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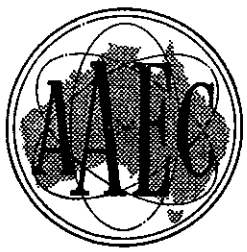

AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

ECONOMICS OF THE H.T.G.C.R. FUEL CYCLE

PART 1. PRE-DESIGN COST STUDY OF FUEL CYCLE FACILITY

by

J. R. MAY
J. M. DEVINE

MAY 1967

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ABSTRACT

A conceptual design study of a facility to recycle fuel from a beryllium oxide moderated high temperature gas-cooled pebble bed reactor has been made. For a facility to handle 300 kg of fuel per day, the capital cost is estimated as $A30 millions and the annual direct operating cost, excluding capital charges, as $A3.1 millions.

PREFACE

The following list details a series of reports dealing with the fuel cycle of the High Temperature Gas Cooled Reactor. This report (AAEC/E175) is the first of the final group of reports dealing with The Economics of the H.T.G.C.R. Fuel Cycle.

Laboratory Development of the Grind–Leach Process for the H.T.G.C.R. Fuel Cycle

Part 1. Dissolution of Urania–Thoria Fuel Particles in Nitric Acid Solutions, by M.S. Farrell and S.R. Isaacs. AAEC/E143.

Part 2. Dissolution of Beryllia in Nitric Acid Solutions, by M.S. Farrell, S.R. Isaacs and M.E. Shying. AAEC/E154.

Part 3. Comminution of Beryllia Matrix Fuels, by M.G. Baillie and R.W. Hubery. AAEC/E162.

Part 4. Leaching and Dissolution of Beryllia–Based Fuels, by M.E. Shying, E.J. Lee and M.S. Farrell. AAEC/E180.

Development of Solvent Extraction Processes for the H.T.G.C.R. Fuel Cycle

Part 1. Design of a Flowsheet for the Recovery of Actinides, by M.G. Baillie and R.K. Ryan. AAEC/E139.

Part 2. Solvent Extraction of Thorium and Uranium from Beryllium Nitrate Feeds by Tri–n–Butyl Phosphate, by R.C. Cairns, M.G. Baillie, B.J. Fox, and R.K. Ryan. Industrial and Engineering Chemistry, Process Design and Development Quarterly. In Press.

Part 3. Chemical Data for the Extraction of Actinides and Fission Products from Aqueous Beryllium Sulphate Solutions using Amines, by J.J. Fardy, M.S. Farrell and D.G. Pinchbeck. A.A.E.C. report in preparation.

Economics of the H.T.G.C.R. Fuel Cycle

Part 1. Pre–design Cost Study of Fuel Cycle Facility, by J.R. May and J.M. Devine. AAEC/E175.

Part 2. Fuel Cycle Cost Studies, by R.W. Hubery and M.G. Baillie. AAEC/E179.

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1. INTRODUCTION

In the A.A.E.C.'s study of the technical and economic feasibility of a pebble bed H.T.G.C.R. the fuel for the reactor was made up of spheres approximately 1 inch in diameter with the fissile and fertile components dispersed as 150–200 micron particles through a beryllium oxide matrix. The whole ball was coated with a thin layer of beryllium oxide (Roberts 1964). As part of the assessment of this reactor type it was necessary to consider the fuel cycle.

The approach taken in devising flowsheets for separation, purification and recycle of the actinides and moderator has been outlined by Cairns (1964). The present paper uses these flowsheets in a preliminary design study to highlight the major unresolved problems in the technology of the fuel cycle and to define the capital and operating costs of a facility to recycle fuel from such reactors. These costs were used in a subsequent assessment of the economics of the fuel cycle (Hubery and Baillie 1967).

1.1 Scope of the Study

It is assumed that the facility receives spent fuel balls from a series of reactors sited at some distance from the fuel cycle facility. The main storage for cooling fuel after discharge from the reactor is at the reactor site, so only limited buffer storage for fuel is provided at the fuel cycle facility. The facility is designed to recover actinides and moderator from the fuel and refabricate them into fuel elements suitable for recycle to the reactors. Provision is made for the handling and storage of waste. The plant is assumed to be sited sufficiently close to a large commerical centre to enable some maintenance, personnel dosimetry and special analyses to be done on contract. Apart from this, the plant is designed to be self–supporting.

The study is conceptual. Some design work was necessary, particularly on equipment installation procedures, to obtain satisfactory estimates. However, no detailed design of any part of the plant was attempted. It must be realised that during the study, continual modifications to the fuel composition were made. These did not markedly affect the major processing steps under development, and in this paper the most recent fuel composition for a 200 MWe H.T.G.C.R. with fuel recycle is used.

1.2 Plant Throughput

The selection of a plant throughput for a study such as this is always difficult. It is desirable to make it as small as possible, yet large enough for the unit cost of fuel recycle to be economic. A minimum throughput of nominally 300 kg of spent H.T.G.C.R. fuel per day was chosen as reasonable. This also corresponds to the minimum continuous daily capacity of the smallest commercial equipment for the head–end. For fuel with burnup of 1.0 F.I.F.A. (fissions per initial fissile atom), the plant could handle the output from a total reactor installation of about 600 MWe.

2. PLANT DESCRIPTION

2.1 The Flowsheets

This fuel containing urania and thoria dispersed in beryllia is exceedingly difficult to reprocess. The matrix of beryllium oxide is extremely refractory and chemically inert, being designed to retain fission products within the fuel ball. Grinding and leaching seemed to be the only reasonable approach for the head–end. Remote refabrication was assumed and this led to the use of one cycle of decontamination in solvent extraction. This would give decontamination factors for fission products sufficiently high to minimise their radiation contribution in the final product. Most of the radiation in the final product would then be associated with the daughter products of the in–bred U232. The assumption of the need for remote refabrication, while appearing reasonable with the expected high concentration of U232, could only be verified by further design studies and a much greater understanding of the effect of the concentration of U232 on the problems of refabrication. It has also been assumed that all the thorium and as much moderator as possible should be recycled. These assumptions could only be verified by much more detailed cost studies. Figure 1 shows the steps in the overall process.

The quantities of materials discharged from a single 200 MWe reactor are given in Table 1. These quantities (Bicevskis, private communication) are based on a burnup of 1.0 F.I.F.A. and a first generation (non–equilibrium) core.

TABLE 1

QUANTITIES OF MATERIALS DISCHARGED FROM A SINGLE 200 MWe H.T.G.C.R.

Material	Quantity Discharged/Core kg
$Th^{232}\ O_2$	13,484
$Pa^{232}\ O_2$	24
$U^{232}\ O_2$	0.2
$U^{233}\ O_2$	494
$U^{234}\ O_2$	75
$U^{235}\ O_2$	16
$U^{236}\ O_2$	1.1
$Pu^{239}\ O_2$	2.5
$Pu^{240}\ O_2$	2.9
$Pu^{241}\ O_2$	11.2
$Pu^{242}\ O_2$	11.7
BeO	78,421
Fission Products (after 120 days' cooling)	8.76×10^7 Ci

A cooling time for the fuel of 120 days was selected for the study. The total fission product yield for this cooling time was obtained from Manning (private communication). This fission product loading should not be unreasonable for the solvent extraction system and the cooling time also gives reasonable protactinium losses. The optimisation of cooling time by balancing such factors as inventory and storage costs associated with long cooling periods against higher protactinium losses and fission product loadings for short cooling is beyond the scope of this study and 120 days has been accepted as reasonable.

Based on a nominal throughput of 300 kg/day, the quantities of materials processed by the plant each day are as given in Table 2.

TABLE 2

MATERIAL QUANTITIES REPROCESSED BY PLANT

Material	Quantity per day
ThO_2	43.88 kg
BeO	255.6 kg
PuO_2	0.096 kg
UO_2	1.980 kg
Fission Products	2.85×10^5 Ci

2.1.1 Head-end process

Laboratory studies on the grinding of unirradiated fuel were reported by Baillie and Hubery (1966). Work on the dissolution of this fuel in nitric and sulphuric acid was reported by Shying et al. (1967), Farrell and Isaacs (1965), and Farrell et al. (1966). The flowsheet selected for the head-end process (Figure 2) was based on that work. It was assumed that the experimental data resulting from low level and inactive laboratory scale studies can be applied to fully irradiated fuel and that plutonium and fission products proceed to the various streams in the same proportions as uranium. Flowsheet conditions for dissolution were selected such that 20 per cent. of the beryllia would dissolve in the nitric acid. This means that 3.5 per cent. of the actinides and fission products would appear in the sulphuric acid solution.

2.1.2 Separation of actinides

The flowsheet for actinide separation from the nitric acid stream (Figure 3) is based on TBP solvent and was designed by Baillie and Ryan (1965). Low activity experimental work (up to 1 Ci/l) was reported by Cairns et al. (1967). Once again it was assumed that this work can be extrapolated to fully irradiated fuel. The plutonium does not have a satisfactory isotopic content for recycle and hence has been assumed to be rejected to the beryllium raffinate stream by adding ferrous sulphamate. It was assumed that 99 per cent. recovery of the thorium and 99.8 per cent. recovery of the uranium would be achieved with a decontamination factor of 1000 from fission products.

2.1.3 Beryllium purification

Beryllium purification is by an amine solvent extraction process and the flowsheet (Figure 4) is based on work by Horner and Coleman (1959) who showed that uranium and plutonium could be readily recovered from sulphuric acid-stainless steel decladding solutions using Primene-JMT in a solvent extraction process. Thorium is readily extractable from beryllium sulphate solution by Primene-JMT, as are zirconium, niobium and cerium (Fardy et al. 1966). Results indicated that only beryllium, caesium and strontium are non-extractable. Ruthenium extraction is low and could be a problem. No experiments have been done under high activity conditions. The major problem appears to be the strontium, caesium and perhaps ruthenium contamination of the beryllium sulphate. A more sophisticated flowsheet than presently envisaged may therefore be needed to achieve the decontamination factor of 10^3 required to permit recycle of the beryllia.

2.1.4 Reconversion of actinides and production of fuel particles

The final chemical step in the recycling process is the reconversion of the actinide nitrates to the oxides and the production of spherical fuel particles from these oxides. The flowsheet (Figure 5) is based on the sol-gel process which was developed at O.R.N.L. (Ferguson et al. 1964). This process was chosen because it involves fewer operations and appears to be more suited to remote operation than other available processes.

Make-up plutonia is added to the main stream in the form of a sol, assumed to be manufactured using the published data of Wymer and Coobs (1965). As the batch size is only 200g for criticality reasons, three batches per shift would be necessary and administrative controls would need to be instituted to prevent double batching. It is assumed that the mixed oxide sol can be satisfactorily dehydrated using the conventional O.R.N.L. process.

2.1.5 Refabrication

The flowsheet for refabrication (Figure 6) is based on extensive work with cold materials by the Research Establishment's Fuel Element Development Section (Silver, private communication). It is made up of three parts; beryllia powder preparation, powder blending and fuel element fabrication. In the powder preparation section, beryllia coming from calcination is milled, screened, dried, precompacted and granulated. The 20 per cent. make-up beryllia is prepared in an identical cold line and is used for coating the fuel element. The blending procedure mixes the prepared beryllia, sol-gel fuel particles and the assumed 30 per cent. unsintered reject material recycled from later stages of the fabrication line and precompacts the mix ready for pressing. Fabrication involves isostatic pressing of the fuel element core at 10,000 p.s.i., machining of this core, coating with beryllia using

isostatic pressing at 45,000 p.s.i., followed by baking at 800°C. After machining to size, the green fuel element is sintered for 3 hours at 1450°C in dry air. The assumed 4 per cent. of sintered rejects which arise in the latter stages of refabrication would be recycled to the dissolver although this is not shown on the head-end flowsheets. The refabrication flowsheet also does not show the complex series of quality control tests and inspection required to produce a fuel element to the required specification.

2.2 Equipment Design

Figure 8 gives the list of symbols used in the equipment flowsheets for the various sections of the plant (Figures 9,10, 11, 12, and 13). A flowsheet for the crushing and grinding section is not given but the equipment is shown in the cell layout in Figure 14. No equipment flowsheet for the refabrication section is given but it is assumed to be based on flowsheets developed for cold fabrication by Silver (private communication).

The equipment selection is based on overseas reprocessing plant practice but there are several unusual operations which have no such precedent. Because of this and the fact that no engineering development has been done, there are major uncertainties in several areas of equipment design.

It is not at all certain that the equipment shown for the ball crushing operation is suitable. It was assumed that commercially available crushers, suitably modified for remote installation, operation and maintenance, can be used to break the balls. Whether this is possible would depend, in part, on the condition of the irradiated balls. No work has been done to elucidate this problem. Similarly no tests have been made to check the suitability of the proposed decantation scheme in the dissolvers. Following nitric acid leaching the residue would be dissolved in sulphuric acid. This requires separation of the nitric acid leach liquor from the residue and careful washing of the residue. No design of the decantation scheme was made but it was assumed to be based on sintered metal filters with provision for backwash. One point in favour of this approach is that the nitric acid leach would effectively remove any fine particles leaving a fairly coarse residue to filter.

The choice of zirconium as material of construction for the dissolver system reflects considerable uncertainty in the design. Little corrosion data is available for materials for service in both concentrated nitric and concentrated sulphuric acids. The more expensive tantalum might be preferable since there is some uncertainty about the use of zirconium based materials in strong oxidising environments. Should it not prove feasible to use the one dissolver for both services, the difficult problem of transfer of the solids from one vessel to another would have to be solved. For this study, the more optimistic approach was used.

There are also uncertainties in the beryllium reconstitution area. Crystallisation of the sulphate needs to be done at reduced temperature to form the tetrahydrate rather than the dihydrate which is extremely difficult to handle. An evaporative crystalliser for this service was not designed. Because of the high temperatures of calcination and the very corrosive environment, an acid brick lining has been assumed for the beryllium sulphate calciner. This would create difficult problems of maintenance.

An extrapolation from inactive to active powders would not be expected to produce any difficulties in the ceramic forming techniques used in fabrication. However, there are serious uncertainties in the refabrication equipment design because of the need to shield the equipment. Some allowance has been made for these expected difficulties but much more design and engineering development would be required to ensure that these allowances were adequate.

2.3 Installation and Maintenance Philosophy

Three different equipment installation philosophies were used. The first, for equipment carrying out operations on solids such as the mechanical head-end, involves the use of conventional hot cells with viewing windows and master-slave and electro-mechanical manipulators. Adequate shielding is provided by concrete. The second, used where radiation levels are not as high and chances of equipment contamination are significantly lower, involves the use of glove boxes with unit shielding around specified areas of high radiation field. The third philosophy, for areas of the plant handling liquids, such as the dissolution and solvent extraction areas, involves the use of racks or frames on which equipment is installed. The racks are then placed in cells below ground level and covered with suitable concrete shielding plugs.

2.3.1 Conventional hot cells

Four conventional cells are provided for process steps; one for the mechanical head-end, one for actinide reconversion, one for refabrication, and one for part of the beryllium purification. As well, two cells are provided for decontamination and four smaller cells for sampling and analytical work.

As these cells are equipped with master-slave manipulators and viewing windows, they would be maintained as far as possible without removing the equipment. If the work were beyond the capability of the manipulators, the unit would be decontaminated in the decontamination cell and removed for repair or replacement. The cells are large enough to give space around the equipment for remote maintenance with manipulators. (See the typical equipment layout in Figure 14). Manipulators requiring maintenance would be withdrawn from the cell face and taken to the decontamination area for repair.

2.3.2 Glove boxes

Glove boxes would be used in only two areas. The first is the preparation of make-up plutonium where no shielding is required. The second is the fabrication area. It is assumed that once the powder has been consolidated so that dusting problems are minimal, the equipment can be installed in glove boxes for contamination control and simple inexpensive unit shielding used where necessary. Maintenance would be done by decontaminating the equipment, removing the shielding and working on the equipment through gloves in the containment. Obviously the success of this philosophy depends on the U232 content of the fuel, its age following purification and the amount of dust produced in the operations. All these points are uncertain at this stage.

2.3.3 Liquid handling cells

Four liquid handling cells are provided; the dissolution cell, the actinide separation cell, the waste handling cell, and one for the solvent extraction part of the beryllium purification process. The installation philosophy for these cells combines both direct and remote maintenance schemes utilising the best features of both schemes and very largely eliminating their disadvantages. The philosophy is a development of the rack concept used in the Trans-Uranium Facility at O.R.N.L. (Unger et al. 1962, Yarbro et al. 1962). It is particularly suited to small plants such as the one in this study and provides many advantages which show as reduced costs for both the facility and the equipment.

The method of installation is based on the use of modular racks containing all the necessary equipment, piping and instrumentation and which are prefabricated in the workshop and lowered into simple shielded cells below ground level. Figure 15 shows a typical equipment layout on a rack. Inter-connections with service, instrumentation, sampling and process lines from outside the cell are made by using semi-remote disconnects at the top of each rack. The many lines that enter the cells are precast in removable shielding plugs that fit in slots in the cell wall. This obviates the need to cast any pipes permanently in the shielding, thereby simplifying the shielding design and construction. Mixer settlers were selected for solvent extraction sections of the process because pulsed columns require much greater head room and are not as suitable for use with this installation philosophy.

Items such as mixer settler drives, pumps, steam jets and valves, which can be expected to require maintenance in continuous service are positioned on the rack so that they can be seen and reached with long tools from the cell top. They are connected into the plant piping with disconnects which can be operated with long tools. Should an item of equipment fail in service it can be replaced semi-remotely after a limited decontamination of the equipment and removal of a section of the cell roof. Most normal maintenance can be handled in this way, thereby minimising the need for costly equipment duplication. In the event of a major plant failure, the whole rack can be decontaminated and removed from the cell for maintenance and repairs.

Operation of the cells would be on a continuous three-shift basis. Recycle of liquid streams has been provided for in a limited number of cases. A large number of in-line monitors and analysers minimises the requirement for recycle and the chance of large losses of valuable materials to waste streams.

2.4 Waste Handling

2.4.1 Gaseous waste

Gaseous waste handling is conventional. Both vessel off-gas and cell off-gas, after filtering through roughing and absolute filters, is discharged by stack together with the rest of the building ventilation discharge. Severe dust problems would arise in the mechanical head-end cell and in the refabrication area so extra filters would have to be installed there to prevent dust clogging the main plant roughing filters. Most of the gaseous fission product release would occur when the balls are crushed, so it might be necessary to install a small gas cleanup circuit in the mechanical head-end cell. Sufficient space has therefore been allowed in the cell.

Tritium may be very troublesome, largely because of the additional build-up in the fuel due to neutron irradiation of the beryllium and it might not be possible to release it from the stack with the normal gaseous wastes. Provision would then need to be made for recycle of the tritium within the plant and eventual discharge into the high-level liquid waste. However, such treatment is not allowed for in this study and it has been assumed to be discharged with the rest of the gaseous effluent.

2.4.2 Solid waste

Solid wastes would consist mainly of discarded equipment and general wastes arising from plant operation and decontamination. A suitable burial ground adjacent to the plant is assumed to be available for routine disposal of these solid wastes. Space for decontamination and packaging, and flasks for transport of these wastes are provided.

2.4.3 Liquid waste

Liquid waste arisings are divided into high-level, intermediate-level, and low-level categories (see Figures 7 and 13). High-level waste, arising mainly as solvent extraction raffinates, would be evaporated to a beryllium concentration of 2.5M. Crystallisation of beryllium salts could be troublesome much beyond this concentration. The evaporator concentrate would be permanently stored in 100,000 gal. cooled and agitated stainless steel tanks. Agitation would be by internal airlift sparging with the tank off-gas adequately filtered. For costing purposes a tank life of 50 years is assumed.

The intermediate-level waste would arise from many points in the plant and is really liquid having too high a radioactive content to be discharged to the environment. This waste is also evaporated, a concentration ratio of 100:1 being assumed. The condensate would be sufficiently decontaminated for disposal as low-level waste. The evaporator concentrate would pass to the high-level system. Such a scheme could lead to chemical incompatibilities such that the two waste evaporator concentrates would need to be stored separately. Also because the high-level evaporator condensate feeds into the intermediate-level system, a closed loop would be set up and this could give rise to problems of build-up of certain fission products in recycling streams. These problems have not been investigated in this study.

Low-level waste from the plant would comprise mainly steam condensate from heating jackets and bleed-off from the cooling water recirculation system. The intermediate-level evaporator condensate would feed into this system as well as many other minor streams. In addition, large volumes of waste would arise in areas such as active change-rooms and these are also fed into the low-level waste system. All these wastes would have to be collected in large (125,000 gal.) holding ponds and analysed before discharge to the environment.

It is assumed that throughout the intermediate and low-level waste systems, in-line monitors would provide early warning of unexpectedly high radiation levels. This would enable the appropriate diversions of the relevant streams to be made, thereby avoiding the recycling of large volumes of waste.

2.5 Building Design and Layout

Normal safety practices were followed in the design of the plant. Adequate biological shielding is provided and all equipment is doubly contained to maintain control of contamination spread in the event of a major incident. Like operations are grouped and an attempt is made to maintain a logical flow of materials and easy movement of personnel around the facility. Figure 16 illustrates this for the refabrication area.

Figure 17 shows how the shielded liquid handling cells are placed between two lines of hot cells, the whole area being serviced by an overhead crane. This area is one of high potential contamination (classified on the plan in Figure 17 as a red area) and space for other operations such as sampling and analysis, equipment decontamination and maintenance, and plutonium make-up has been included in this central area. Around this central zone is one of lesser potential contamination (classified as blue) which provides space for operating the cells, further maintenance and analytical work, and all the refabrication equipment that is enclosed in glove boxes with unit shielding. The essentially clean areas required for offices, stores, plant room and laundry facilities are spaced around the periphery of the building. By zoning in this way and carefully controlling personnel movement between the zones, contamination spread around the plant is minimised.

The ventilation system for the facility is designed to maintain the various zones at progressively lower negative pressures as the contamination risk rises. It is assumed that all air entering the facility would be filtered and that two stages of filtration would be given to all exhaust air to the stack. Conventional absolute filters are used for the final stage. The capacity of the main ventilation system is of the order of 100,000 ft^3/min. This would provide for about 20 air changes per hour in the cells and 5 air changes per hour in the red and blue contamination zones. Clean areas would have their own local ventilation systems where needed.

The total floor area of the building is about 42,000 ft^2. Additional features required (not shown in Figure 17) are garages for vehicles, the high-level waste tank farm, and low-level delay ponds.

2.6 Process Control

Control of the plant would be maintained by conventional sampling of various points in the plant indicated in the flowsheets. However, only a small number would be in routine use. The following table indicates the expected number and frequency of these routine analyses during normal running of the plant.

Analysis	Frequency per day
Gross γ	5
Gross β	5
Gross $\beta\gamma$	16
Caustic strength	2
Acid strength	13
Total solids	3
Pu concentration	16
U concentration	7
Th concentration	17
Be concentration	16
γ spectra	2
α spectra	1
Sieve analysis	3

To minimise the number of routine analyses required and to improve plant operation, it is assumed that a number of in-line monitors would be used. Thus in the waste system several γ monitors are shown (Figure 13). This type of monitor is well developed and used extensively in plants overseas. For the actinide separation section (Figure 12) and the beryllium purification section (Figure 11), several monitors for actinides are specified. Similar monitors have been used in plants overseas but no monitors specifically for the requirements of this plant have been developed. It is assumed that such development is feasible.

The laboratory provides for the handling of all normal analyses required to operate the plant. However, special analyses requiring expensive equipment, such as a mass spectrometer, or arising out of plant study or research and development, are assumed to be done on contract with some suitable laboratory. This minimises capital outlay for equipment that cannot be fully utilised. It is also assumed that the process is fully developed before the plant is built. Thus very few analyses would be required for flowsheet proving.

In–plant instrumentation for liquid level, density, temperature, interface measurement and the like would be conventional. Level and density measurement would be by the well–proven pneumatic technique. Provision is made for fissile accounting throughout the plant using conventional techniques such as ball counting and weighing of products, coupled with the necessary analyses.

2.7 Services

Normal services such as electricity, steam, compressed air, demineralised water and cooling water are provided. Equipment for steam production, compressed air supply and demineralised water is provided within the confines of the plant. It is anticipated that peak requirements for steam would be 14,000 lb/hr at 100 p.s.i.g., for compressed air 1,000 ft^3/min, and for demineralised water 2,200 gal/day.

Storage for demineralised water and bulk chemicals such as nitric and sulphuric acids is provided. Any storage for raw water is assumed to be provided as part of the site development.

3. CAPITAL COST ESTIMATES

The preliminary capital cost estimates for this facility are based on previous site experience, experience in the Australian chemical industry and overseas experience in similar plants. Because of the lack of experience in this country with this type of facility and the difficulty of relating overseas cost experience to the Australian scene, these estimates are bound to involve considerable uncertainty. The costs are presented in some detail to make the study more meaningful. All costs are given in Australian dollars.

3.1 Installed Equipment

Costs for delivered process equipment for each section of the plant are given in Appendix 1. Allowance is made for the cost of modifying standard equipment before installation. These modifications involve equipment design changes to minimise dust release to the cells, to facilitate equipment decontamination, to simplify remote maintenance or replacement of equipment, and to replace radiation sensitive components. Costs for equipment in the refabrication area were adapted, with assistance from staff in the Research Establishment's Fuel Element Development Section, from estimates for similar equipment for inactive work. Adjustments were made for change in size where required and additions were made for modifications for remote operation and maintenance.

Costs for non–process equipment are also given in Appendix 1. This includes equipment for analytical and health physics laboratories, workshop and decontamination areas. It also includes items such as vehicles and equipment for the laundry.

Appendix 2 shows the estimated cost of installing the equipment in the various cells. Estimates for piping were made from building layouts and the service plugs for running pipes through the shielding were taken as an equipment installation cost rather than a building cost. In–line monitoring and sampling costs are also listed in Appendix 2. Instrumentation and electrical costs are given and these have been factored from the installed equipment costs. Instrumentation for the refabrication section of the plant is not included in these costs. (See Appendix 3).

3.2 High–Level Liquid Waste

Estimates for the cost of storing high–level waste are based on U.S. experience with waste of a similar fission product concentration. It is assumed that arrangements must be made for perpetual storage. This involves periodic replacement of the storage tanks and perpetual surveillance of the tank farm even after the processing facility has ceased to function. The method proposed to provide the money for tank replacement is to invest a certain sum when the tank is bought. The investment must

provide at the end of the tank life just enough money to replace the tank and set up a new fund. Obviously, the tank life is not known and there is very little operating information available to guide the selection of a suitable tank life. Also, the future interest expected from such a fund and the changes in money values cannot be predicted. Although the approach to costing waste storage involves several uncertainties, it is considered reasonable.

Storage for 2 years' arisings is provided by a 108,000 gal. stainless steel tank. A similar tank is provided as a spare for emergency use. These tanks are assumed to cost $9/gal. A tank lifetime of 50 years is assumed for estimation of replacement fund requirements and it is assumed that surveillance costs are 1 per cent. of the installed capital cost of the waste farm. Invested funds are assumed to earn interest at 4 per cent. Adding the replacement and surveillance charges to the unit cost of the tanks gives a total waste storage cost of $13/gal.

3.3 Building and Cells

Appendix 4 shows the details of the costs for building and cells. In estimating costs of concrete a differentiation was made between concrete for the liquid process cells which requires only minimal formwork and that for the more complicated solids handling cells which, because of the many penetrations, requires much more complicated formwork. Similarly, the more simple building required for the refabrication area was costed at a lower unit cost than the more complicated high bay area.

Service and utility costs were factored from the total costs of installed equipment including non-process equipment and waste. A factor of 0.15 was assumed.

3.4 Other Items of Capital Cost

As the site for the facility is assumed to be a new one, much expense would be involved in site development. These costs were factored from the cost of physical plant but are markedly dependent on its location and hence there is considerable uncertainty in the actual costs involved. No allowance was made for land purchase which could add greatly to the already high capital cost of the project.

Design and engineering charges were also factored from costs of installed equipment costs. The factor used is 0.30. The processes involved in the facility are new and complex and it must therefore be expected that design charges would be high. The costs shown are expected to cover development charges associated with the design, but certainly do not cover research costs for process development. Architects' fees and construction overheads were estimated from the costs of the buildings and site using a factor of 0.20. These are expected to cover building design costs and all normal supervision and construction overheads during the building of the facility.

Pre-operational or start-up costs were estimated as one year's operating costs. This is typical practice for similar plants overseas. An allowance was also made for working capital, but this depends markedly on arrangements for the supply of such things as make-up fissile material. It is expected to cover the costs of holding spare items of major equipment. With the chosen installation and maintenance philosophy, it is important to have a fairly comprehensive stock of spare parts since equipment duplication in the plant is minimal. A figure of 5 per cent. of costs of installed equipment excluding costs of waste plus 10 per cent. of the annual operating cost was used.

A contingency of 30 per cent. is used. At the present stage of design and process development, nothing less could realistically be chosen.

Capital costs for the facility are summarised in Table 3.

TABLE 3

CAPITAL COST SUMMARY

	$A	$A
A. (i) Delivered Process Equipment (Appendix 1)	2,648,000	
(ii) Installation (Appendix 2)	2,481,000	
Total Process Equipment Cost		5,129,000
B. Non--Process Equipment – Installed (Appendix 3)		440,000
C. Instrumentation and Electrical Equipment (Appendix 3)		1,300,000
D. High–Level Permanent Waste Storage Tanks		2,800,000
E. Buildings and Cells (Appendix 4)		3,225,000
F. Services and Utilities, calculated as 15% of Installed Equipment (A,B,C,D)		1,450,000
Sub–Total, Physical Plant Cost		$14,344,000
G. Site Improvements, calculated as 7% of Physical Plant		1,004,000
H. Design and Engineering Charges for Equipment		2,901,000
I. Architects' Fees and Construction Overhead		1,136,000
J. Startup Cost		3,093,000
K. Working Capital		652,000
Sub–Total, Total Plant Cost		$23,130,000
Contingency 30%		$6,939,000
TOTAL CAPITAL COST		$30,069,000

4. OPERATING COSTS

The estimated direct operating costs are given in Table 4 and a breakdown of these costs is shown in Appendix 5. These do not include capital charges.

TABLE 4

DIRECT OPERATING COST SUMMARY

	$A
Labour	784,000
Chemicals	110,000
Waste	700,000
Services	149,000
Other Supplies	460,000
Contract Analytical Work	550,000
Contract Medical and Health Physics Services	200,000
Contract Maintenance	150,000
	$3,103,000

4.1 Labour

An assessment was made of the staff required to operate the plant effectively. Three-shift operation was assumed, thereby requiring four shifts of personnel. Allowance was made for stores, workshop, and clerical staff, guards etc. A 25 per cent. loading was provided for holiday and sick leave and other benefits.

By estimating labour costs in this way, both payroll and plant overheads were included. However, no allowance was made for corporate administration costs. These should not be great as there is assumed to be only one facility and a simple administrative organisation. In keeping with the optimistic nature of the cost estimation in this study, corporate administration costs were omitted. The classification of overheads is that of Buchanan and Sinclair (1964).

4.2 Chemicals

The cost of major chemicals for the plant is given in Appendix 5. Nitric acid and solvent make-up contribute by far the greatest part. The assumption that 1 per cent. of throughput is a reasonable make-up figure for the solvent is most uncertain. This figure would depend on the amount of radiation damage suffered by the solvent and on the entrainment losses from the solvent extraction system. Both these factors are functions of the design of the contactors.

4.3 Waste

The annual cost of high-level waste is a function of the amount of new tank volume required each year and the surveillance costs for the tank farm which must be supervised long after the processing plant has shut down. The annual high-level waste arisings total 54,000 gallons. For simplicity, it was assumed that the cost of new tank capacity is given by the product of the annual arisings and the unit cost of storage given in Section 3.2 (that is, $13/gal.), even though new tanks might only be installed every two years. This gives an annual high-level waste storage cost of $700,000.

4.4 Services and Other Supplies

Estimates for services were based on the use of fuel oil for the production of steam. Other supplies were assumed to include all direct operating supplies other than the chemicals shown in Section 4.2. Such items as replacement grinding media come into this category. All indirect supplies and consumable stores items were also included as other supplies. So have maintenance materials, although spare major equipment items were provided for in the working capital.

4.5 Contract Work

To minimise the employment of specialist staff that cannot be fully occupied and to reduce expenditure on major items of equipment that cannot be fully utilised, it was assumed that contracts could be arranged for all non-routine analyses including those for fissile material accounting, plant study and raw materials specification, personnel dosimetry, personnel medical examinations, much of the health physics and environmental surveys and all scheduled maintenance of cold equipment and buildings.

This assumption depends on the availability of organisations to do such contract work. It should be feasible to negotiate this type of contract when a nuclear power technology has been established in Australia.

5. SUMMARY AND CONCLUSIONS

The facility described for recycling this difficult fuel is a large, complex unit, with high capital and operating costs. The cost estimates depend on the validity of the assumptions on which

the flowsheets (Section 2.1) are based. Even more important are the assumptions concerning the engineering feasibility of parts of the flowsheet and which would be of major consequence if invalid. For example, the assumption that the fuel balls can be mechanically broken down has a marked bearing on the costs for the head-end. The assumed costs of equipment for operations on active solids in the hot cells also have a great effect on the equipment costs given in Appendices 1 and 2. The material of construction of the dissolver, assumed to be zirconium, has not been proved and the dissolver costs form a significant part of the head-end costs. Nor has the difficult solids decantation step in the head-end been proved. The alternative to doing both nitric acid and sulphuric acid dissolutions in the one vessel is an even more uncertain step. No matter which approach is used, a technically difficult head-end results and its cost is most uncertain at the present stage of development.

Other areas of the flowsheet also have their uncertainties but they are perhaps not quite so critical as the head-end. The installation philosophy used for the liquid handling cells is unproved but seems reasonable. It gives considerable savings in the shielded building space required when compared with conventional installation techniques.

There are major uncertainties in the capital and operating costs given, but for a conceptual design estimate, these are believed to be reasonable and quite adequate for preliminary assessments of the fuel cycle economics. Because of the many optimistic assumptions made during the course of the study, it is believed that the costs given would tend to be low. This should, in part, be offset by the appreciable contingency used.

6. ACKNOWLEDGEMENTS

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APPENDIX 1

COSTS OF DELIVERED EQUIPMENT

Summary:

		$A
Mechanical Head–End	(Table A)	56,000
Dissolution	(Table B)	823,400
Actinide Separation	(Table C)	123,400
Beryllium Purification	(Table D)	136,100
Sol–Gel and Plutonium Make–up	(Table E)	104,200
Waste Handling	(Table F)	140,800
Cold Make–up Equipment	(Table G)	54,100
Refabrication	(Table H)	1,210,000
		$2,648,000

Tables A to H follow.

APPENDIX 1 (continued)

TABLE A. EQUIPMENT LIST – MECHANICAL HEAD-END

Item	Component	Material	Comments	Cost $A
1.	2 x 350 ℓ Hopper	304L		1,600
2.	4 x Vibrating Conveyor	304L	One is 2' 6" long, 2 at 2' 9" long, one at 4' 6" conveys material to the dissolvers	4,700
3.	2 x Jaw Crusher		2" x 6" gape	14,000
4.	1 x Gyratory Separator	304L	3 deck, 24" dia.	6,000
5.	3 x Vibratory Ball Mill	304L		18,000
6.	1 x Vibrating Spiral Elevator	304L	8' 6" lift	9,700
7.	20 x Remote Disconnects	304L	For 2" pipe	2,000
			Total:	$56,000

TABLE B. EQUIPMENT LIST – DISSOLUTION

Item	Component	Material	Comments	Cost $A
1.	2 x 1000 ℓ Jacketed Dissolver	Zirconium	1" thick plate assumed	640,000
2.	2 x Reflux Condenser	Zirconium		60,000
3.	Dissolver Off-Gas Scrubber	316L		1,500
4.	1 x 50 ℓ Tank	316L		1,400
5.	1 x 1500 ℓ Tank	High Mo/Cu S.S. alloy	For use with H_2SO_4	4,500
6.	1 x 1500 ℓ Tank	304L		2,700
7.	3 x 1100 ℓ Tank	304L		7,200
8.	1 x 4000 ℓ Tank	304L		5,000

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
9.	Evaporator	316L	Assume 2' x 4' long	7,000
10.	Heat Exchanger	316L	Assume 50 ft² area	5,000
11.	Fractionation Column	316L	Assume 1' x 10' long	5,000
12.	Reboiler	316L	Assume 50 ft² area	5,000
13.	Condenser	316L	Assume 50 ft² area	5,000
14.	Cooler	316L	Assume 7 ft² area	1,600
15.	1 x 1000 ℓ Tank	304L		2,300
16.	17 x Steam Jet		Assume 9 of these require special materials, e.g., zirconium	3,900
17.	3 x Valve	304L	Flow control type	3,300
18.	2 x Dissolver Sealing Valve	304L	For charging chute	20,000
19.	3 x Diverter	304L		2,400
20.	1 x Piston Metering Pump	Monel	DCL "M" type pump, for handling sodium hydroxide	600
21.	4 x Decantation Filter	Zirconium	Remote replacement required	40,000
			Total:	$823,400

TABLE C. EQUIPMENT LIST – ACTINIDE SEPARATION

Item	Component	Material	Comments	Cost $A
1.	3 x 1100 ℓ Tank	304L		7,500
2.	1 x Extraction Mixer Settler	304L	2 stages	5,000
3.	1 x Scrub Mixer Settler	304L	16 stages	26,000
4.	1 x Strip Mixer Settler	304L	3 stages	6,500

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
5.	7 x 1400 ℓ Tank	304L		18,900
6.	2 x Packed Column	304L	4" dia. x 4' long	4,000
7.	4 x 450 ℓ Tank	304L		7,200
8.	1 x Evaporator and Heat Exchanger	316L	16 ft^2 area	9,000
9.	1 x Condenser	316L	15 ft^2 area	1,500
10.	1 x Cooler	316L	0.26 ft^2 area	1,000
11.	3 x Diaphragm Pump	304L	Remote duplex head – Weyburn type	6,000
12.	19 x Steam Jet	304L		2,900
13.	5 x Diverter	304L		4,000
14.	1 x Valve	304L	Flow control type	1,100
15.	2 x Valve	304L	Assume Mason–Neilan type remote operated, diaphragm sealed	1,000
16.	1 x 50 ℓ Tank	304L		1,400
17.	1 x 1000 ℓ Tank	304L		2,400
18.	1 x 1400 ℓ Jacketed Tank	316L		8,000
19.	1 x Reflux Condenser		Assume 120 ft^2 area	10,000
			Total:	$123,400

APPENDIX 1 (continued)

TABLE D. EQUIPMENT LIST – Be PURIFICATION

Item	Component	Material	Comments	Cost $A
1.	2 x 5400 ℓ Tank	316L		14,000
2.	1 x Extraction Mixer Settler	316L	2 stages	5,000
3.	1 x Strip Mixer Settler	316L	3 stages	6,500
4.	1 x Diaphragm Metering Pump	316L	Remote duplex head – Lapp type	10,000
5.	1 x Diaphragm Metering Pump	304L	Remote duplex head – Weyburn type	2,000
6.	1 x 540 ℓ Tank	304L		1,800
7.	1 x Wash Column	304L	Packed with Raschig rings, 3" dia. x 4' long	2,000
8.	2 x 225 ℓ Tank	304L		3,400
9.	2 x 225 ℓ Tank	316L		4,000
10.	1 x 50 ℓ Tank	304L		1,700
11.	1 x Condenser	316L	90 ft² area	6,500
12.	1 x Evaporative Crystalliser	316L	With vacuum pump, heat exchanger and circulation pump	10,000
13.	1 x Continuous Centrifuge	316L		10,000
14.	1 x Calciner	Acid Brick	10' heated length, 2' diameter, continuous operation, directly heated	31,000
15.	3 x Product Bin	304L		3,000
16.	1 x 500 ℓ Tank	Incoloy 825	For use with H_2SO_4	3,000
17.	1 x Packed Column	Zirconium	SO_3 scrubber condenser, 1' dia. x 6' long	3,100
18.	1 x Packed Column	316L	SO_2 scrubber condenser, 8" dia. x 6' long	2,000
19.	8 x Steam Jet	316L		1,200

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
20.	2 x Diverter	304L		1,600
21.	3 x Valve	304L	Assume Mason–Neilan type remote operated, diaphragm sealed	1,500
22.	1 x 1600 ℓ Tank	316L		2,800
23.	1 x Diaphragm Pump	316L	Remote duplex head – Lapp type	10,000
			Total:	$136,100

TABLE E. EQUIPMENT LIST – SOL–GEL AND PLUTONIUM MAKE–UP

Item	Component	Material	Comments	Cost $A
1.	Rotary Denitrator and Furnace	316L		20,000
2.	4 x 100 ℓ Tank	304L		6,000
3.	Condenser Scrubber		2' dia. x 6' high overall	2,000
4.	80 ℓ Slab Tank	304L	Critically safe	3,000
5.	Dehydration Column	304L	4" dia. x 6' high. Tapered column, close tolerances required on taper	10,000
6.	Filter Classifier	304L	Complicated remote solids removal required. Unit is as yet undesigned	5,000
7.	Evaporator	316L	70 ft^2 area	6,000
8.	Heat Exchanger	316L	450 ft^2 area	9,000
9.	Condenser	316L	4 ft^2 area	1,000
10.	Liquid–Liquid Separator	304L		500
11.	2 x 1450 °C Sintering Furnace	Inconel Trays	5 kW each with super Kanthal heating elements	12,000
12.	60 ℓ Bin	304L	Product storage bin	600

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
13.	3 x Canned Motor Pump	304L	Capacity 1 g.p.m.	3,600
14.	Sol Feed Pump	304L	Infusion withdrawal pump	1,200
15.	Gravimetric Balance		Satorius 2100, modified for in-cell use	1,000
16.	3 x Steam Jet	316L		500
17.	2 x Diverter	304L		1,600
18.	4 x Valve	316L	Flow control type	4,400
19.	Plutonia Sol Preparation Equipment		5 gloveboxes, with equipment on a laboratory scale	15,000
20.	1 x 450 ℓ Tank	304L		1,800
			Total:	$104,200

TABLE F. EQUIPMENT LIST - WASTE HANDLING

Item	Component	Material	Comments	Cost $A
1.	2 x Jacketed Tank	316L	800 gal capacity	20,000
2.	2 x 1500 gal Tank	304L		14,000
3.	1 x Intermediate Level Evaporator	316L	2½' dia. x 6' long	7,000
4.	1 x Heat Exchanger	316L	160 ft^2 area for item 3	8,000
5.	1 x Condenser	316L	130 ft^2 area for item 3	7,000
6.	2 x 150 gal Tank	304L		4,000
7.	1 x High Level Evaporator	316L	1½' dia. x 5' long	2,500
8.	1 x Heat Exchanger	316L	25 ft^2 area for item 7	3,000
9.	1 x Condenser	316L	20 ft^2 area for item 7	3,000

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
10.	24 x Diverter	304L		19,200
11.	6 x Steam Jet	316L		900
12.	2 x Valve	304L	Flow control type	2,200
	OUT-OF-CELL WASTE EQUIPMENT			
13.	2 x Low Level Tanks	Concrete	125,000 gal	40,000
14.	2 x Ion Exchange Column	Mild Steel	Low activity level	10,000
			Total:	$140,800

TABLE G. EQUIPMENT LIST - COLD MAKE-UP AREA

Item	Component	Material	Comments	Cost $A
1.	5 x Piston Pump	316L	DCL, series "M" type	2,500
2.	4 x 1000 ℓ Tank	304L		7,600
3.	3 x 3000 ℓ Tank	304L		10,200
4.	1 x Piston Pump	Monel	DCL, series "U" type	1,500
5.	2 x Piston Pump	304L	DCL, series "U" type	2,700
6.	1 x 100 ℓ Jacketed Tank	304L	Make-up thoria dissolver	1,500
7.	1 x 10 ℓ Tank	304L		500
8.	1 x Condenser	304L		600
9.	1 x Packed Column	304L	1' dia. x 6' high	300
10.	2 x 150 ℓ Tank	304L		2,400
11.	1 x 1000 ℓ Tank	High Mo/Cu S.S. alloy	With mixer to handle H_2SO_4 solutions	3,800

(continued)

APPENDIX 1 (continued)

Item	Component	Material	Comments	Cost $A
12.	1 x 20,000 ℓ Tank	Mild Steel	To handle 18M H_2SO_4	10,000
13.	1 x 15,000 ℓ Tank	304L		10,000
14.	1 x Centrifugal Pump	Mild Steel	For 18M H_2SO_4 transfer	500
			Total:	$54,100

TABLE H. COSTS OF REFABRICATION EQUIPMENT

Sub-section	Delivered Cost $A	Comments
1. BeO powder preparation	200,000	Includes 100% for modification
2. BeO-fuel blending	70,000	
3. Make-up BeO line	70,000	
4. Refabrication line	750,000	Includes 50% for modification
5. Transit tunnel	50,000	
6. Return line (vibratory conveyors)	50,000	
7. Laboratory equipment	20,000	
	$A1,210,000	

These costs include allowances for enclosures and shielding for the refabrication line; also all instrumentation costs.

APPENDIX 2

EQUIPMENT INSTALLATION COSTS

Equipment Installation Cost Summary:

	$A
1. Mechanical Head–End	260,000
2. Dissolution	84,000
3. Actinide Separation	98,000
4. Beryllium Purification	146,000
5. Sol–Gel and Plutonium Make–up	128,000
6. Waste Handling	88,000
7. Cold Make–up	54,000
8. Refabrication	587,000
9. Piping	625,000
10. Service Plugs	93,000
11. Sumps (ejection, piping and monitoring)	150,000
12. In–line analytical and sampling (installed cost)	168,000
	$2,481,000

APPENDIX 2 (continued)

EQUIPMENT INSTALLATION COSTS

	$A	
1. Mechanical Head-End		
(a) Equipment installation cost including flexible stainless steel lines, at 200% of delivered cost	110,000	
(b) Special dust collection cost	50,000	
(c) Miscellaneous items including weighing, ball counting devices and valves	100,000	
		$A260,000
2. Dissolution		
2 racks	62,000	
Disconnects, 200 at $A60 each	12,000	
Miscellaneous, including initial installation of racks in cell	10,000	
		$A84,000
3. Actinide Separation		
3 racks	64,000	
Disconnects, 400 at $A60 each	24,000	
Miscellaneous, including initial installation of racks in cell	10,000	
		$A98,000
4. Beryllium Purification		
(a) Liquid		
4 racks	28,000	
Disconnects, 200 at $A60 each	12,000	
Miscellaneous, including initial installation of racks in cell	5,000	
		$A45,000
(b) Solid		
Installation	75,000	
Disconnects, solid and liquid	6,000	
Dust control equipment	10,000	
Miscellaneous	10,000	
		$A101,000

(continued)

APPENDIX 2 (continued)

5. Solid-Gel and Plutonium Make-up	$A	
Installation	110,000	
Disconnects, solid and liquid	8,000	
Miscellaneous	10,000	
		$A128,000
6. Waste Handling		
4 racks	53,000	
Disconnects, 200 at $A60 each	12,000	
Miscellaneous, including initial rack installation	8,000	
Installation of low-level piping and ion exchanger (calculated as 30% of low-level tanks cost)	15,000	
		$A88,000
7. Cold Make-up		
100% of delivered costs		$A54,000
8. Refabrication		
Calculated as 100% on items 1, 2 and 5 of Table H, Appendix 1,	320,000	
and 30% on items 3, 4, 6 and 7 of Table H, Appendix 1	267,000	
		$A587,000
9. Piping		
Rack piping, 15,000 ft at $A10/ft installed	150,000	
Instrument piping, 43,000 ft at $A5/ft installed	215,000	
Cold make-up piping, 13,000 ft at $A5/ft installed	65,000	
Active piping, 4,500 ft at $A10/ft installed	45,000	
Miscellaneous piping, including decontamination lines and electrical lines, 30,000 ft at $A5/ft installed	150,000	
		$A625,000
10. Service Plugs		
17 plugs at $A2,500 each	43,000	
Plug piping	50,000	
		$A93,000
11. In-line Analytical and Sampling (installed equipment costs)		
4 in-line monitors for actinides	40,000	
10 in-line gamma monitors	50,000	
13 no-flow alarms	13,000	
Sampling equipment and carriers	65,000	$A168,000

APPENDIX 3

COSTS OF NON-PROCESS EQUIPMENT, INSTRUMENTATION, AND ELECTRICAL EQUIPMENT

Costs of Non-process Equipment:

	$A
(1) Analytical laboratory and health physics equipment (installed)	193,000
(2) Maintenance workshops and decontamination equipment (installed)	119,000
(3) Special remote maintenance equipment, vehicles, miscellaneous	65,000
(4) Laundry, office furniture, miscellaneous laboratory equipment	63,000
	$440,000

Instrumentation and Electrical Equipment:

Costed as 30 per cent. of all installed process equipment excluding equipment for refabrication. (Refabrication instrumentation has been included in refabrication equipment costs).

$1,300,000

APPENDIX 4

BUILDING AND CELL COSTS

	$A	
1. All excavation, including cell space and foundations, 3000 yd^3 at $A5/$yd^3$.	15,000	
Shielding and foundation concrete		
simple construction, 1200 yd^3 at $A60/$yd^3$	72,000	
complex construction, 1450 yd^3 at $A100/$yd^3$	145,000	
		$232,000
2. Basic conventional building cost		
15,500 ft^2 at $A25/$ft^2$	388,000	
28,000 ft^2 at $A30/$ft^2$	840,000	
		$1,228,000
3. Building and cell ventilation assuming cells require 20 air changes/hr and other areas 5 air changes/hr, total air movement is approximately 100,000 ft^3/min		$350,000
4. Manipulators, master slave and electrochemical, 46 master slave manipulators at $A5,500 each	253,000	
2 handling trolleys	12,000	
2 electromechanical manipulators at $A36,000 each	72,000	
		$337,000
5. Cell Windows		
23 windows at $A11,400 each including relevant linings	262,000	
2 window trolleys at $A2,800 each	6,000	
		$268,000
6. In-cell Cranes (2) including track assemblies, installation and power rails		$37,000
7. Cell Doors		
16 doors at $A12,500 each including rear and inter-cell doors		$200,000
8. Flasks		
6 internal use flasks at $A10,000 each	60,000	
3 external use flasks at $A16,500 each	50,000	$110,000
9. Posting Facilities		
5 facilities for analytical cells at $A5,000 each	25,000	
5 larger facilities for bulk movements at $A10,000 each	50,000	
		$75,000

(continued)

APPENDIX 4 (continued)

	$A
10. Stainless Steel Cell Linings	
12 gauge 304L 14,000ft^2 at $A12/ft^2	$168,000
11. Storage Holes in Vault	$20,000
12. Plugs for service lines for all conventional hot cells including conveyor hole to dissolver	$100,000
13. Special equipment, including viewing devices, vacuum cleaning for cells and radiation monitoring equipment	$100,000
	$3,225,000

APPENDIX 5

OPERATING COSTS

Labour Costs	$A	
1 at $A7,000 p.a.	7,000	plant supervisor
5 at $A6,000 p.a.	30,000	3 deputies, accountant and lab. supervisor
13 at $A5,000 p.a.	65,000	8 shift supervisors and lab. personnel
175 at $A3,000 p.a.	525,000	operators, and indirect labour
	627,000	
Add 25% overhead	157,000	
	$784,000	

Chemical Costs	$A
94% H_2SO_4, 9 x 10^4 litres at 9¢/litre	8,000
70% HNO_3, 1.5 x 10^5 litres, 12¢/lb.	44,000
Na_2CO_3, 23,000 kg, 8¢/kg	2,000
Organic solvent, 1% of throughput	
$A2/lb, including T.B.P. and amines	46,000
$Al(NO_3)_3$, 12 ton, at $A460/ton	6,000
Other miscellaneous chemicals	4,000
	$110,000

Waste (see Section 4.3)

Annual arisings = 54,000 gal or ½ tank capacity, therefore,	
physical cost of ½ tank	495,000
Perpetual replacement fund charge	81,000
Perpetual surveillance fund charge	124,000
Total Annual Cost	$700,000

(continued)

APPENDIX 5 (continued)

Services	$A
Electricity, 2.8×10^6 kWh at 1.6¢/kWh	45,000
Fuel Oil, 3×10^6 lb at 3¢/lb	100,000
Water, 2×10^7 gal at 20¢/1000 gal	4,000
	149,000
Contract Analytical Work	550,000
Contract Medical and Health Physics Services	200,000
Contract Maintenance	150,000
Other supplies	460,000
DIRECT OPERATING COST	$3,103,000

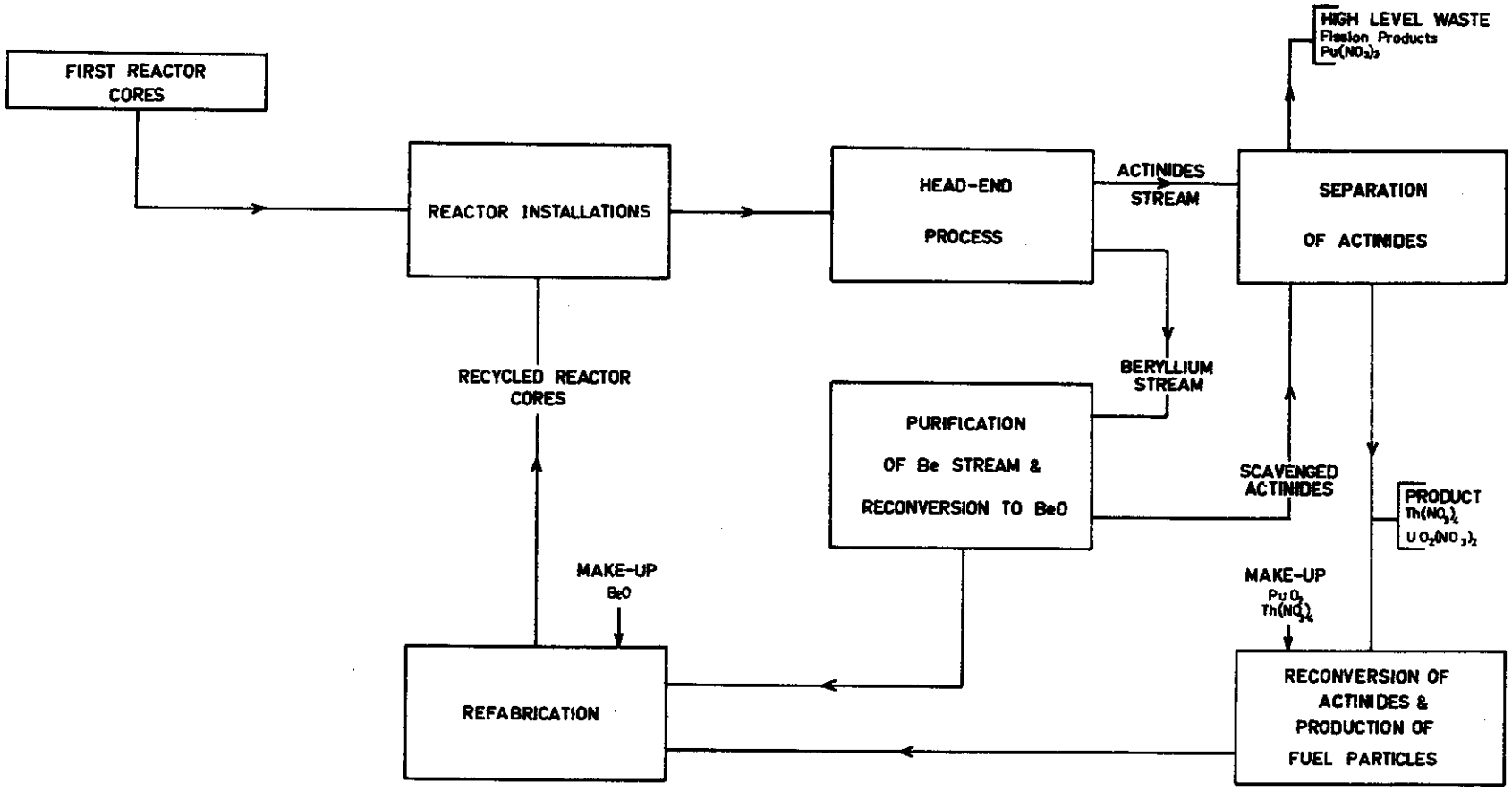


FIGURE 1. PROCESS STEPS IN THE H.T.G.C.R. FUEL CYCLE

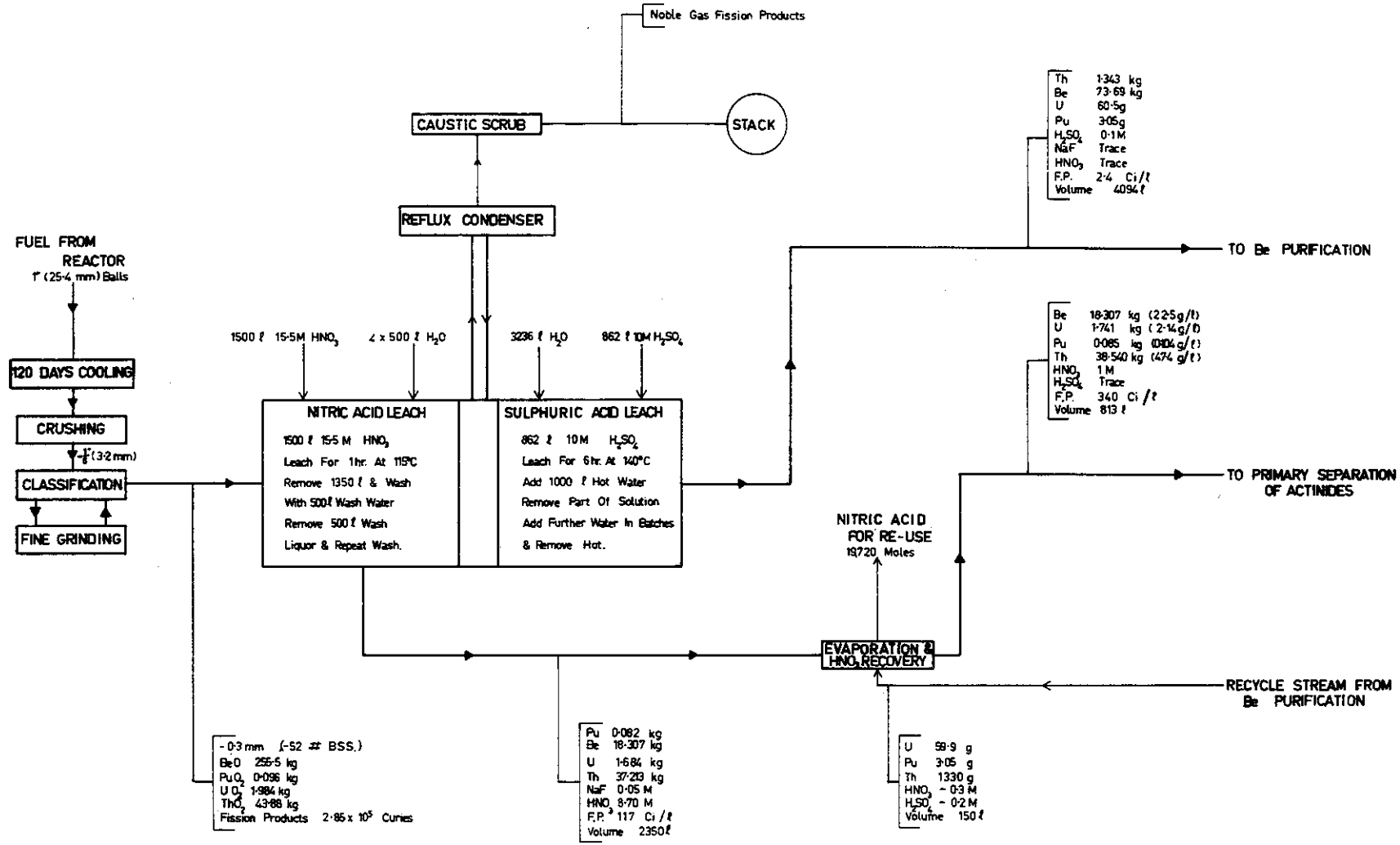


FIGURE 2. CHEMICAL FLOWSHEET OF DISSOLUTION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

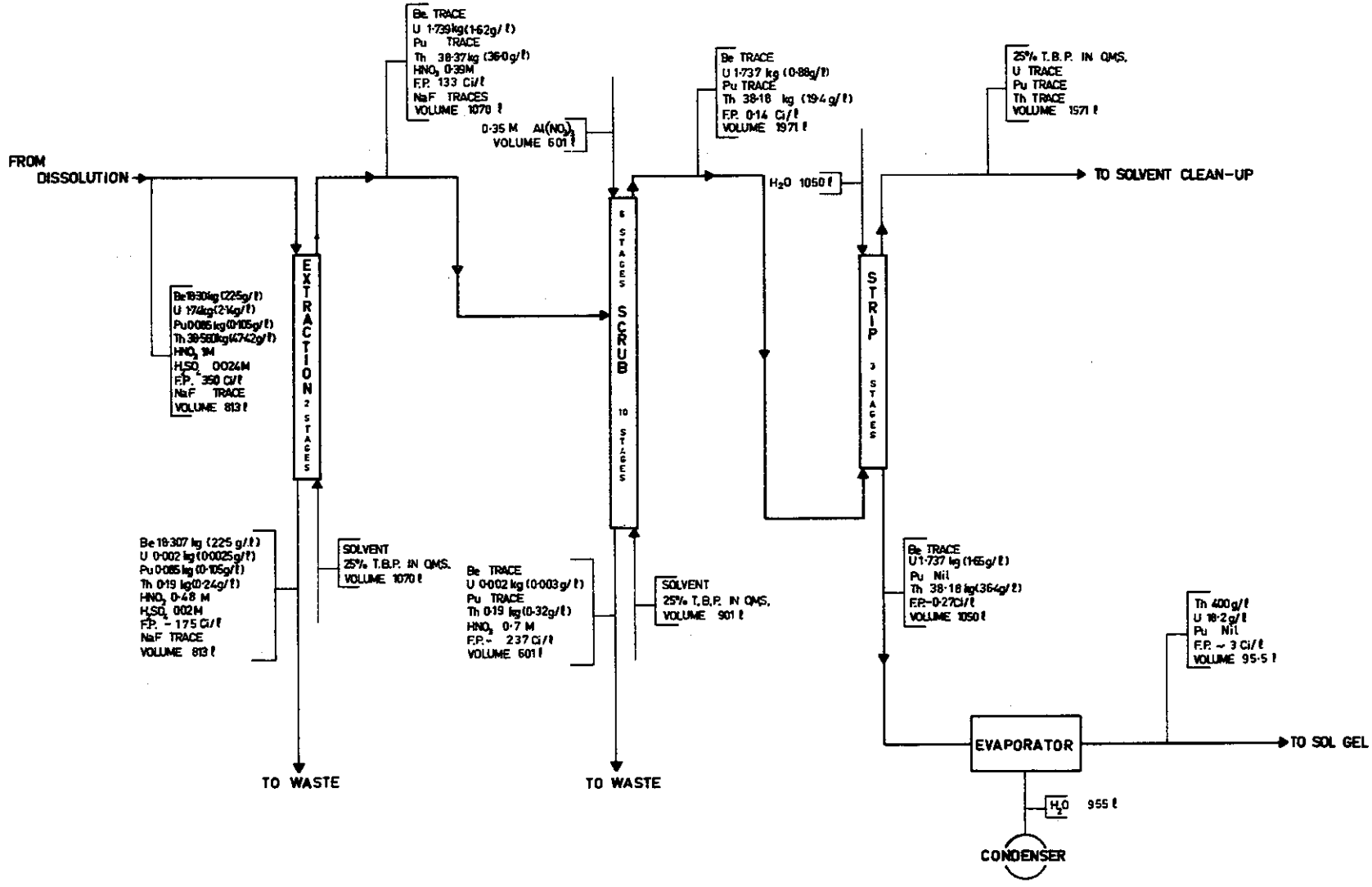


FIGURE 3. CHEMICAL FLOWSHEET OF ACTINIDE SEPARATION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

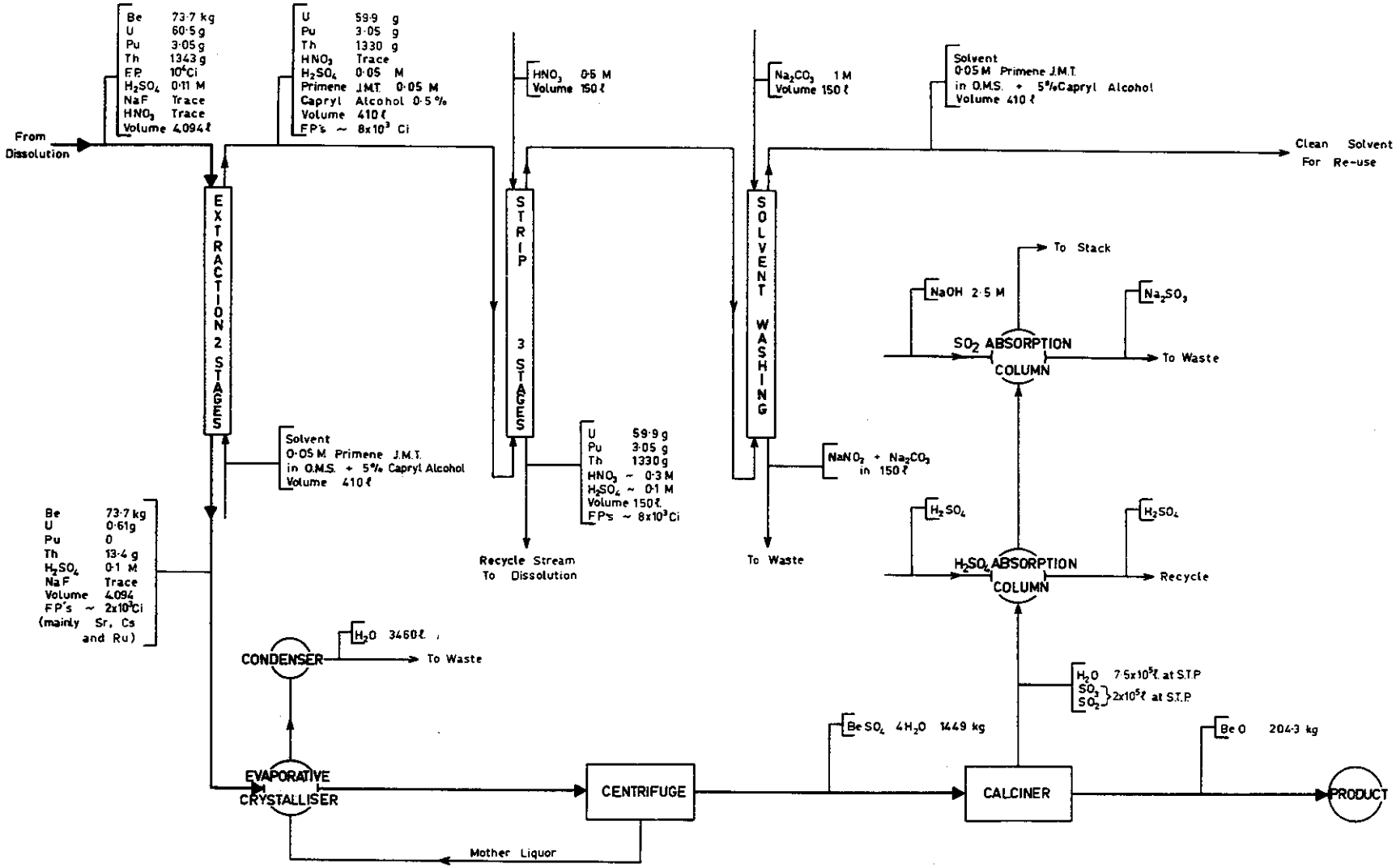


FIGURE 4. CHEMICAL FLOWSHEET OF BERYLLIUM PURIFICATION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

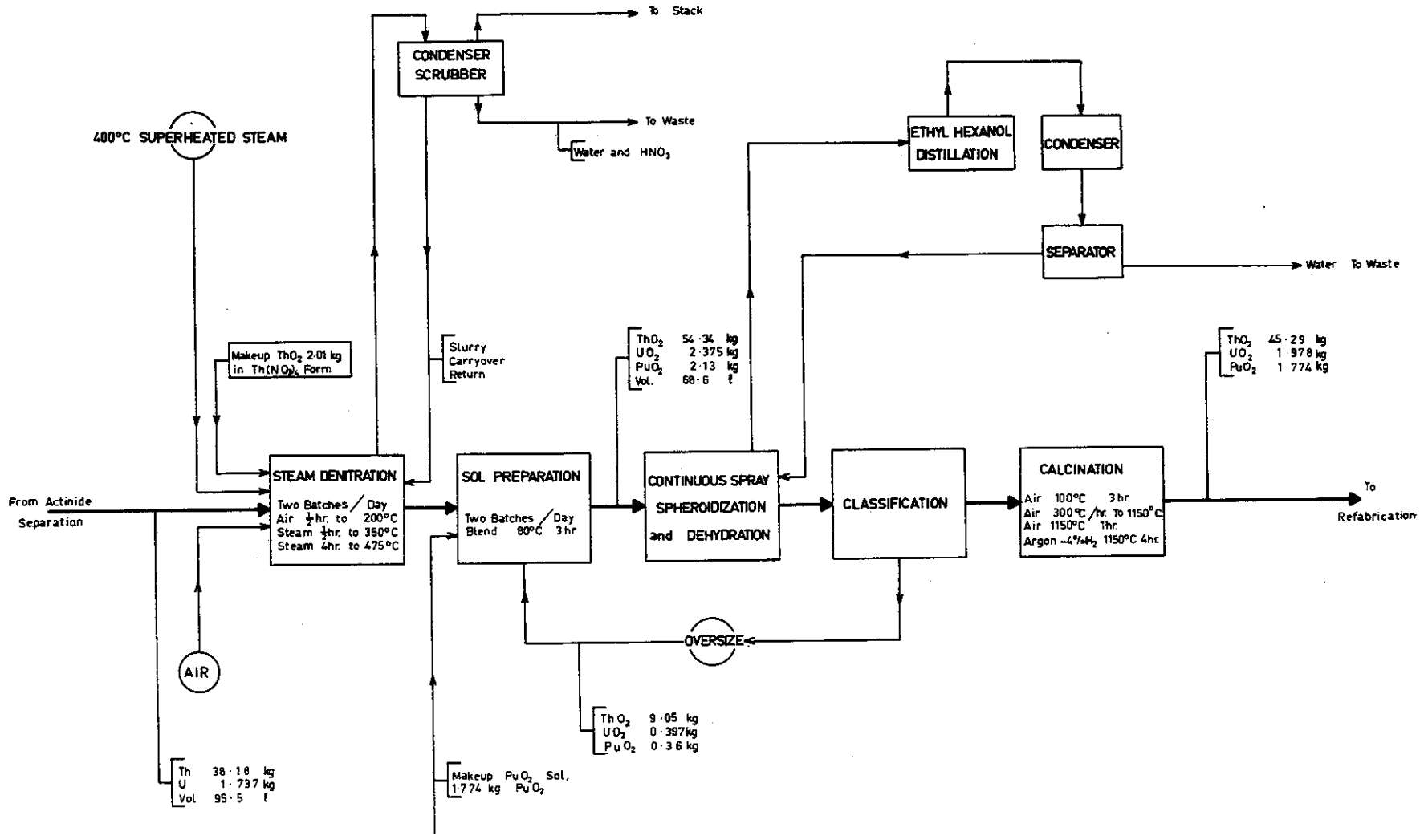


FIGURE 5. CHEMICAL FLOWSHEET OF SOL-GEL SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

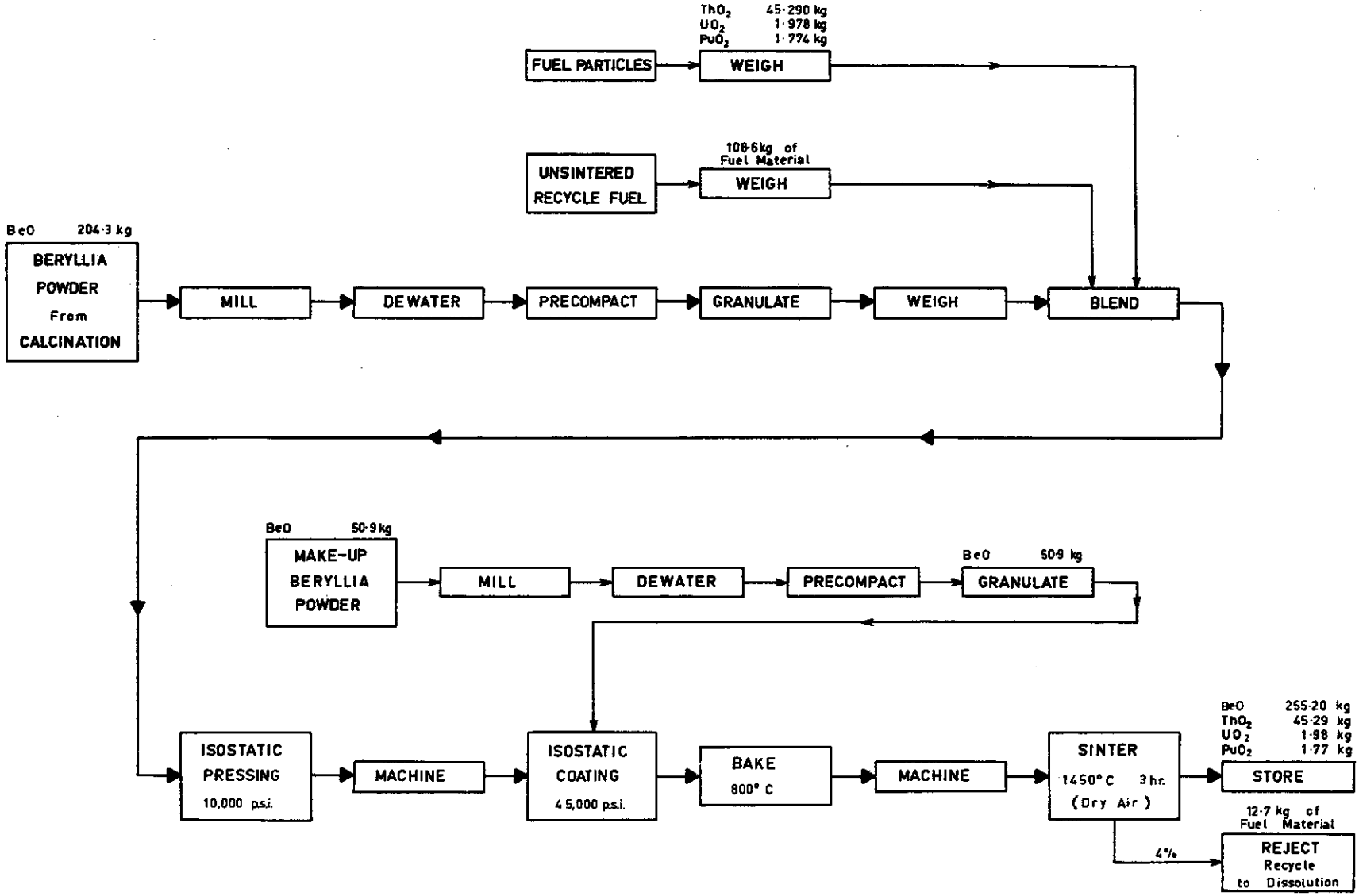


FIGURE 6. FLOWSHEET OF REFABRICATION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

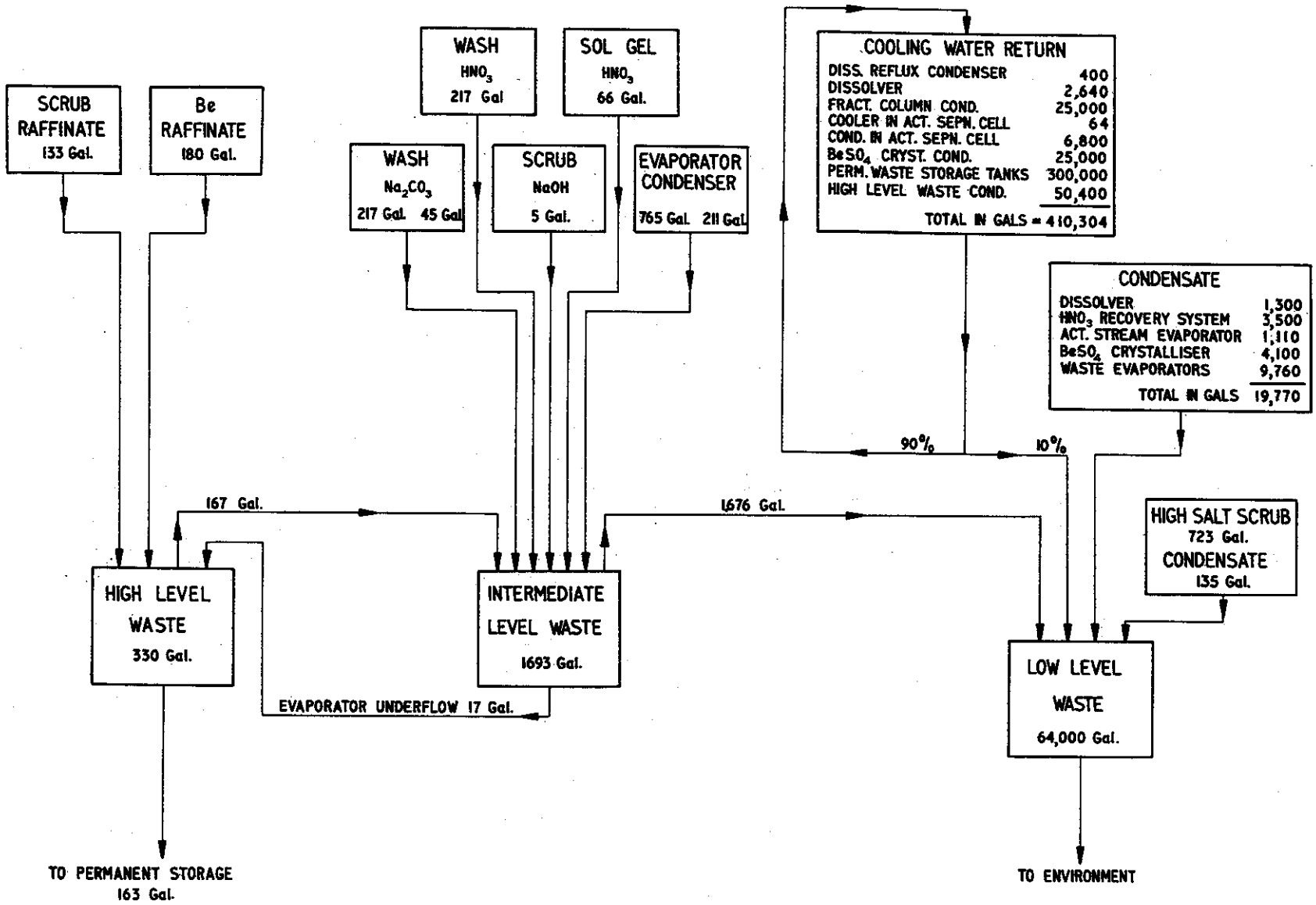


FIGURE 7. CHEMICAL FLOWSHEET OF WASTE SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

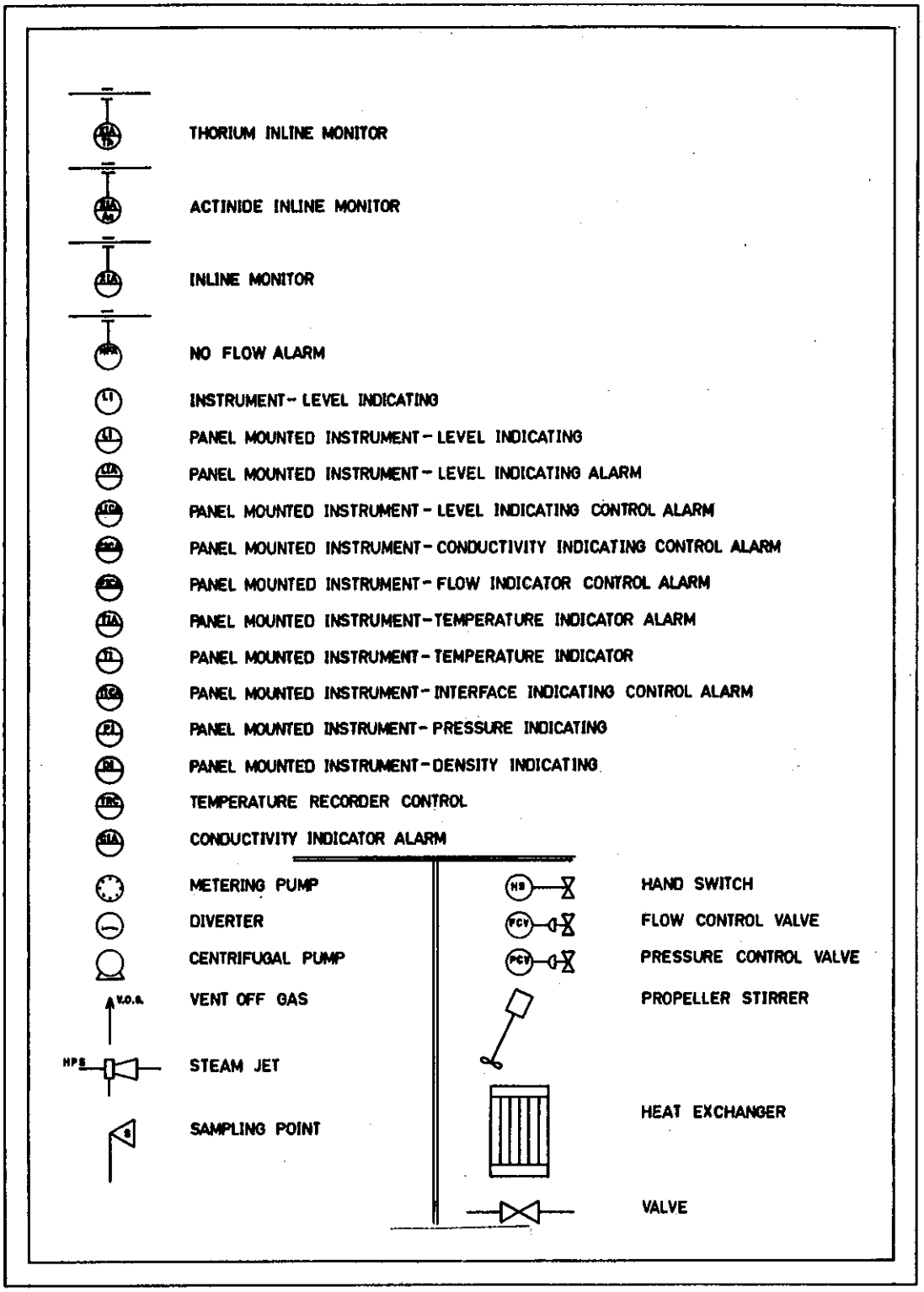


FIGURE 8. FLOWSHEET SYMBOLS

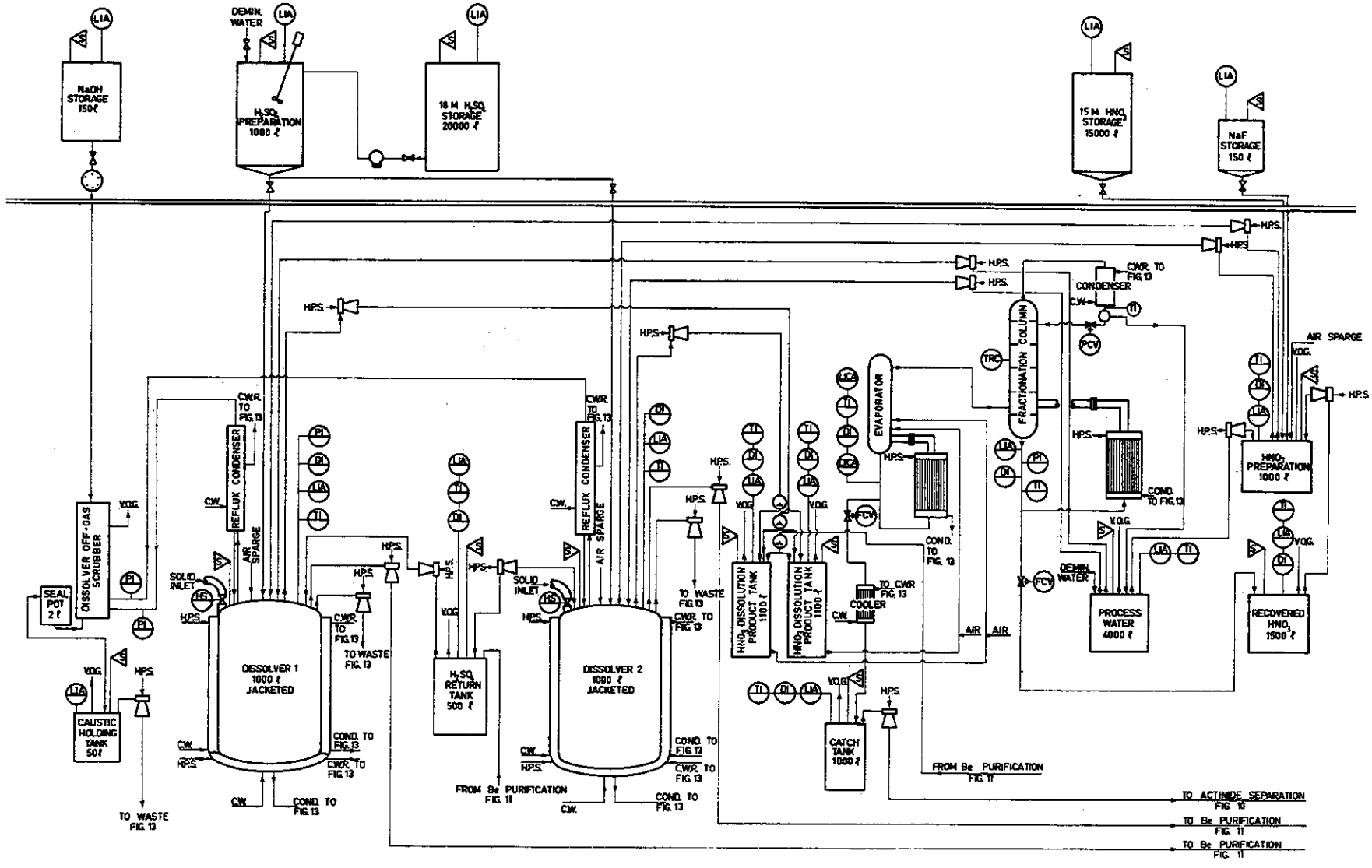


FIGURE 9. EQUIPMENT FLOWSHEET FOR DISSOLUTION SECTION
H.T.G.C.R. FUEL RECYCLE FACILITY

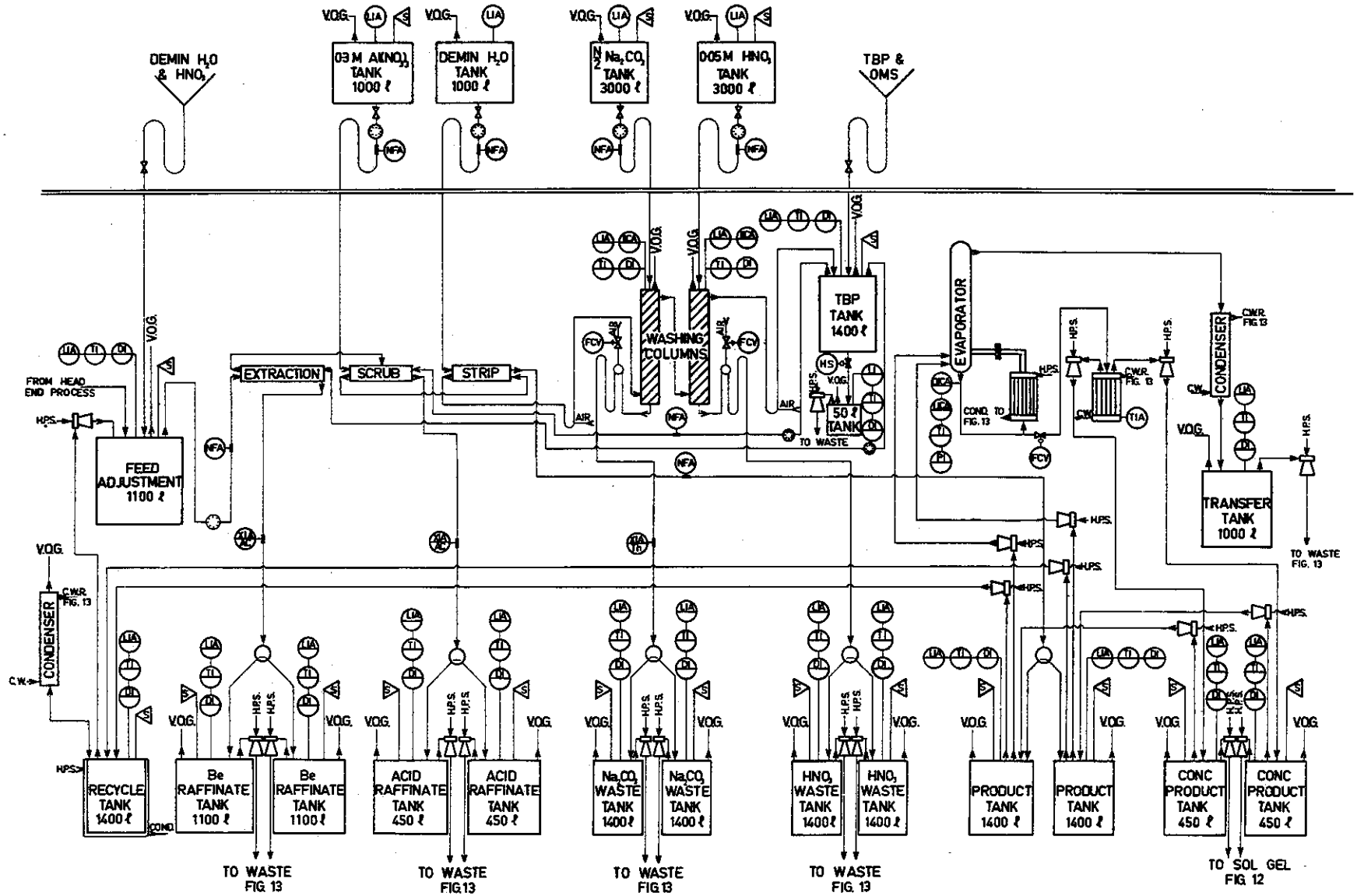


FIGURE 10. EQUIPMENT FLOWSHEET FOR ACTINIDE SEPARATION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

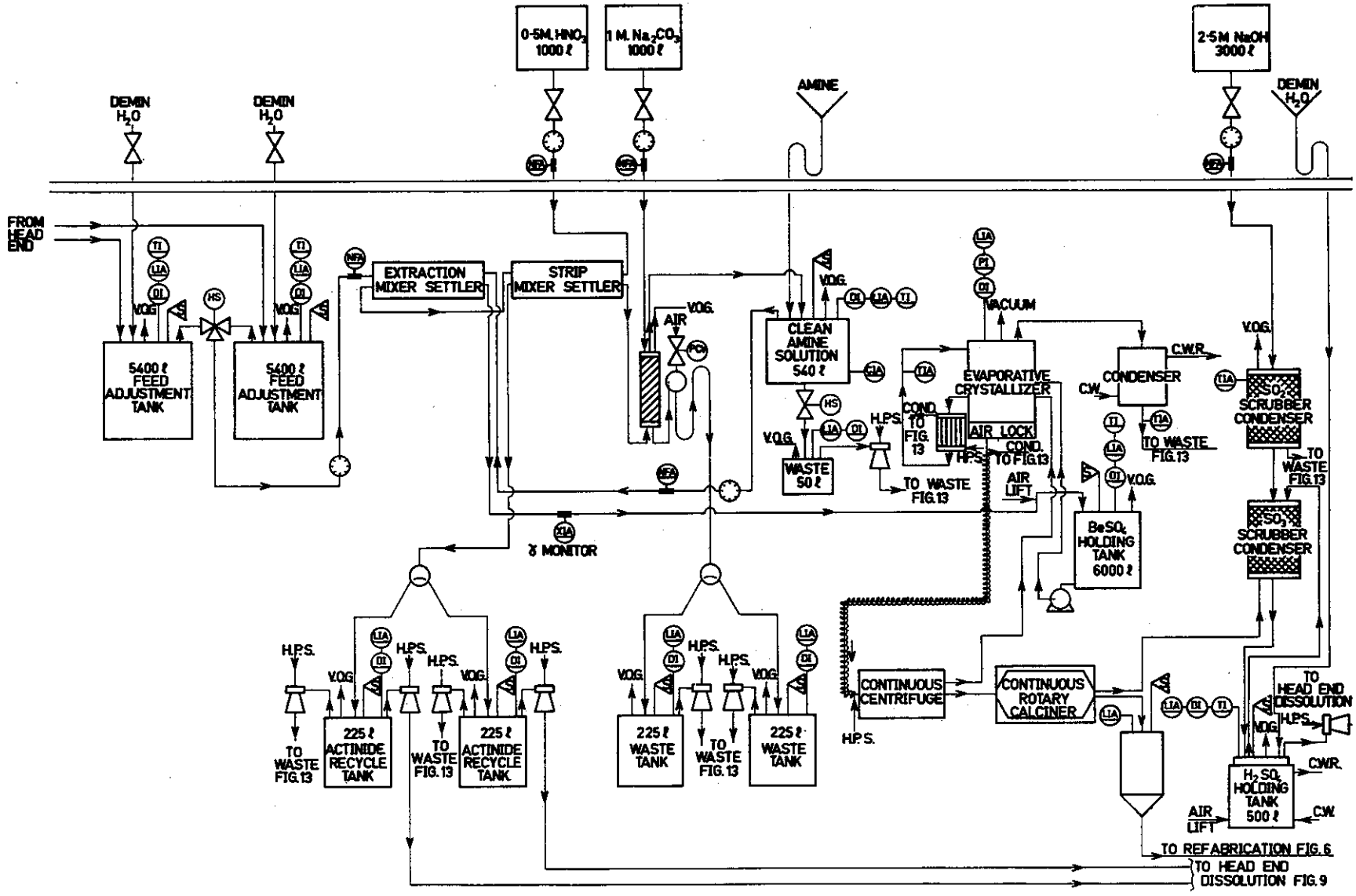


FIGURE 11. EQUIPMENT FLOWSHEET FOR BERYLLIUM PURIFICATION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

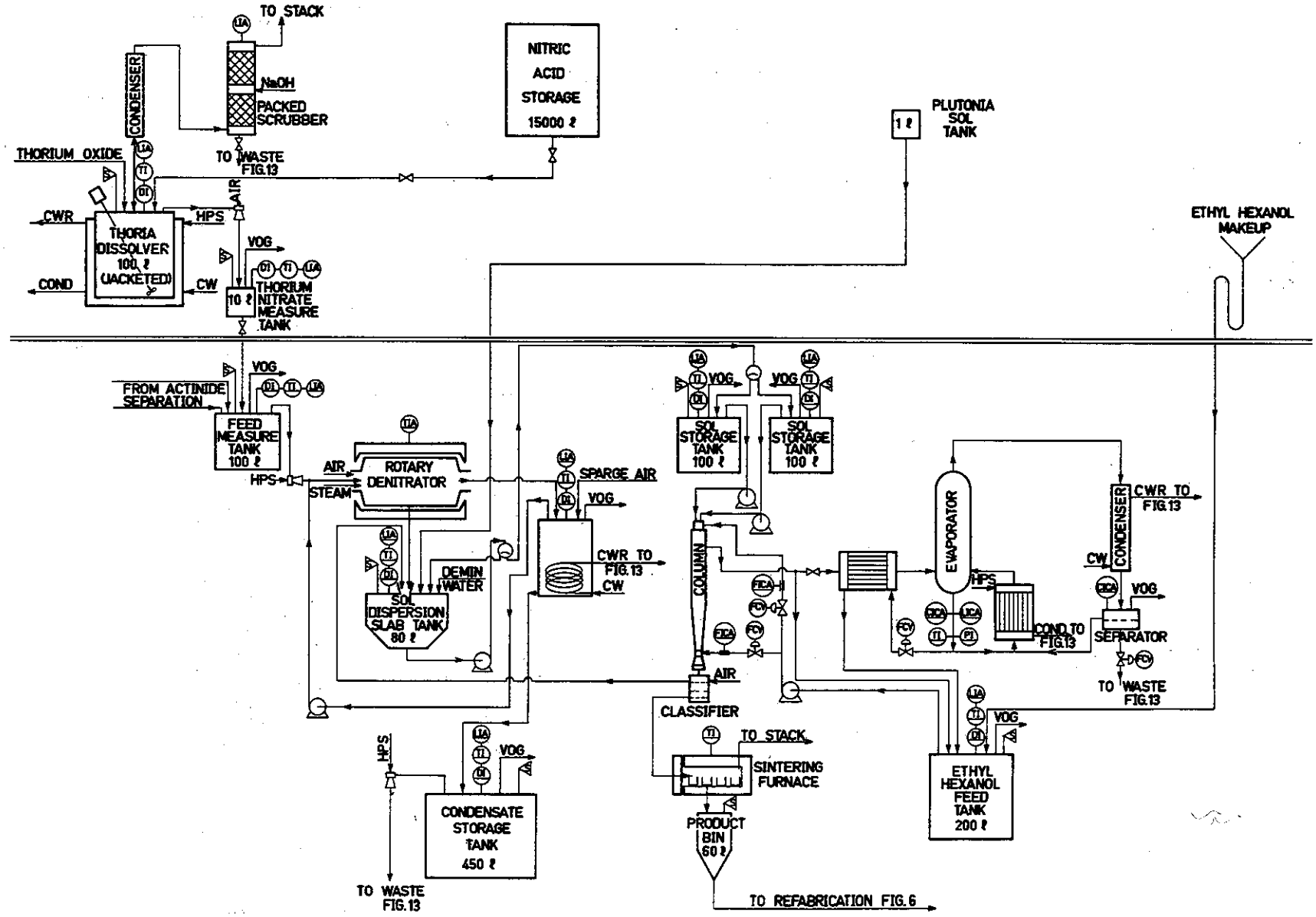


FIGURE 12. EQUIPMENT FLOWSHEET FOR SOL-GEL SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY

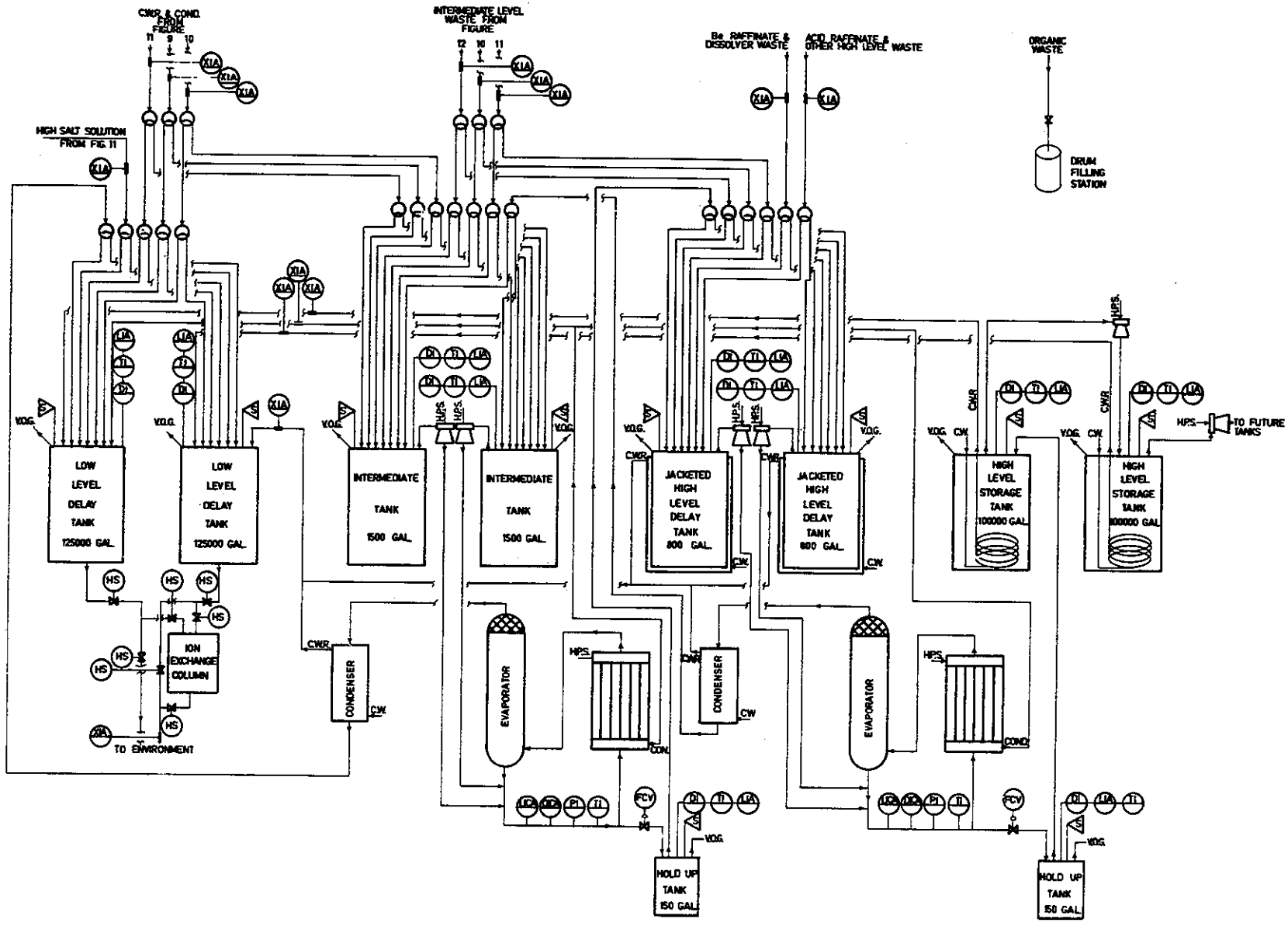
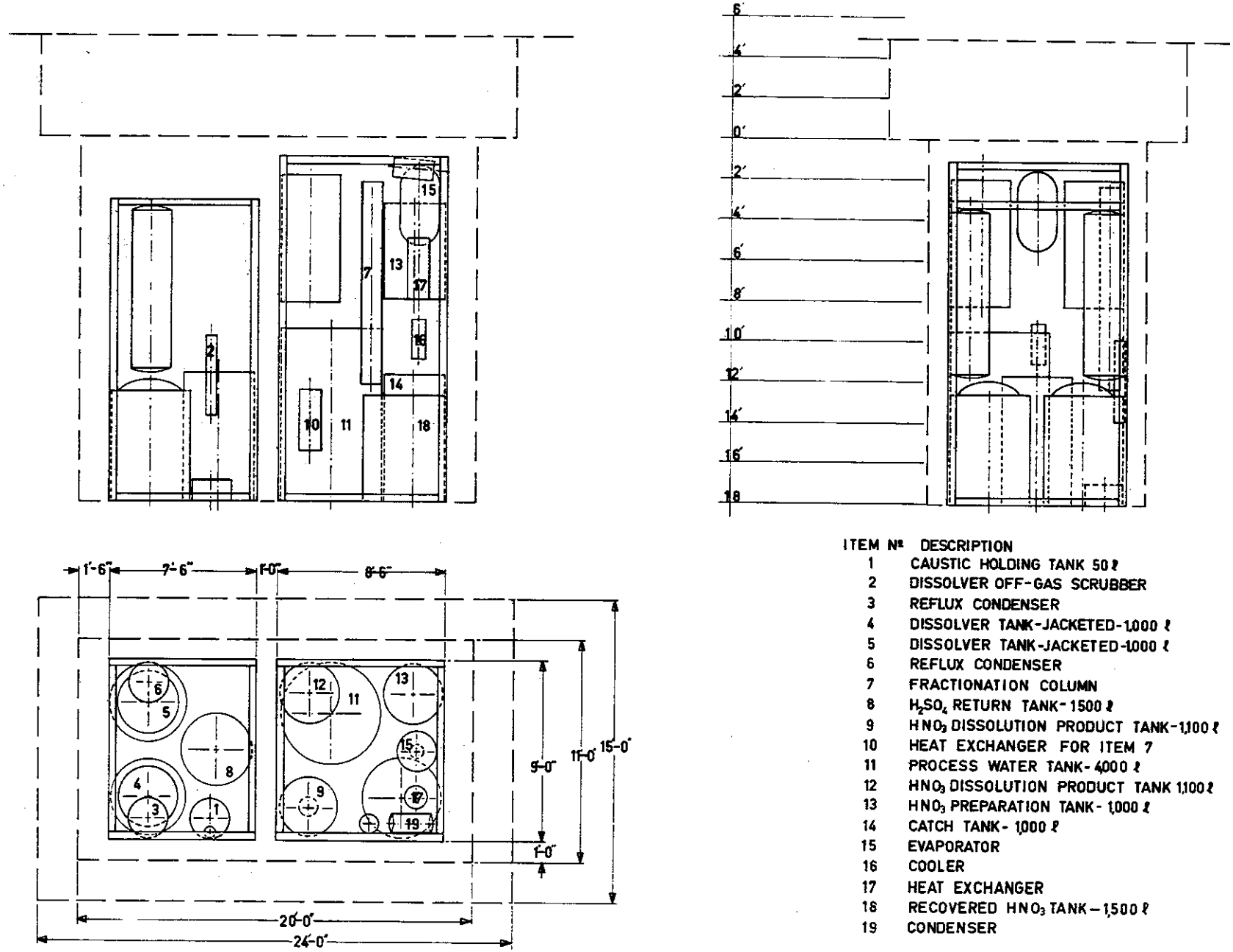
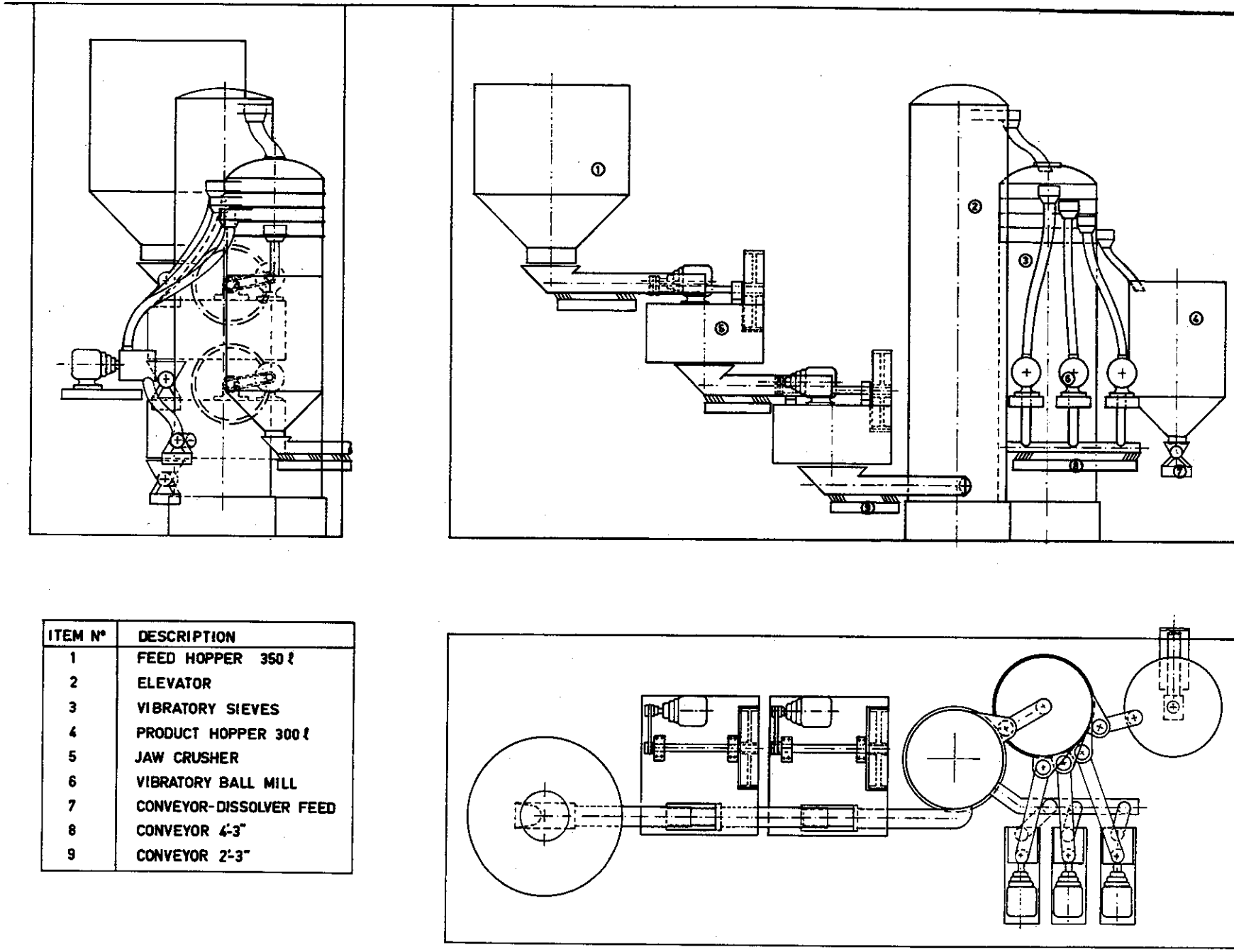


FIGURE 13. EQUIPMENT FLOWSHEET FOR WASTE SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY



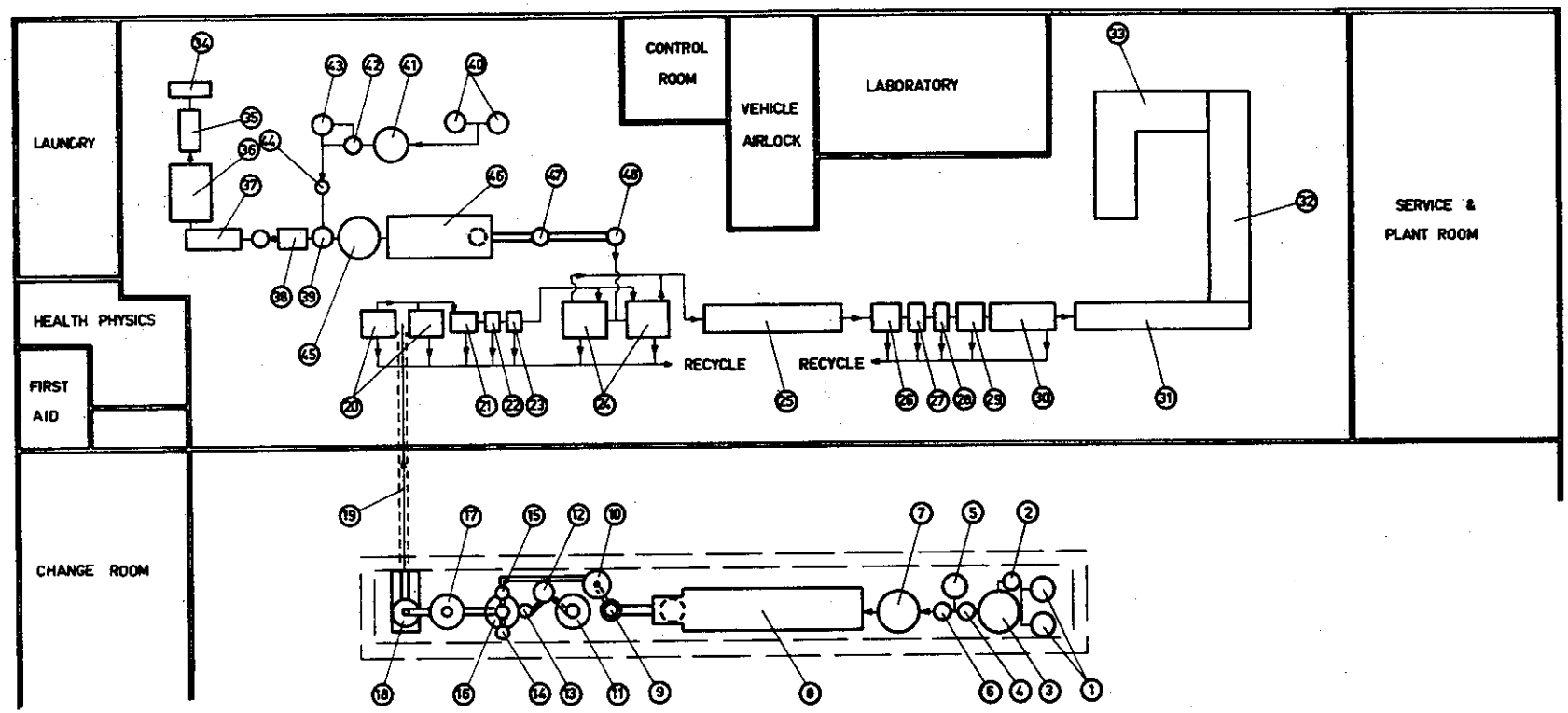
ITEM Nº	DESCRIPTION
1	CAUSTIC HOLDING TANK 50 ℓ
2	DISSOLVER OFF-GAS SCRUBBER
3	REFLUX CONDENSER
4	DISSOLVER TANK-JACKETED-1,000 ℓ
5	DISSOLVER TANK-JACKETED-1,000 ℓ
6	REFLUX CONDENSER
7	FRACTIONATION COLUMN
8	H_2SO_4 RETURN TANK-1500 ℓ
9	HNO_3 DISSOLUTION PRODUCT TANK-1,100 ℓ
10	HEAT EXCHANGER FOR ITEM 7
11	PROCESS WATER TANK-4,000 ℓ
12	HNO_3 DISSOLUTION PRODUCT TANK 1,100 ℓ
13	HNO_3 PREPARATION TANK-1,000 ℓ
14	CATCH TANK-1,000 ℓ
15	EVAPORATOR
16	COOLER
17	HEAT EXCHANGER
18	RECOVERED HNO_3 TANK – 1,500 ℓ
19	CONDENSER

FIGURE 14. EQUIPMENT LAYOUT FOR HEAD END SIZE REDUCTION SECTION - H.T.G.C.R. FUEL RECYCLE FACILITY



ITEM N°	DESCRIPTION
1	FEED HOPPER 350 ℓ
2	ELEVATOR
3	VIBRATORY SIEVES
4	PRODUCT HOPPER 300 ℓ
5	JAW CRUSHER
6	VIBRATORY BALL MILL
7	CONVEYOR-DISSOLVER FEED
8	CONVEYOR 4'-3"
9	CONVEYOR 2'-3"

FIGURE 15. DISSOLVER CELL LAYOUT - H.T.G.C.R. FUEL RECYCLE FACILITY



ITEM	DESCRIPTION
1	BLUNGERS
2	VIBRATING SCREEN
3	VIBRO MILL
4	VIBRATING SCREEN
5	BLUNGER
6	MAGNETIC SEPARATOR
7	EVAPORATOR
8	CONTINUOUS TRAY DRIER
9	ROLL COMPACTOR GRANULATOR
10	BeO STORAGE BIN
11	RECYCLE BLENDING BIN
12	RECYCLE STORAGE BIN
13	RECYCLE FUEL & BeO BIN
14	FUEL BIN
15	BeO BIN
16	1ST BLENDER

ITEM	DESCRIPTION
17	2ND BLENDER
18	BeO & FUEL STORAGE BIN
19	UNDERGROUND CONVEYOR
20	CORE PRESS
21	GRINDING MACHINE
22	MEASURING GAUGE
23	WEIGHING MACHINE
24	COATING PRESS
25	BAKING FURNACE
26	GRINDING MACHINE
27	MEASURING MACHINE
28	WEIGHING MACHINE
29	CONCENTRICITY INSPECTION
30	NON DESTRUCTIVE TESTING
31	UNSINTERED FUEL ELEMENT STORAGE
32	SINTERING FURNACE

ITEM	DESCRIPTION
33	INSPECTION & PACKING
34	INSPECTION
35	RUMBLER
36	SINTERING & BAKING FURNACE
37	PELLET PRESS
38	CONTINUOUS ROTARY DRIER
39	BLUNGER
40	BLUNGERS
41	VIBRO MILL
42	VIBRATING SCREEN
43	BLUNGER
44	MAGNETIC SEPARATOR
45	EVAPORATOR
46	CONTINUOUS TRAY DRIER
47	ROLL COMPACTOR & GRANULATOR
48	BIN

FIGURE 16. EQUIPMENT LAYOUT OF REFABRICATION AREA - H.T.G.C.R. FUEL RECYCLE FACILITY

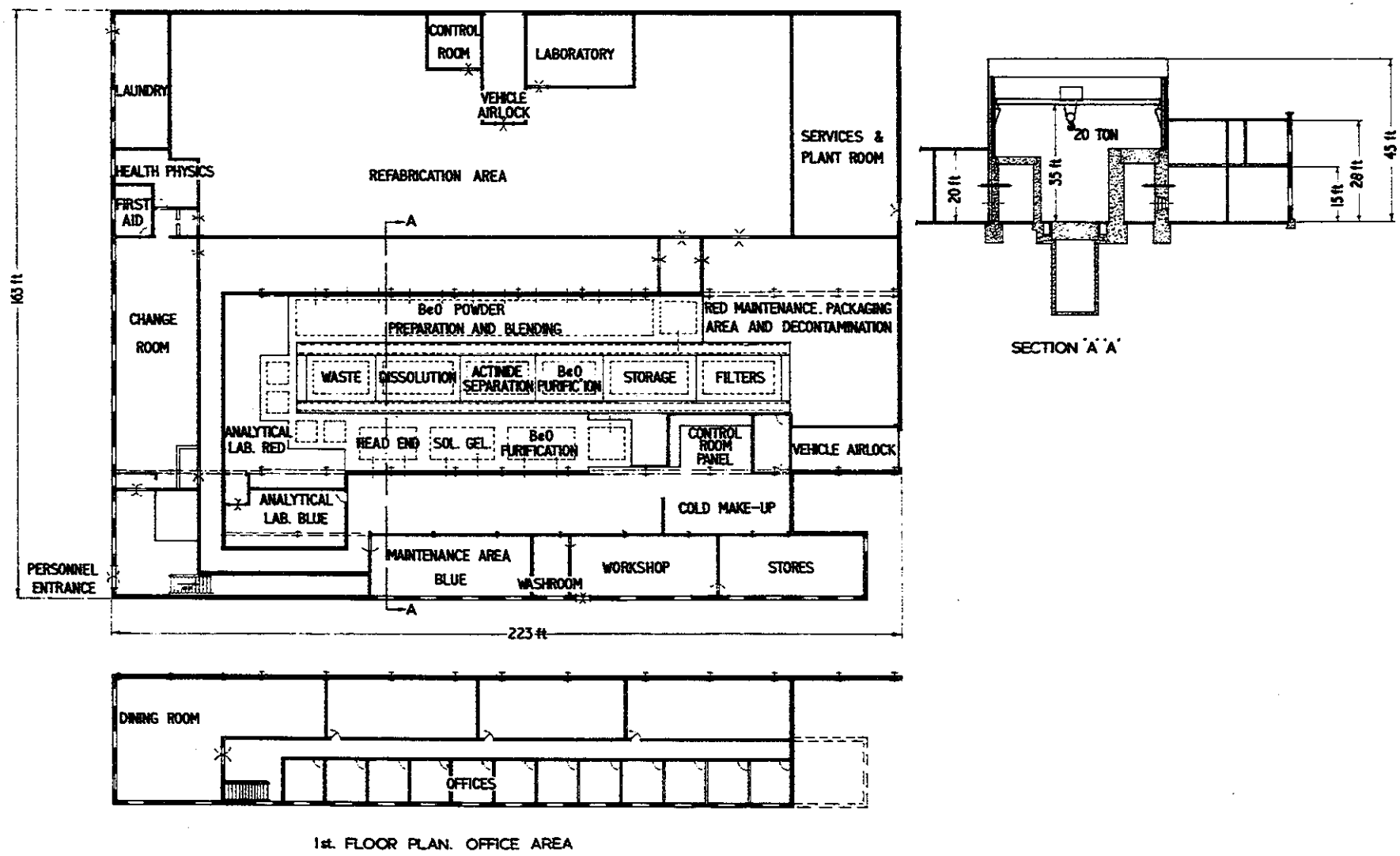


FIGURE 17. FLOOR PLAN OF PROPOSED RECYCLE FACILITY FOR H.T.G.C.R. FUEL