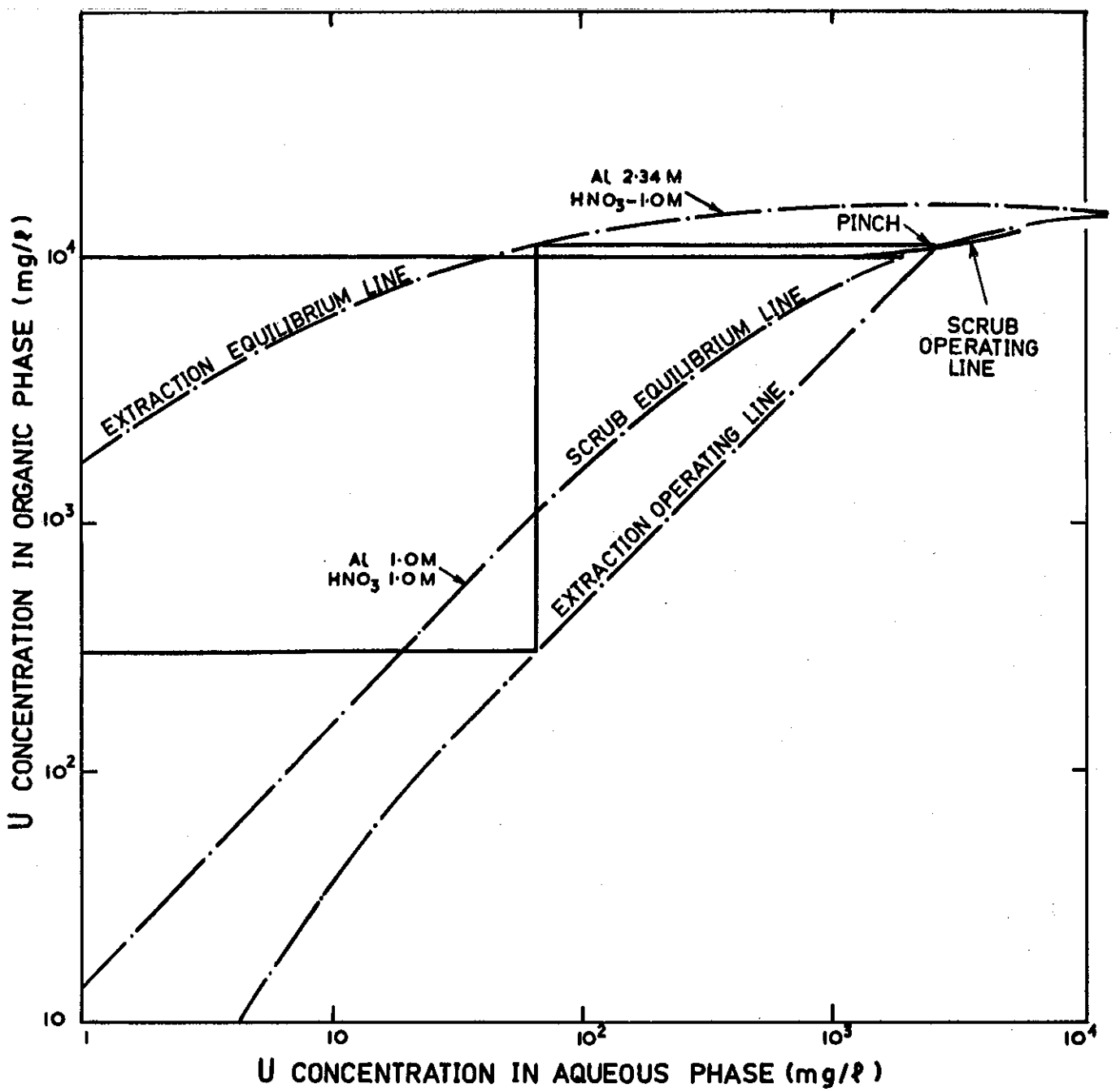


FIGURE 4. McCABE-THIELE DIAGRAM FOR FIRST CYCLE EXTRACTION AND SCRUBBING (Refer Flowsheet, Figure 3)

P1038

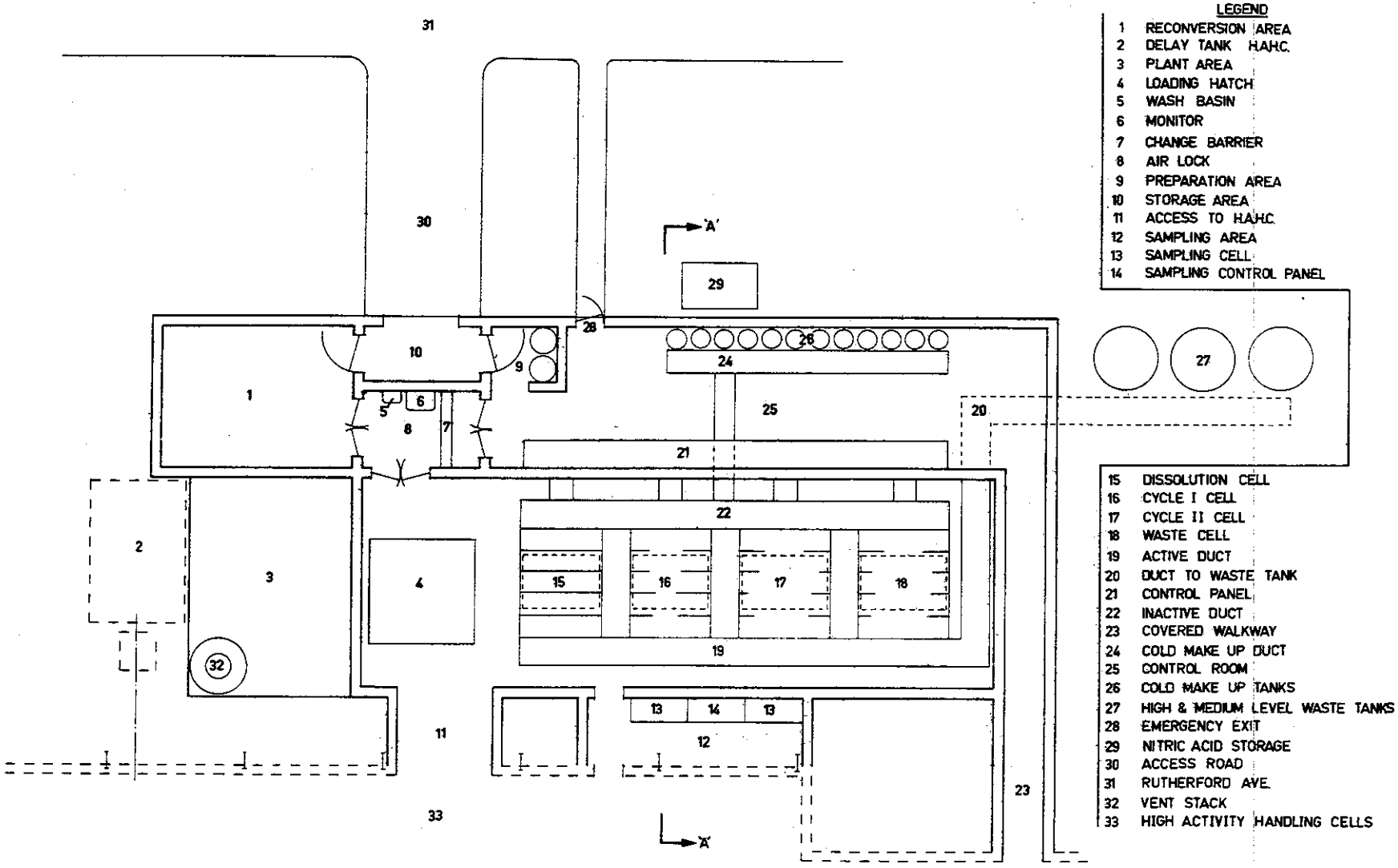
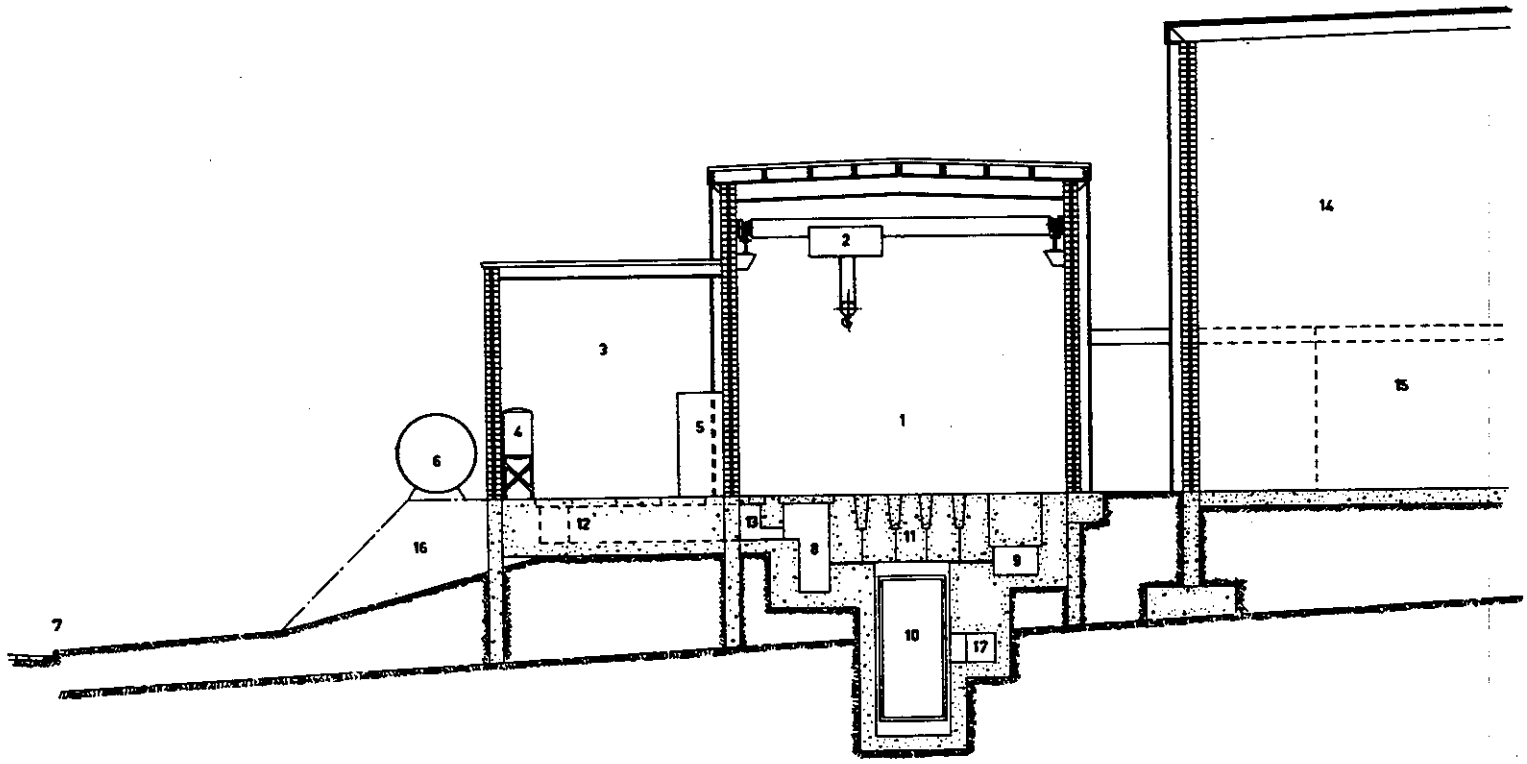


FIGURE 5. PLAN OF PROCESSING PLANT FOR HIFAR FUEL



LEGEND

1	MAIN BAY	10	FRAME IN CELL
2	TRAVELLING CRANE	11	ROOF PLUG
3	CONTROL ROOM	12	DUCT FOR COLD MAKE-UP LINE
4	COLD MAKE-UP TANKS	13	DUCT FOR INSTRUMENTATION LINES TO CONTROL PANEL
5	CONTROL PANEL	14	HIGH ACTIVITY HANDLING CELLS N° 2
6	NITRIC ACID STORAGE TANK	15	OFFICE, HIGH ACTIVITY HANDLING CELLS N° 2
7	RUTHERFORD AVE.	16	FILLING
8	INACTIVE DUCT	17	CELL VENTILATION DUCT
9	ACTIVE DUCT		

FIGURE 6. SECTIONAL ELEVATION OF PLANT FOR PROCESSING HIFAR FUEL

(Section A-A of Figure 5)

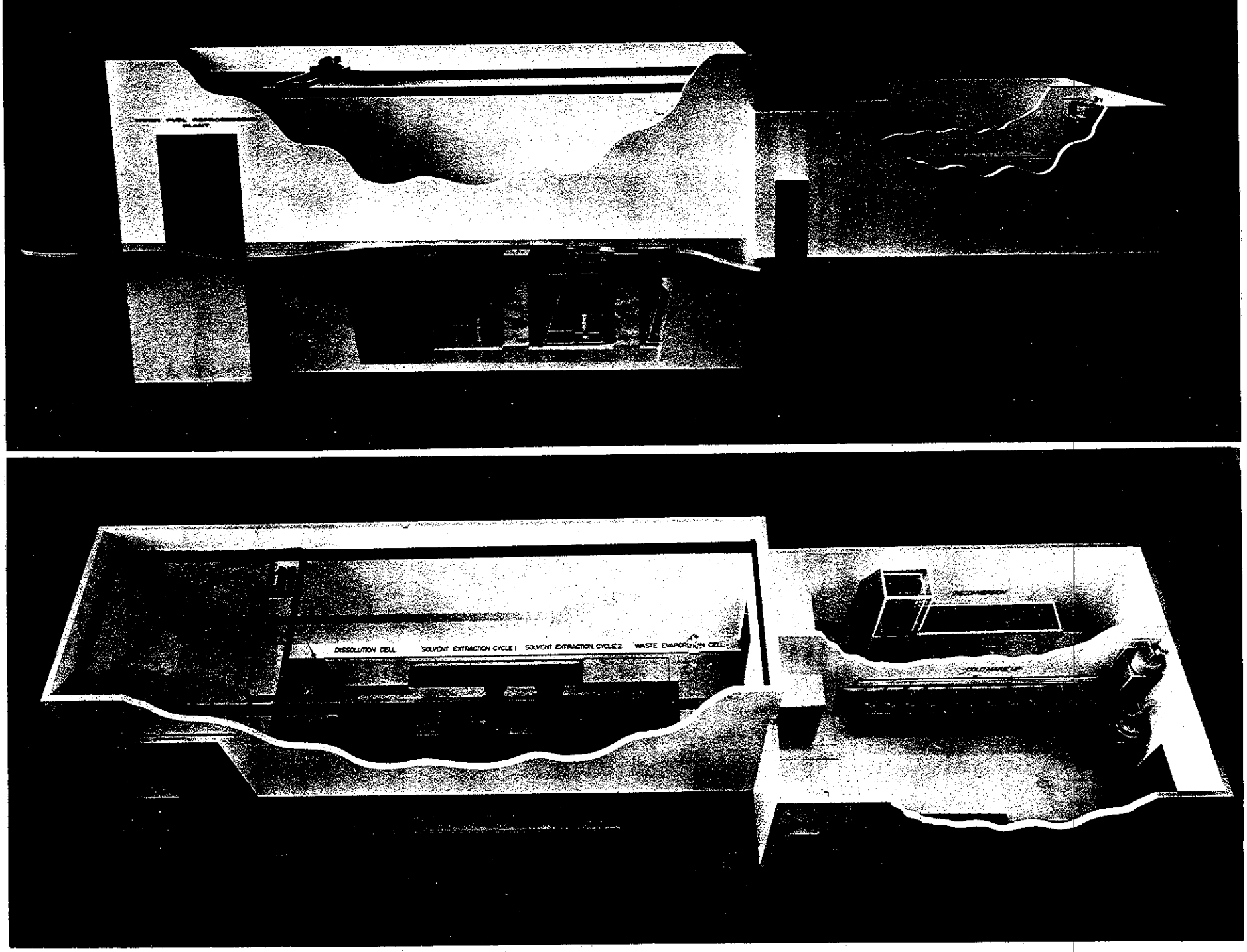


FIGURE 7. SCALE MODEL OF PRELIMINARY DESIGN OF A PLANT FOR REPROCESSING HIFAR FUEL

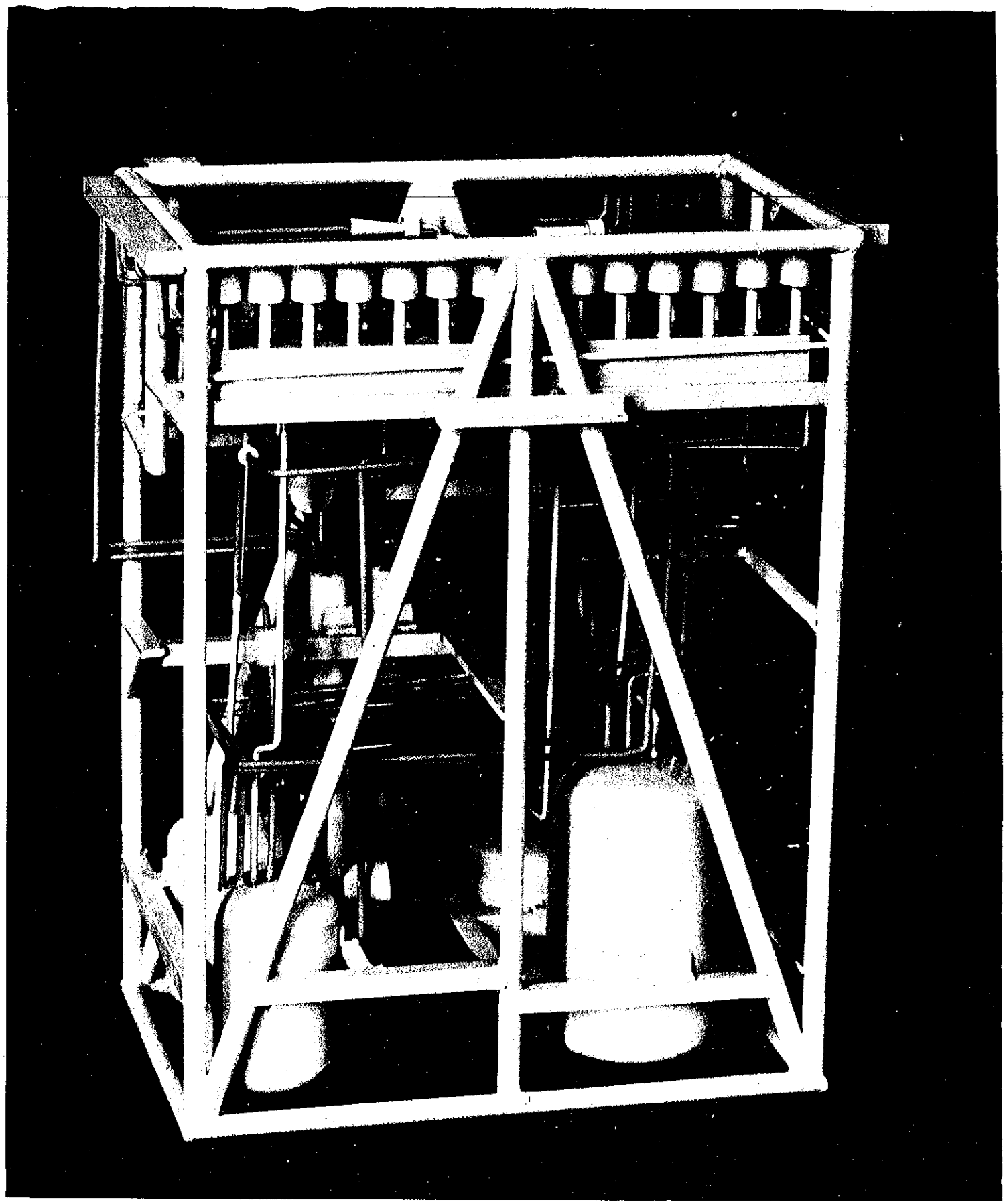
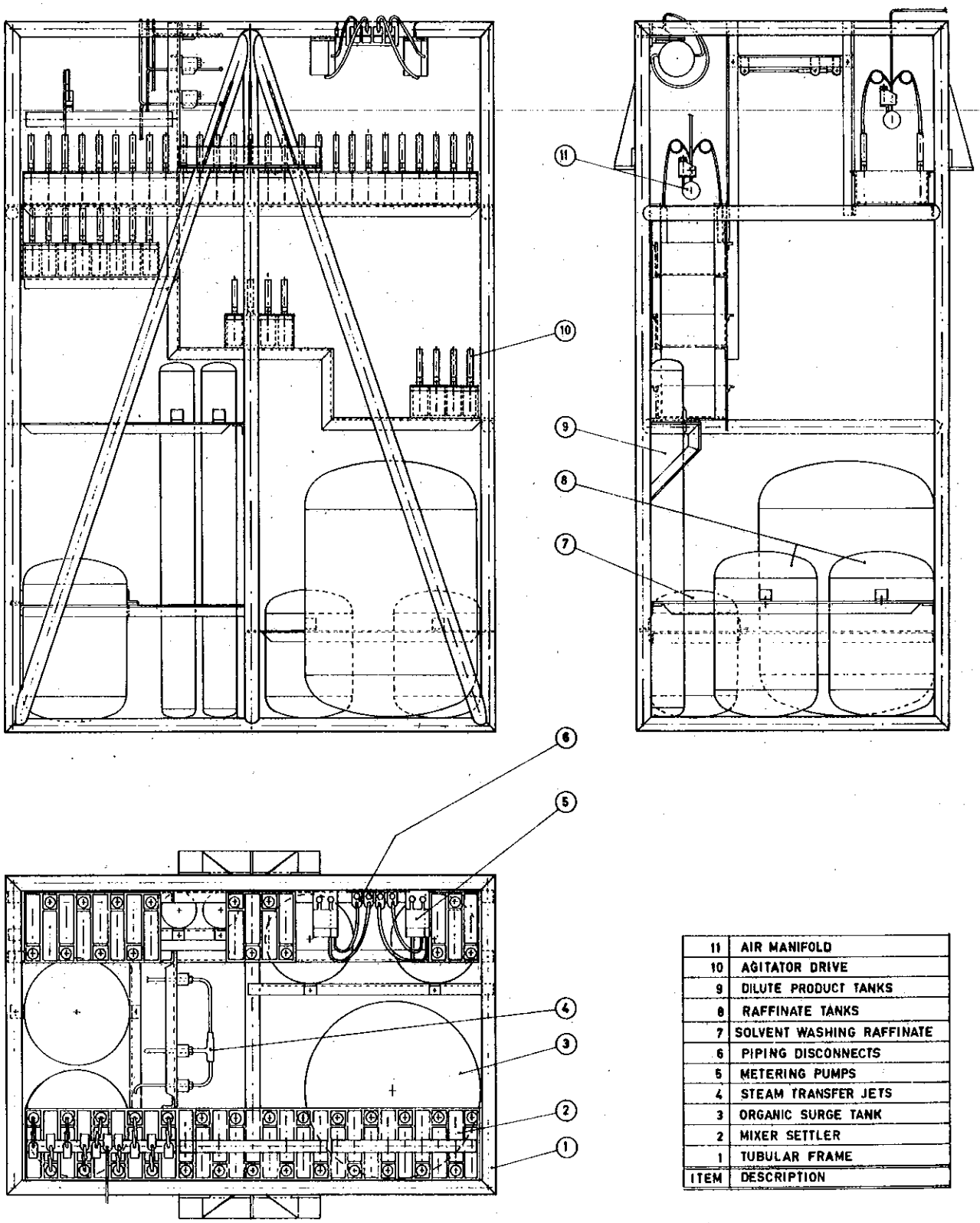


FIGURE 8. SCALE MODEL OF FRAME FOR SECOND CYCLE SOLVENT EXTRACTION EQUIPMENT



ITEM	DESCRIPTION
11	AIR MANIFOLD
10	AGITATOR DRIVE
9	DILUTE PRODUCT TANKS
8	RAFFINATE TANKS
7	SOLVENT WASHING RAFFINATE
6	PIPING DISCONNECTS
5	METERING PUMPS
4	STEAM TRANSFER JETS
3	ORGANIC SURGE TANK
2	MIXER SETTLER
1	TUBULAR FRAME

FIGURE 9. TYPICAL FRAME LAYOUT FOR SECOND CYCLE SOLVENT EXTRACTION EQUIPMENT

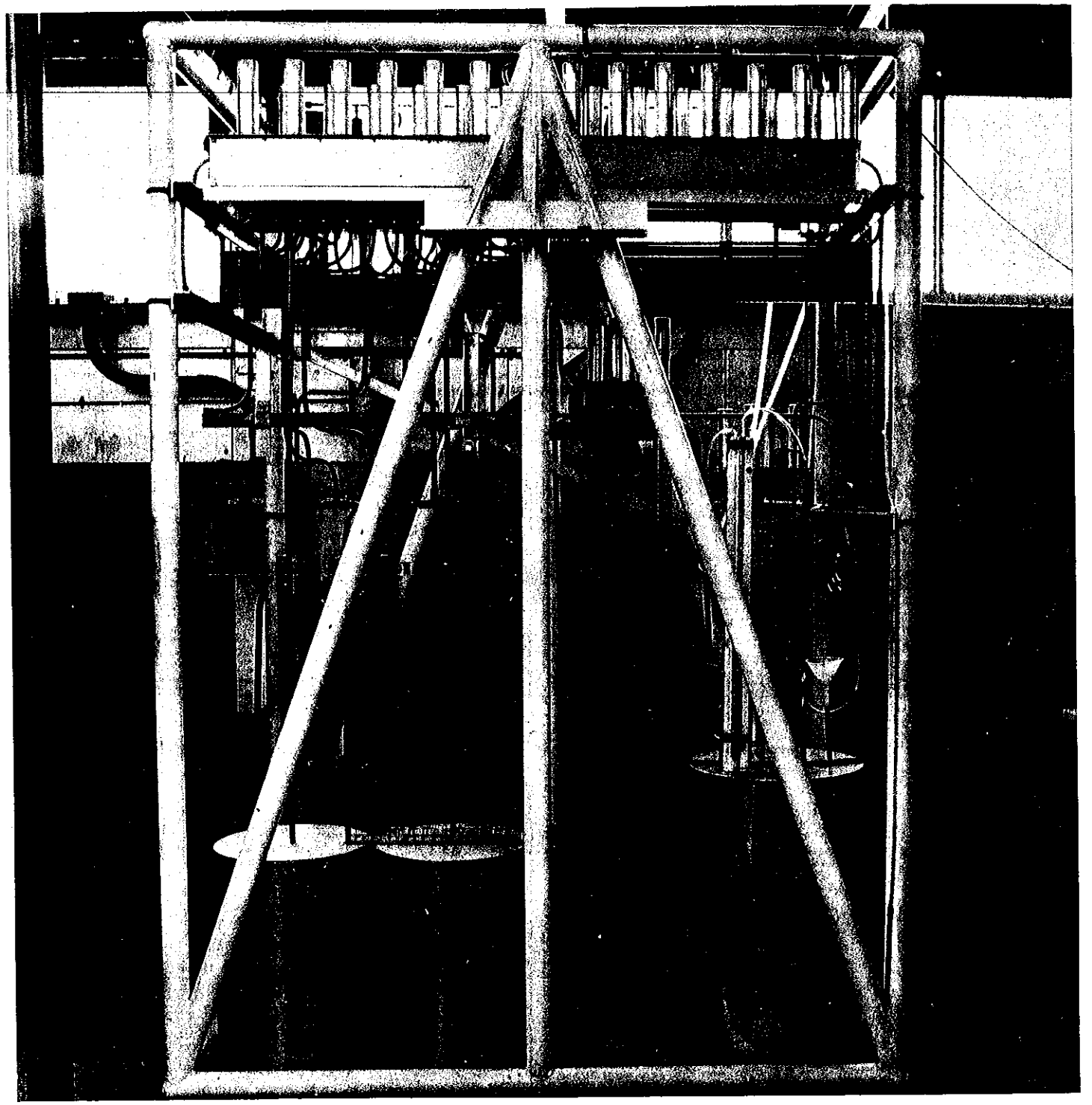


FIGURE 10. FULL SIZE MOCK-UP OF FRAME FOR SECOND CYCLE SOLVENT EXTRACTION EQUIPMENT

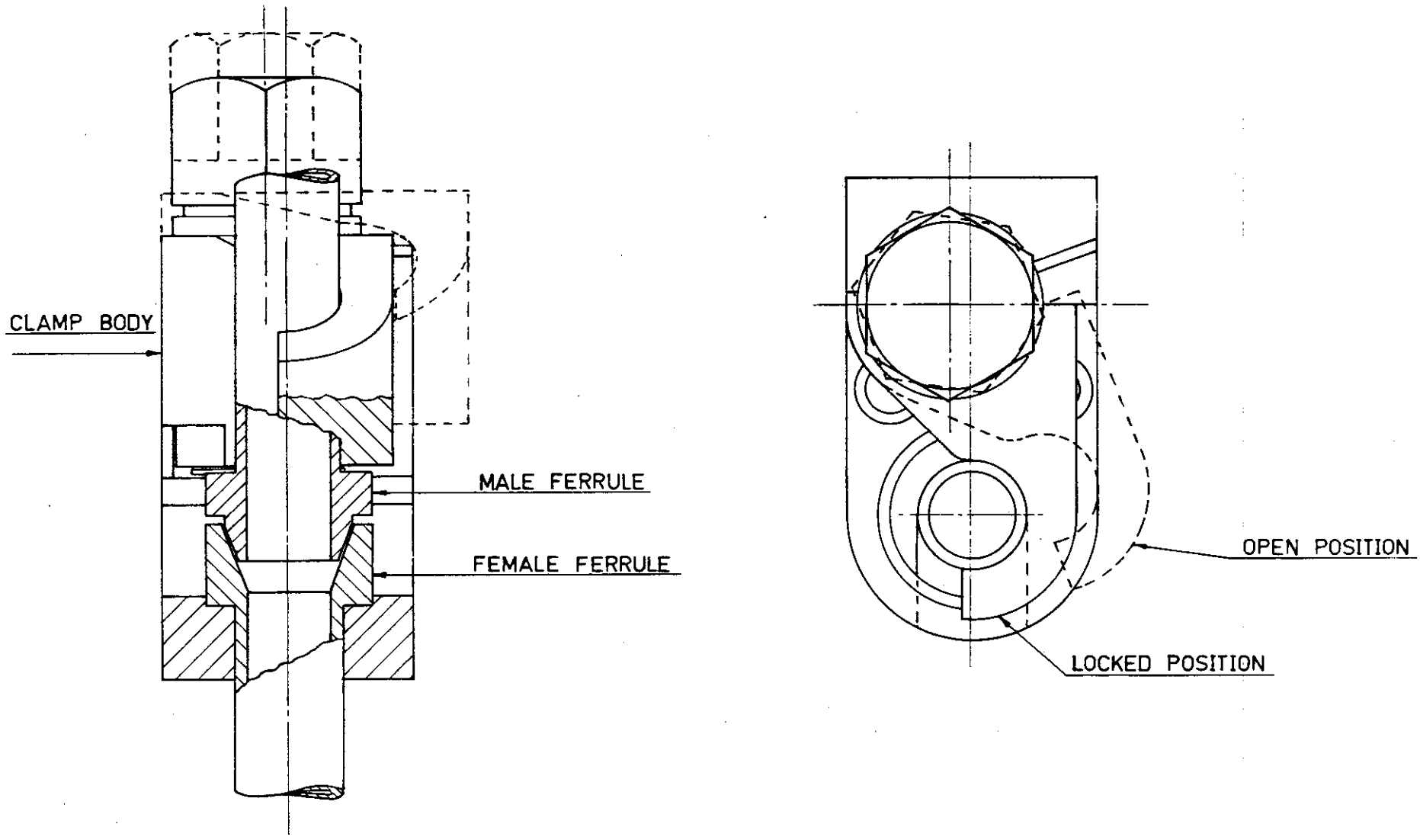


FIGURE 11. REMOTELY OPERATED DISCONNECT (As used in O.R.N.L. Transuranium Facility)

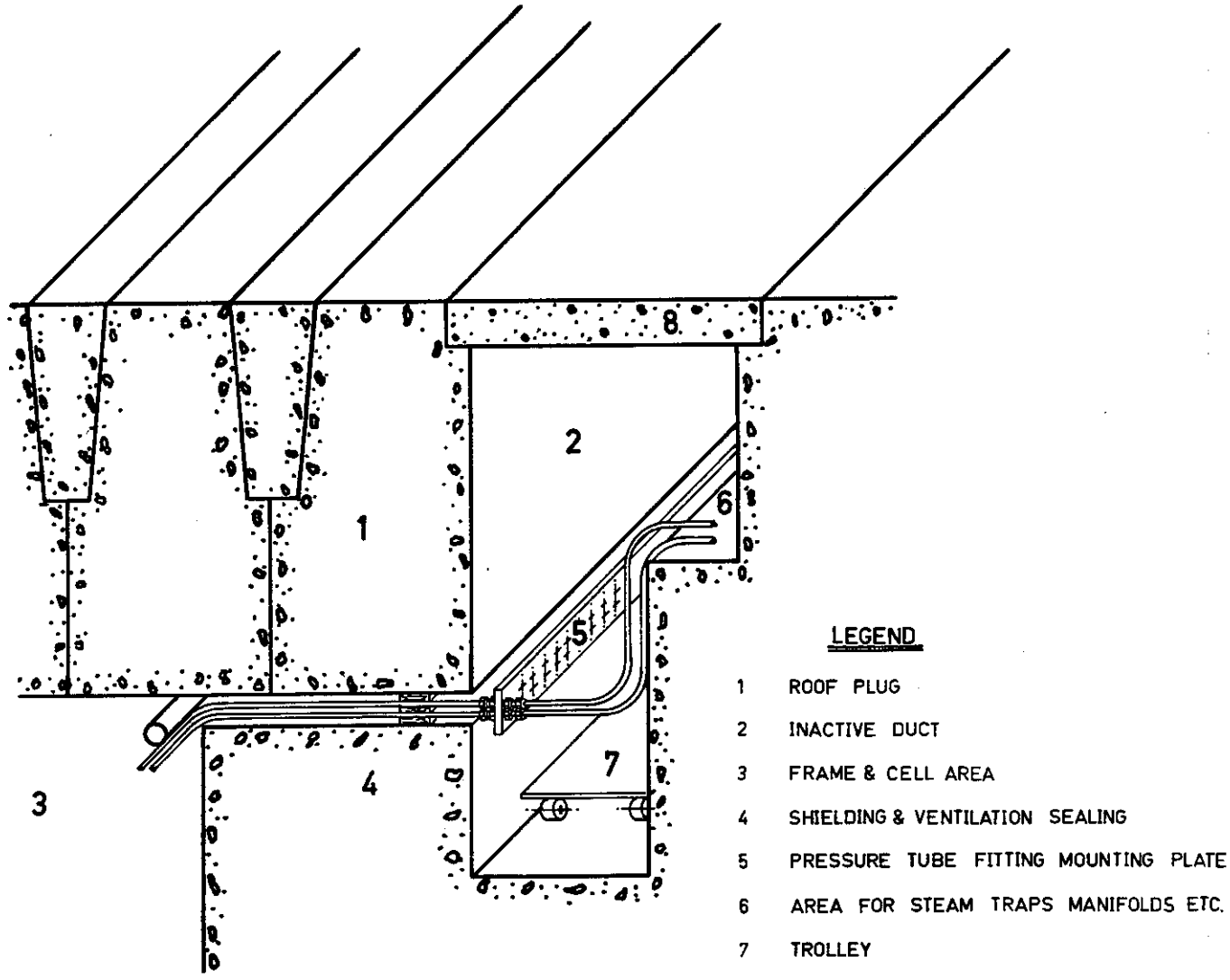


FIGURE 12. LAYOUT OF ROOF PLUG AND DISCONNECT

SK.1846

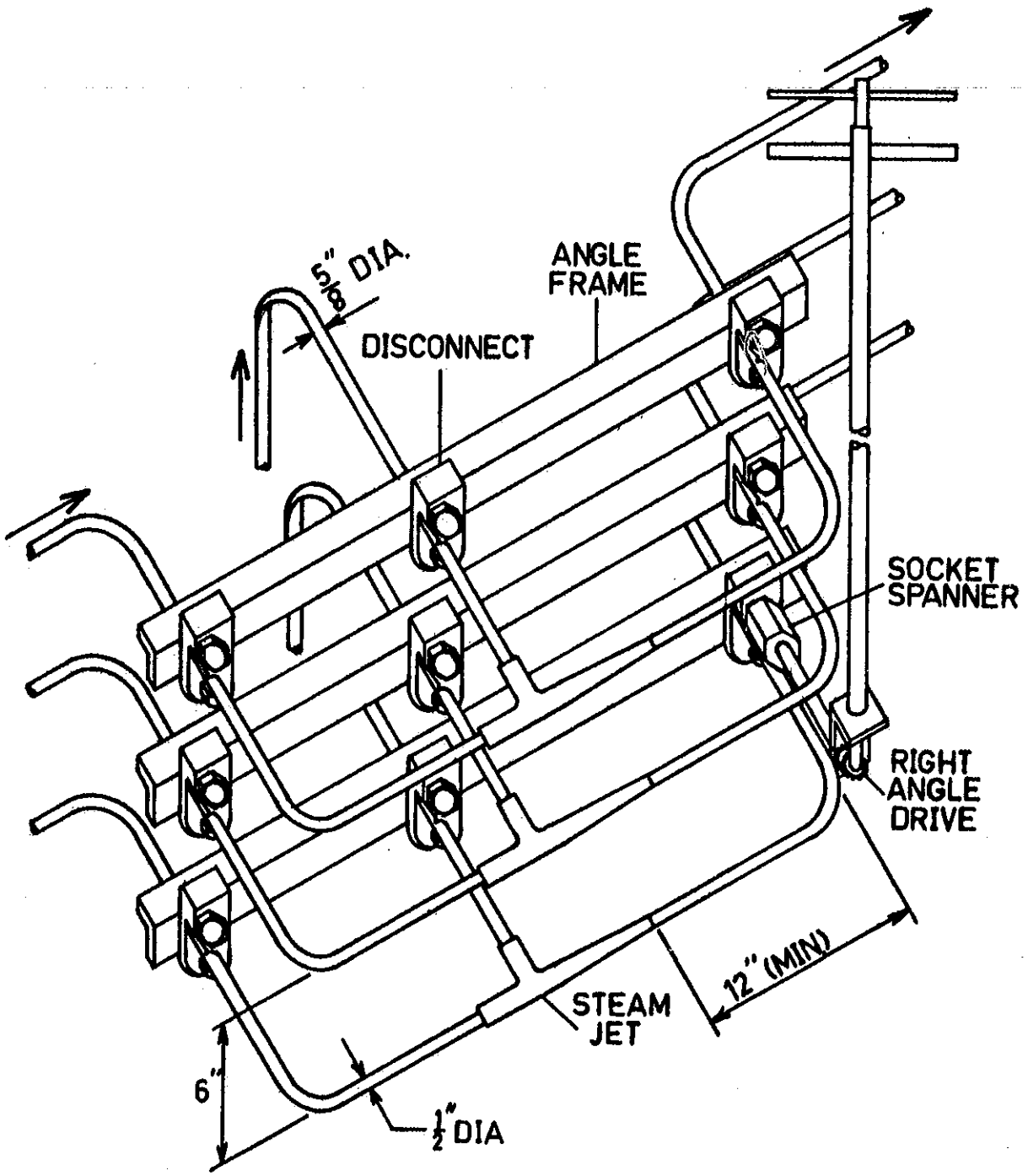


FIGURE 13. TYPICAL STEAM JET ARRANGEMENT

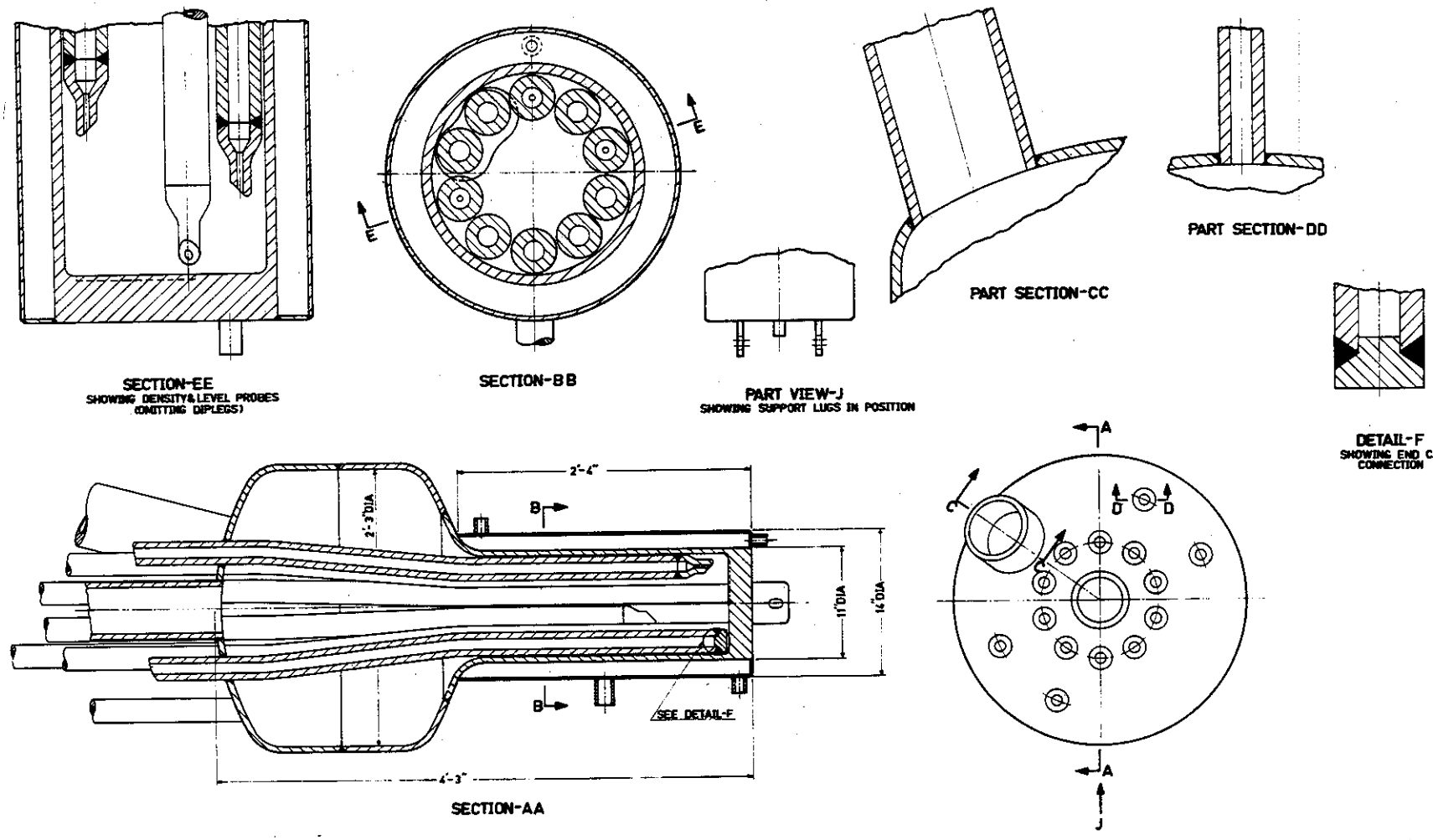


FIGURE 14. DISSOLVER VESSEL FOR PROCESSING HIFAR FUEL

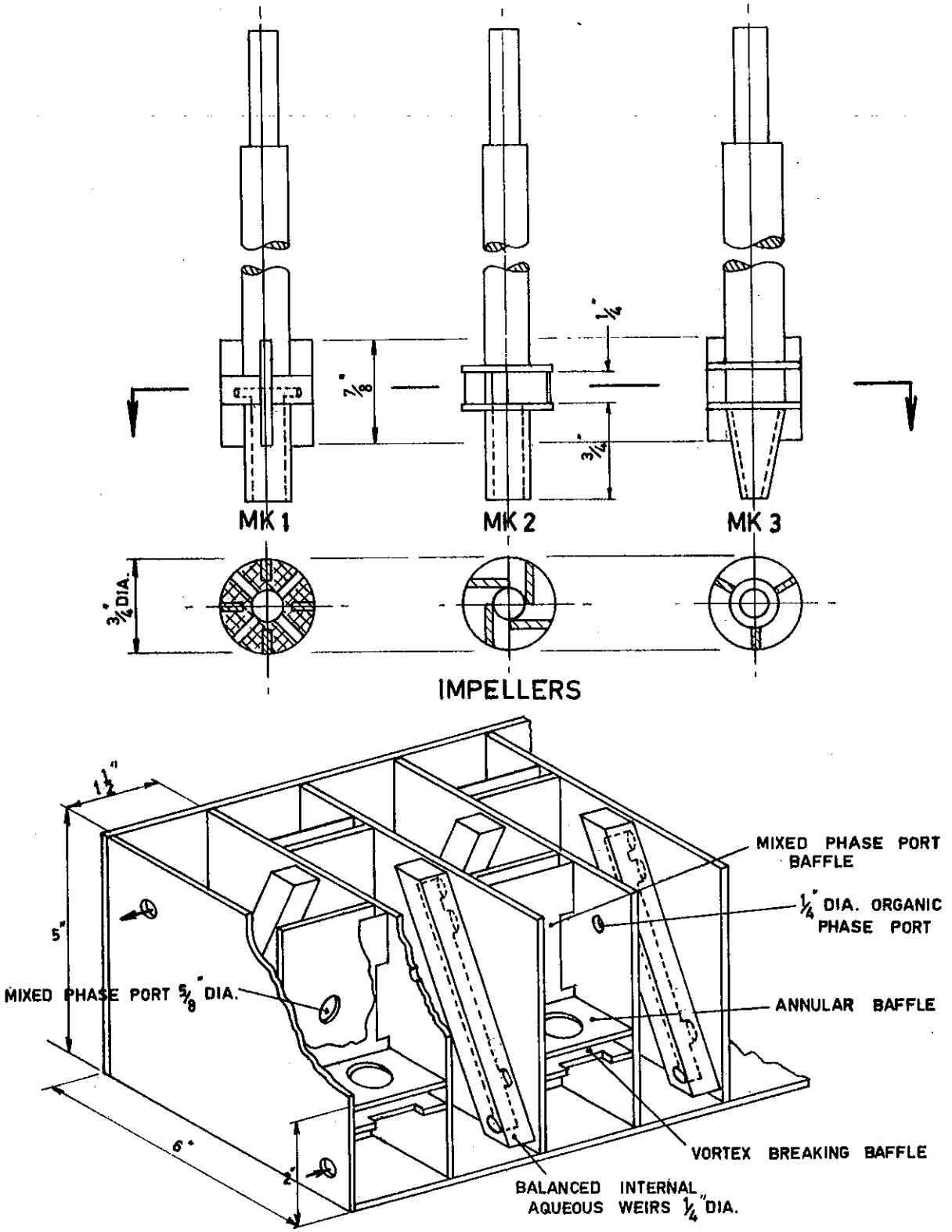


FIGURE 15. PROTOTYPE MIXER SETTLER
(9 ℓ/hr. total phase flow)

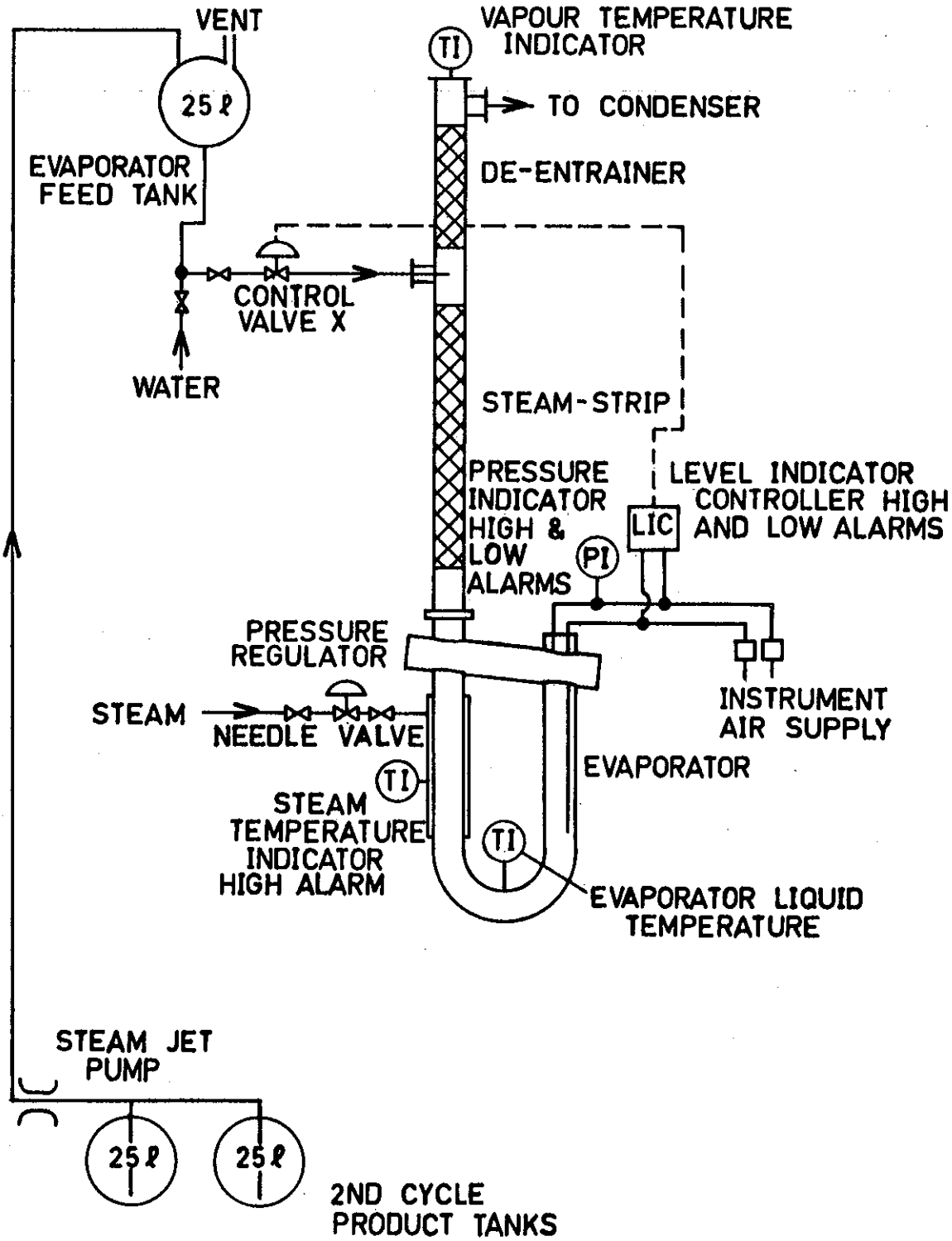


FIGURE 16. EVAPORATOR FOR URANYL NITRATE PRODUCT

P1011

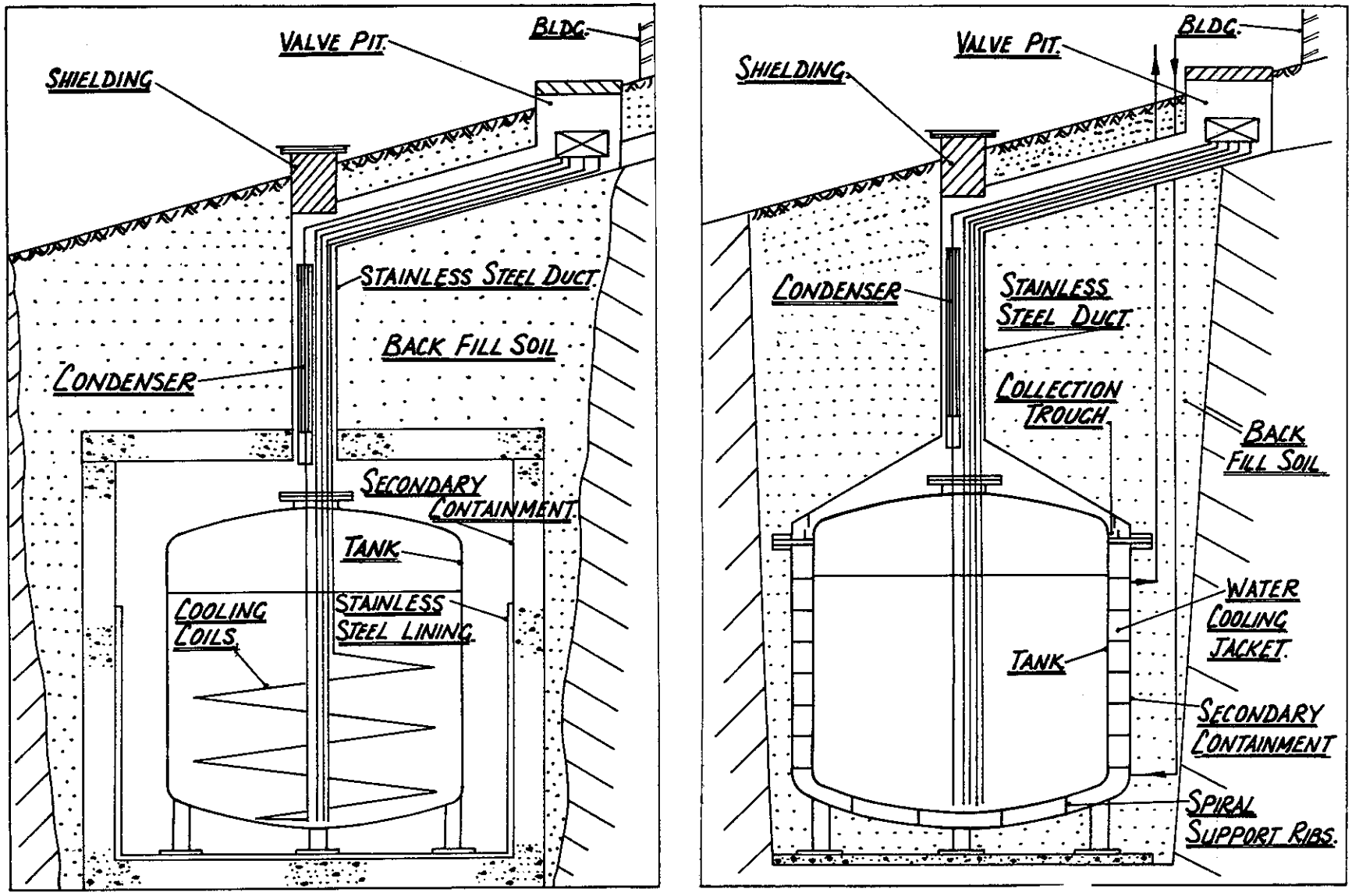


FIGURE 17. SKETCH OF HIGH LEVEL WASTE TANK CONCEPTS

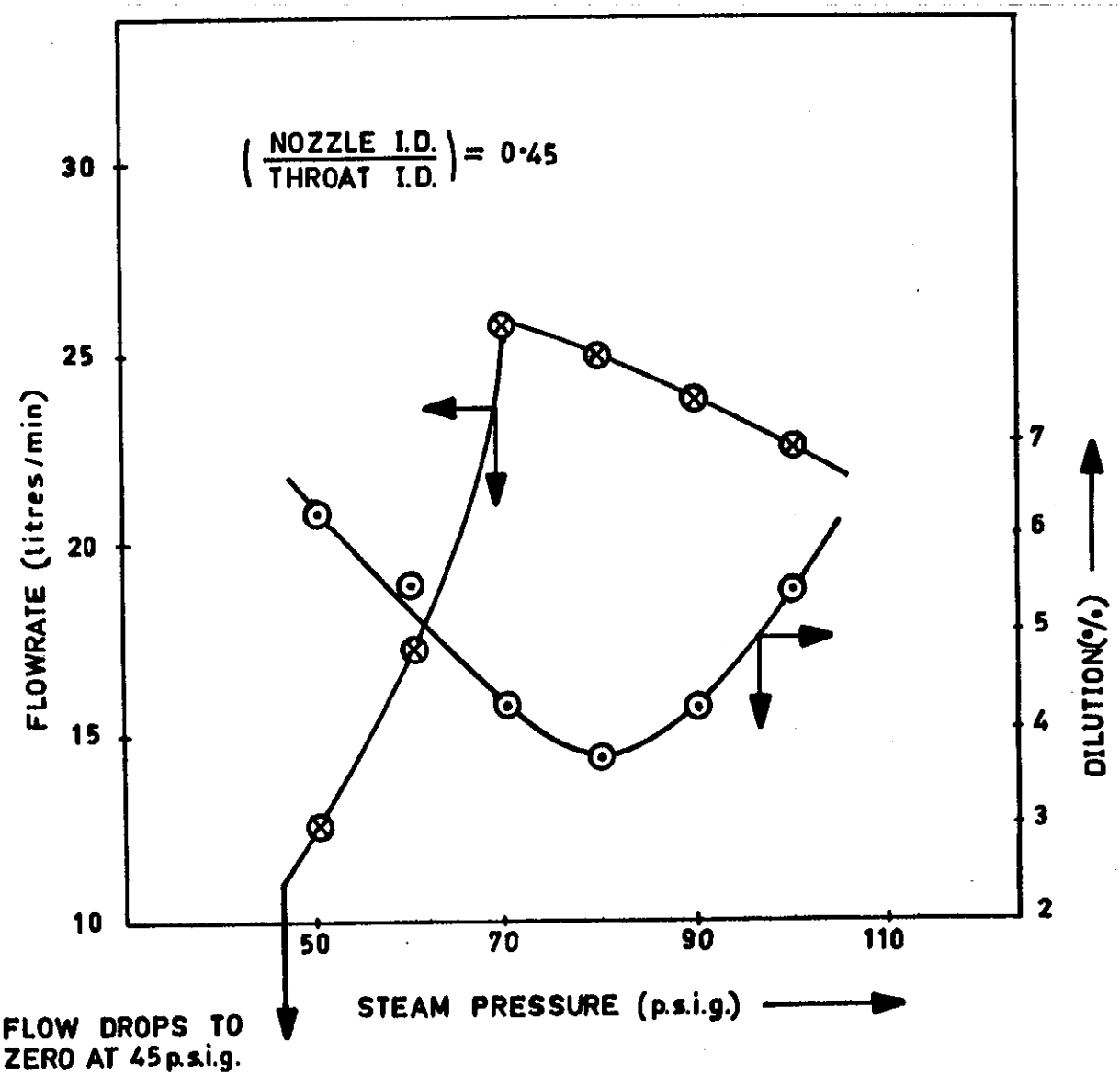
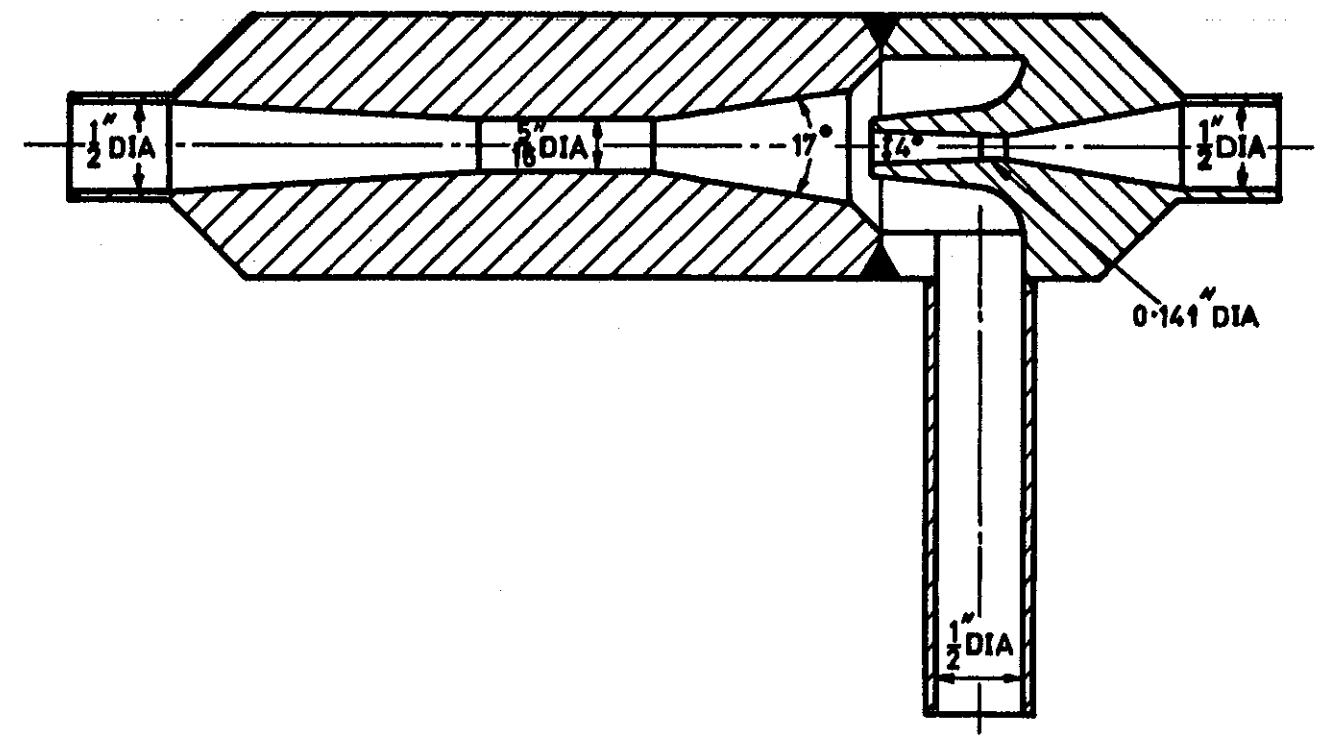


FIGURE 18. CHARACTERISTICS OF STEAM JET PUMP WITH NOZZLE 0.141 INCH AND VENTURI ENTRANCE ANGLE 17°



SECTION 'A-A'

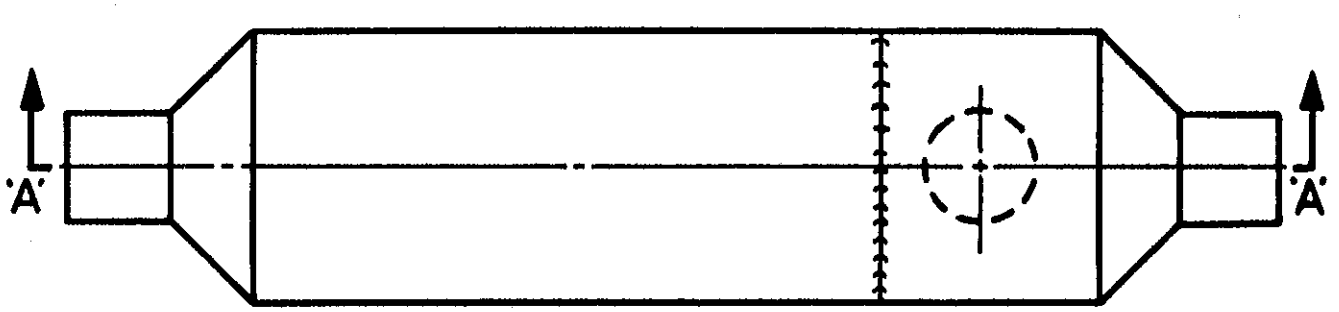


FIGURE 19. STEAM JET PUMP FOR ACTIVE SOLUTIONS

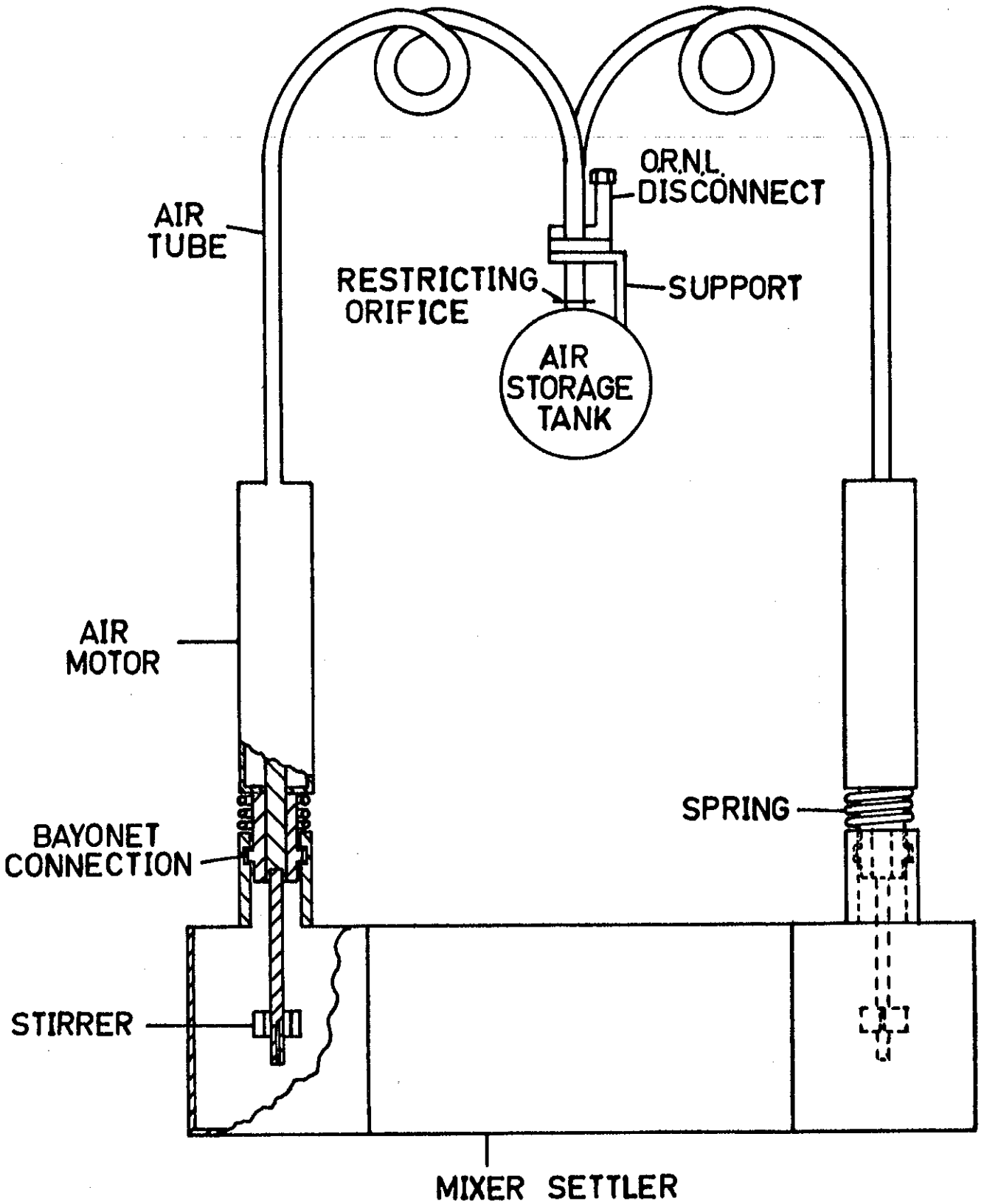


FIGURE 20. MIXER SETTLER DRIVE

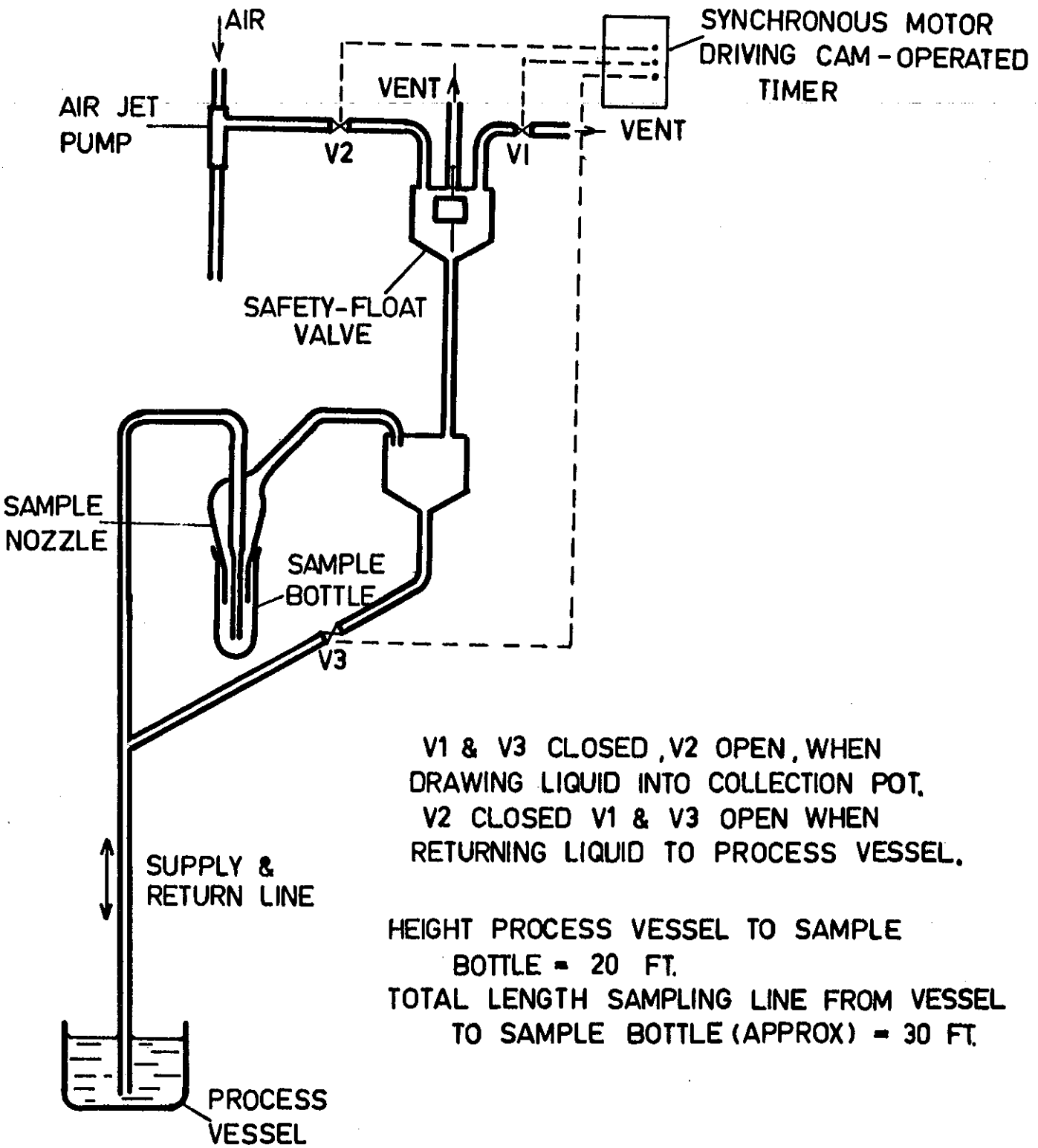


FIGURE 21. SINGLE LINE (NON-RECIRCULATING) SAMPLING SYSTEM FOR ACTIVE SOLUTIONS

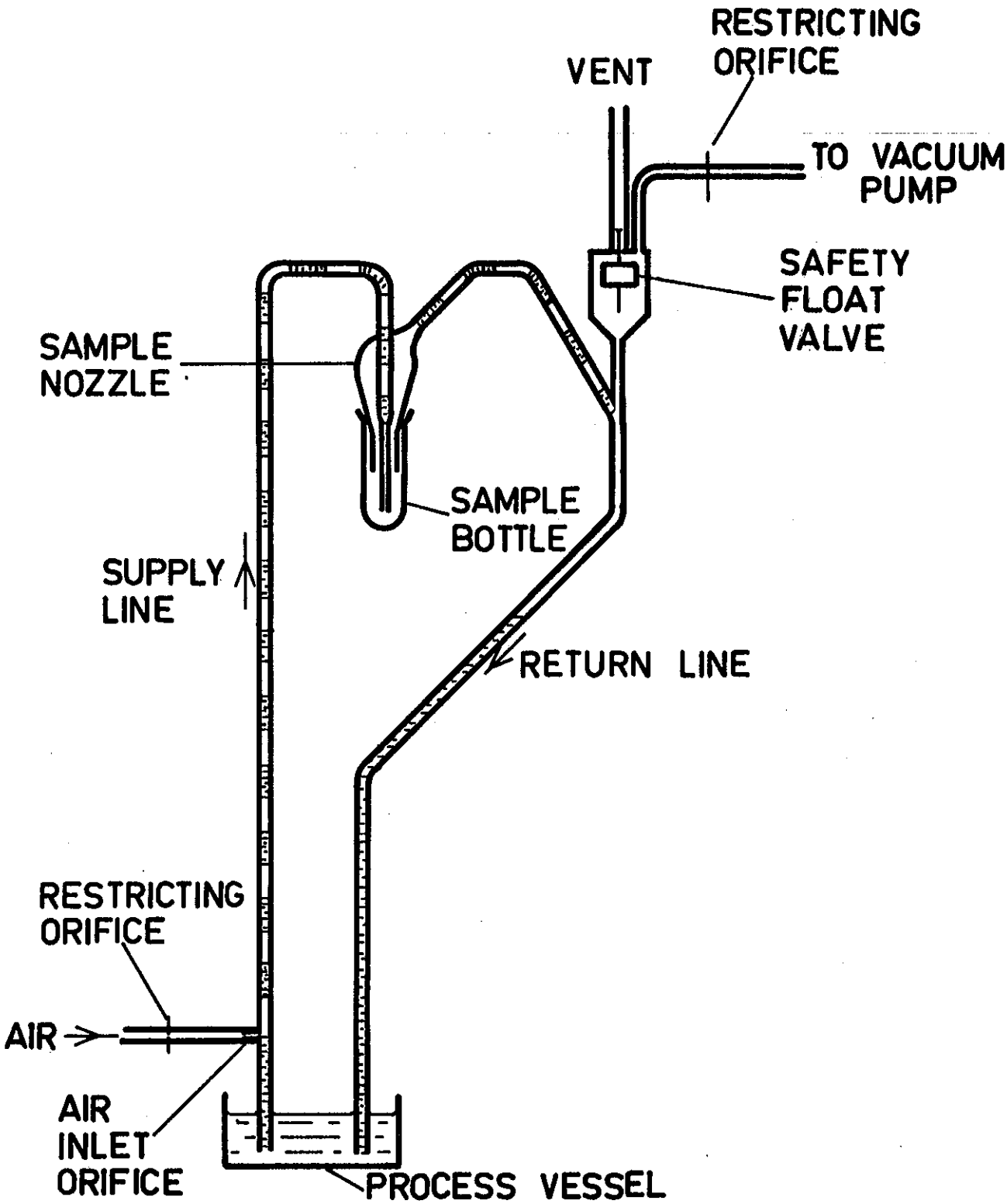


FIGURE 22. RECIRCULATING SAMPLING SYSTEM FOR ACTIVE SOLUTIONS

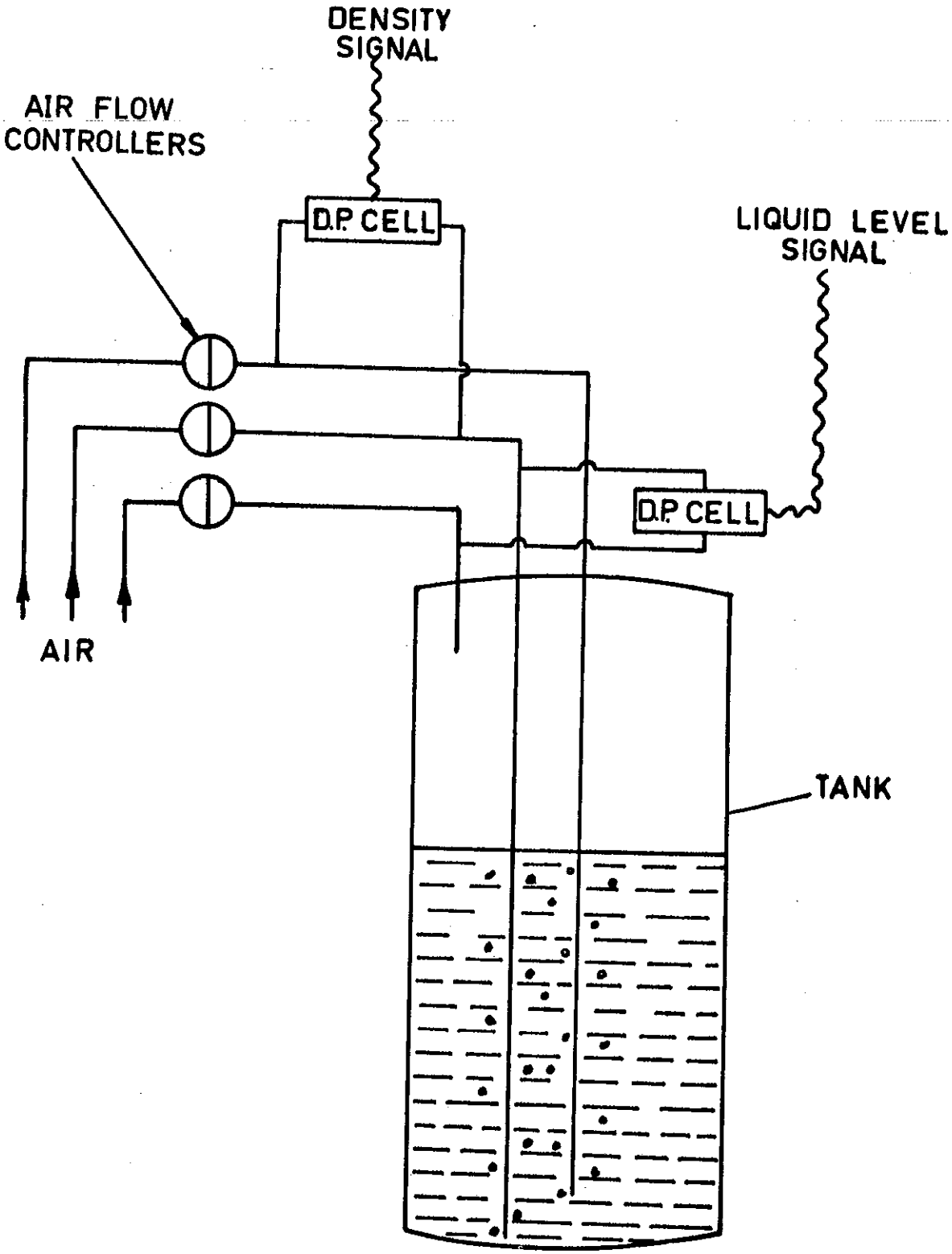
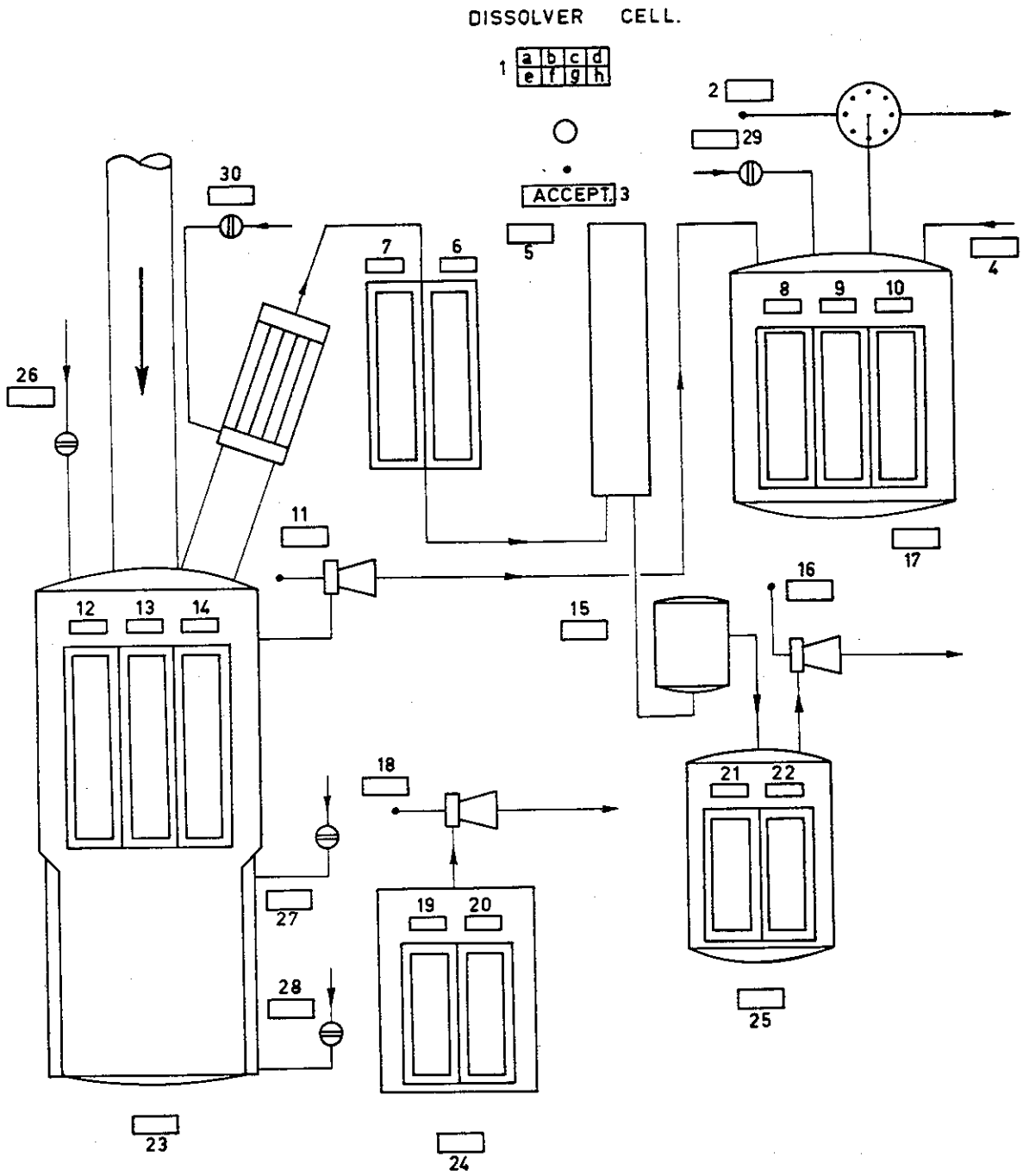


FIGURE 23. TYPICAL LIQUID LEVEL AND DENSITY MEASURING SYSTEM FOR IN-CELL VESSELS



LEGEND

1. a. DISSOLVER LEVEL HIGH
   b. CONDENSER TEMPERATURE HIGH
   c. CONDENSER PRESSURE HIGH
   d. SPENT NaOH TANK LEVEL HIGH
   e. STORAGE TANK LEVEL HIGH
   f. SUMP LEVEL HIGH
   g. ——
   h. ——
2. TRANSFER TO SOLVENT EXTRACTION
3. ALARM ACCEPT
4. FROM REWORK EVAPORATOR
5. SCRUBBER
6. PRESSURE
7. TEMPERATURE
8. LEVEL
9. DENSITY
10. TEMPERATURE
11. TRANSFER TO STORAGE TANK
12. LEVEL
13. DENSITY
14. TEMPERATURE
15. SEAL POT
16. TRANSFER TO DIVERTER POT
17. DISSOLUTION PRODUCT STORAGE TANK
18. TRANSFER TO DIVERTER POT
19. LEVEL
20. DENSITY
21. LEVEL
22. DENSITY
23. DISSOLVER
24. SUMP
25. SPENT NaOH TANK
26. AIR TO DISSOLVER
27. STEAM TO DISSOLVER JACKET
28. COOLING WATER TO DISSOLVER JACKET
29. AIR TO STORAGE TANK
30. COOLING WATER TO CONDENSER

• PUSH BUTTON

○ ALARM LAMP

▭ LABEL

⊖ MIMIC SWITCH

FIGURE 24. TYPICAL LAYOUT FOR CONTROL PANEL FOR PLANT TO PROCESS HIFAR FUEL