A DESIGN APPROACH TO LOW LEVEL LIQUID WASTE TREATMENT AT SELLAFIELD

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ABSTRACT

British Nuclear Fuels PLC (BNFL) provides a total fuel cycle service, comprising fuel manufacture, uranium enrichment, and spent fuel storage and reprocessing for the U.K. electricity generating boards and many other utilities worldwide. It is through its spent fuel reprocessing operations at Sellafield in West Cumbria that BNFL has needed to give priority to facilities for treating the low level radioactive liquids discharged into the Irish Sea.

The International Commission on Radiological Protection (ICRP) principles of radiological protection including As Low As Reasonably Achievable (ALARA) are taken fully into account and, in addition to ALARA considerations, discharges are controlled such that the radiation exposure of the most highly exposed members of the public is limited to less than 0.5 mSv per year (that is 10% of the limit recommended by the ICRP for any single year's exposure).

Similar principles have been applied to the control and reduction of radiation exposure of the workforce and for some time BNFL have designed and built plants with the objective of achieving an annual dose of not greater than 5 mSv. The annual statutory limit on whole body exposure is 50 mSv. In practice recently completed plants have achieved exposures well below this target objective of 5mSv.

INTRODUCTION

Since its formation in 1971 British Nuclear Fuels PLC (BNFL) has pursued a policy aimed at significantly reducing the levels of radioactive discharge to the Irish sea from the Sellafield Site. This policy has been paralleled by one aimed at reducing the radiation exposure of operations and maintenance personnel, ensuring that reduced discharges to the environment are not accompanied by increased workforce exposure.

The technologies and processes developed by BNFL have now fully proved themselves in service for some years in a number of plants. For example the Site Ion Exchange Effluent Plant (SIXEP), which was built to treat aqueous effluents to remove strontium and caesium derived principally from fuel storage pond operations, has operated continuously since May 1985 and has achieved an availability in excess of 99%.

These developments have now been applied to the requirement to treat other low active alpha bearing effluents generated from reprocessing operations. A practical treatment process comprising ferric floc precipitation followed by dewatering using ultrafiltration has been demonstrated and the Enhanced Actinide Removal Plant (EARP) is now under construction. The design principles developed for SIXEP have been continued and refined in EARP which retains the remotely maintainable pump, valve and instrument concept of SIXEP and extends the concept to a nuclearized ultrafilter module which is a vital component in the BNFL process.

This paper addresses some of the BNFL design and process development philosophies as applied to the EARP project.

PLANT DESIGN PHILOSOPHY

Before describing some of the process aspects of the EARP project, it is of interest to consider some of the main underlying requirements which had to be addressed by BNFL in selecting the process.

One requirement was to ensure that full account was taken of the whole cycle from the arising and definition of the effluent to be treated, through to the final disposal of all wastes, including maintenance wastes. In the case of EARP, the floc generated will be encapsulated in cement prior to disposal. This disposal will be a deep repository which will not be available until early in the next century. The waste therefore must be in a form suitable for safe interim storage until the ultimate disposal date.

A second requirement was to ensure that full account was taken of the political and economic aspects of waste management. The demonstration of compliance with national regulations at costs which can be justified is an important aspect as far as public acceptability is concerned.

A third requirement was to ensure that the benefits derived, in terms of reducing discharges to the environment with consequential reduction in doses to the public, should not be achieved at the expense of increased dose uptake to the operating and maintenance personnel. For many years, an objective in designing new plants by BNFL has been that the average radiation dose uptake by such plant personnel should be not more than 5 mSv/yr which can be compared to the statutory limit of 50 mSv/yr. A primary objective of this paper is to focus on some of the successful approaches

BNFL have applied to the design of EARP aimed at reducing dose uptake by plant personnel.

REMOTELY MAINTAINABLE PLANT

An effluent treatment plant of the scale of EARP, based upon floc precipitation followed by ultrafiltration for floc concentration, will have a considerable number of vessels and many thousands of feet of pipework. These can be designed and constructed to very high standards, using the relevant codes and non-destructive testing techniques, such that the probability of failure over a plant operating life of thirty years or more can be shown to be remote. It would be desirable to have pumps and valves which require no maintenance and BNFL have developed a range of fluidic devices for flow control and pumping purposes which achieve this objective. These devices are now extensively used in BNFL plants, including EARP.

However, for the high flowrates and pressures encountered in the main ultrafiltration circuit, there is still a need to rely on conventional pumps and valves. Such plant items can never be designed to last tens of years without maintenance. These items however, will become contaminated with radioactivity during the course of operation and in some cases relatively high levels can occur if, for instance, local plate-out of activity occurs. As these plant items will require some maintenance and, since the radiation dose uptake to personnel must be kept to a minimum (in the case of BNFL the limit is less than 5 mSv/yr), special attention has to be paid to the maintenance techniques adopted. BNFL found, during the design of SIXEP, that no equipment suitable for remote maintenance was available, and therefore developed a special range of remotely maintainable items. The remote maintenance concept is illustrated in Fig. 1.

The item housing the pump or valve is of the highest integrity such that no maintenance will be required, and is built into the plant below a permanent radiological shield which may be of concrete or steel, depending upon requirements. The operating device which may require maintenance is fitted into this body from above the radiological shield such that it can be withdrawn into a shielded maintenance flask when maintenance is required. This remote removal and replacement concept minimizes plant shutdown time and enables a quick return of the plant into service. All of the items requiring routine maintenance, the drive systems, pump motors or valve actuators are fitted above the shield. The removable unit which includes a suitable shield plug where it penetrates the permanent shield, is sealed to the non-removable body at the lowest point, that is as near to the liquor connection as possible. In practice this seal is a double seal with the interspace pressurized by clean water. It must be recognized that this seal may fail in service, and therefore a drain system is fitted to prevent the permanent body becoming filled with active liquor, thus pressurizing the seal at the shield level. This drain connection also serves two other purposes. Firstly, it can be monitored to indicate seal failure. Secondly, by connection to a cell ventilation system, can maintain the

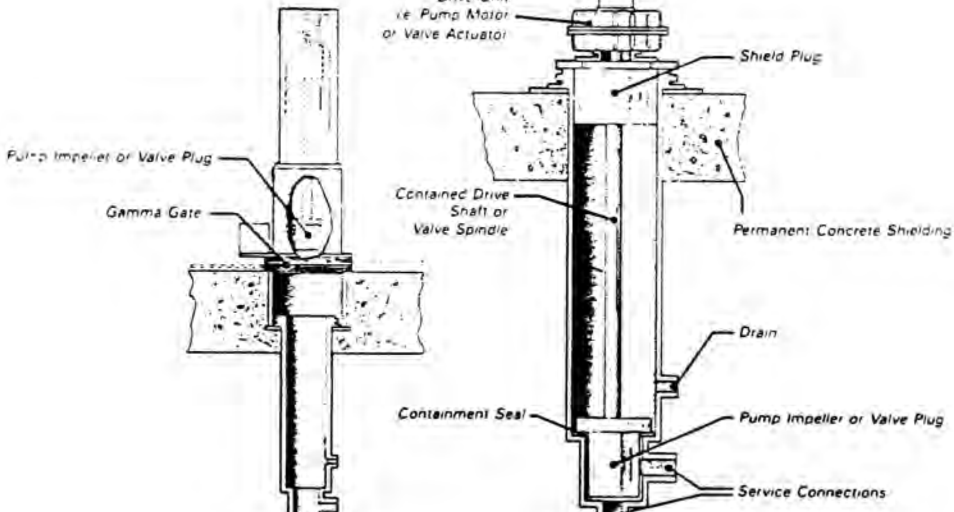

Fig. 1. Maintenance Concept.

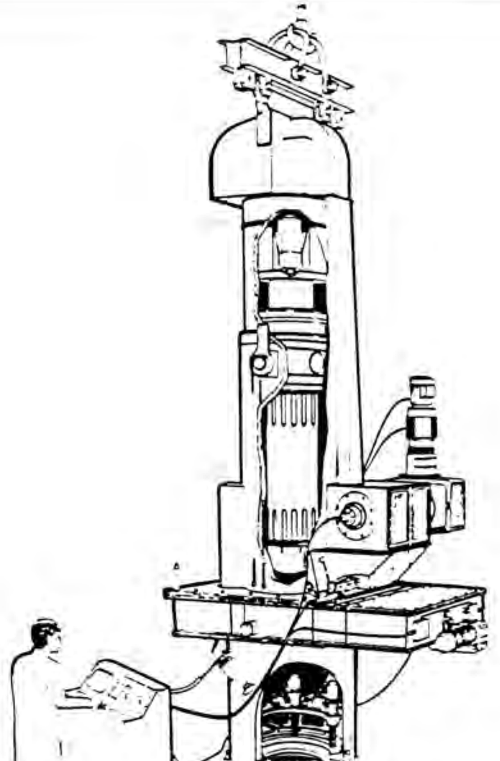

Fig. 2. Maintenance Flask.

body at a lower pressure than the maintenance area in which the maintenance flask will be situated. This ensures that activity does not escape during maintenance operations. Figure 2 illustrates the method of removal by means of the shielded flask.

Prior to the removal of a failed item into the shielded flask, it is flushed to remove gross contamination. The failed item is taken in the flask to a dedicated maintenance facility for decontamination and repair. At the maintenance facility, the item can be decontaminated, stripped down and rebuilt. Depending upon the activity levels on the decontaminated item, the strip-down and rebuilding can be carried out remotely in shielded cells by means of special purpose equipment and tools or by "hands-on" methods.

The remotely maintainable equipment has been specially designed to ease subsequent maintenance operations by modularization where possible. For instance, on pumps, the seals and bearings are of modular design since these are items likely to require renewal. A typical maintenance cell is shown in Fig. 3.

Maintenance Cell

Actual plant items have been designed and developed by BNFL to ensure that this concept works in practice, to optimize the necessary sealing systems and to ensure that the units have the highest possible operating reliability.

This concept was applied to the Site Ion Exchange Plant (SIXEP) - a plant completed in 1985 to remove mainly strontium and caesium from fuel storage pond purges. In

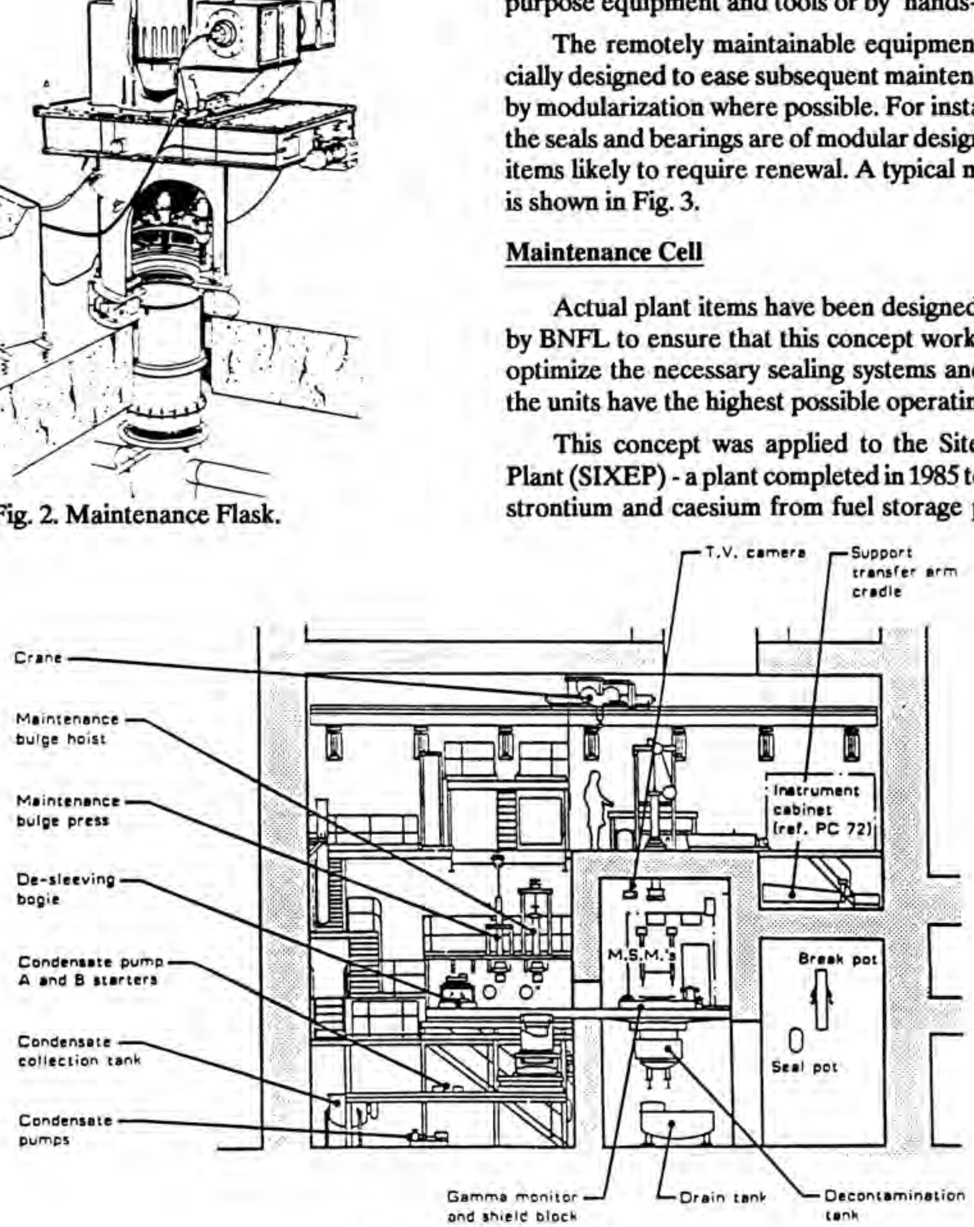

Fig. 3. Maintenance Cell.

over three years of continuous operation of SIXEP, no failure of any of these special units occurred. In the fourth year some deterioration of the rotating shaft seals on the pumps, not the containment seal to the body, did occur and the pumps were removed and satisfactorily maintained. It should be noted that when the shaft seal deteriorated the design ensured that the leakage was from the clean water system into the process and hence no hazard.

Following the successful demonstration of this concept on an operating plant, it was decided this should also be applied to the Enhanced Actinide Removal Plant (EARP). The purpose of EARP is to reduce both alpha and beta activity in aqueous discharges to the Irish Sea.

The Nature Of Effluents To Be Treated In EARP

Low active effluents arise from a variety of sources over the Sellafield site and these are routed to sea only after neutralization, filtration and batch monitoring; the discharge facilities are designed to allow unsatisfactory batches to be returned for concentration and storage. These effluents, made up of about 50 separate streams, arise at a rate of about 800,000 U.S. gal/day and contain about 2 TBq/yr (50 Ci/yr) of alpha activity, although virtually all of this is in only five streams, amounting to about 66,000 U.S. gal/day.

Medium active liquors are concentrated by evaporation and stored. Although in the past storage was employed only to allow decay of short-lived fission products prior to discharge, all concentrates are now being held until appropriate treatment facilities are available. Arisings are about 180,000 U.S. gal/yr and current stocks amount to about 1.7 million U.S. gallons. Typical activity concentrations are 0.8 TBq/m^3 (20 Ci/m^3) beta and about 0.04 TBq/m^3 (1 Ci/m^3) alpha.

The five low active bulk effluent streams, amounting to about 66,5000 U.S. gal/day and the medium active concentrates will be treated in EARP. Both bulk and concentrates feeds result directly from reprocessing operations and are therefore acidic; they also contain significant amounts of iron in solution (up to 40 tons per year in the bulk stream).

Process Definition

A study of the methods available for the treatment of both feed streams has shown that flocculation is the most suitable process, which has now been adopted for EARP. The addition of sodium hydroxide to iron-bearing acidic streams to increase the pH from 0.5 to 9.5 results in the formation of a ferric hydroxide floc with which the majority of the alpha activity co-precipitates, leaving a virtually inactive aqueous phase. If necessary, iron will be added to the feed to bring it up to the required minimum level in order to achieve acceptable decontamination.

Development work has demonstrated that, by the addition of relatively small amounts of specific chemicals, it is also possible to improve the beta activity removal particularly in the case of the concentrates. This work has also shown that higher decontamination factors (DF) can be obtained with the concentrate stream if it is treated separately from the bulk effluents. An indication of the DFs expected to be achieved for each nuclide is given in Table I, which also shows the approximate contribution of each nuclide to the total alpha and beta activity present in the two streams.

TABLE I

Decontamination Factors Expected Per Nuclide

Nuclide	Bulk Effluents		Concentrates	
	% Activity	DF	% Activity	DF
Alpha Activity				
Np237	15	30	1	30
Am241	25	100	19	500
Pu (other than 241)	60	100	80	500
Beta Activity				
Co60	6	50	-	NA
SR90	2	10	5	150
Zr/Nb95	40	20	-	NA
Tc99	1	1	5	1
Ru106	10	2	20	15
Cs134/137	10	10	10	50
Ce 144	1	20	3	100
Pu241	30	100	57	500

Separation of the ferric floc from the large volume of associated liquor is essential. This must result in not only a liquid discharge free from active solids, but also a concentrated feed suitable for immobilization in cement. After careful assessment of other process options, it was concluded for example that neither gravity separation nor centrifugation would achieve the required objectives and ultrafiltration was chosen for the EARP project. Before being discharged to sea the filtrate or permeate will be monitored and sentenced on a batch basis to ensure that it meets the discharge criteria. Any batch which fails to meet the set requirements can be recycled within the plant for

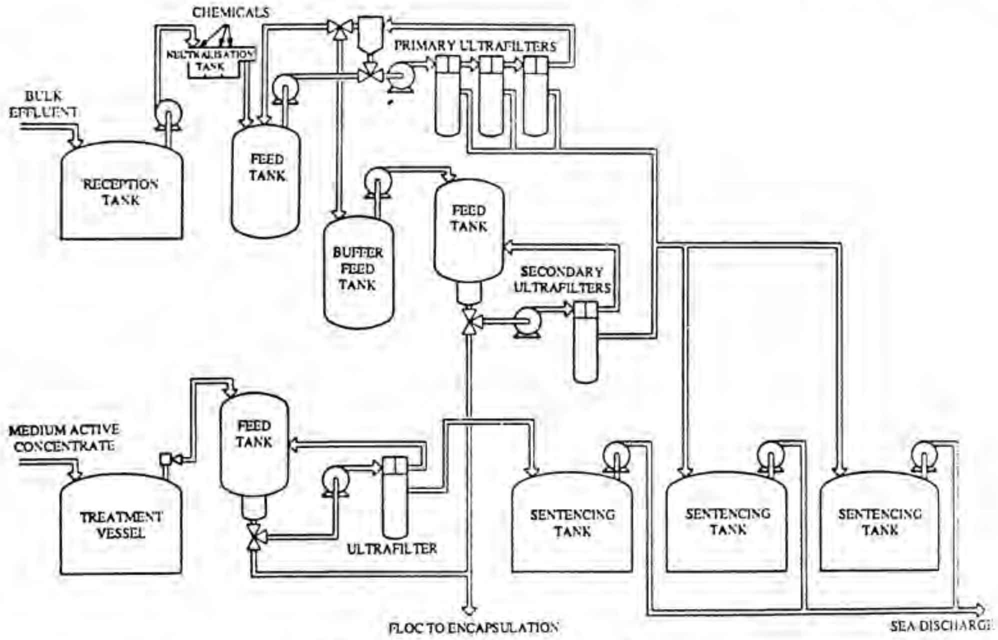

Fig. 4. EARP Process Flow Diagram.

further treatment. Figure 4 shows the simplified process flow diagram.

To assure reprocessing operations during maintenance or breakdown outages, EARP will be provided with a buffer storage capacity equal to three days' volume of essential arisings, which will also allow variations in the iron concentration to be smoothed. Thus, in order to recover from outages and from any recycle requirements, the main process section of the plant has been sized to treat twice the normal feed rate of 66,000 U.S. gal/day - that is, a total of 132,000 U.S. gal/day.

Ultrafiltration

The principles of ultrafiltration require that the liquid to be filtered is pumped at pressure and at relatively high velocity, typically 4.5 m/s, (15 ft/sec), through a tubular membrane. This high velocity prevents the build-up of solids on the membrane wall (surface filtration), while the pressure induces a flow of permeate through the membrane wall (cross-flow filtration). The pore size of the membrane coating is, typically, a micron (4×10^{-5} in) or less and is often expressed in terms of the smallest molecular weight of material which it can retain.

The recirculation loop is kept pressurized by pumping new feed into the circuit at the same rate as the permeate flows out through the tube. The flow of permeate through a single tube is of course small, and hence ultrafiltration modules are built up of many tubes arranged in parallel - that is, in a similar manner to that employed in a shell and tube heat exchanger. As some surface filtration is, in practice, virtually unavoidable this means that fouling of the

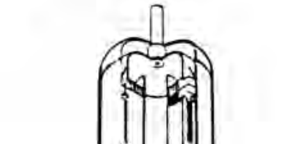

Fig. 5. Ultrafilter Cartridge.

tubes does occur and methods of backwashing and chemical cleaning have had to be developed to counter its effect. All membranes have a finite life, although at least three years of continuous operation is expected before renewal becomes necessary.

Standard ultrafilter units used in non-nuclear industries do not lend themselves to remote replacement within very low radiation uptake limits, and hence remotely maintainable units based on the pump and valve principles have been developed by BNFL for use in EARP.

Figure 5 shows the BNFL ultrafilter cartridge design and Fig. 2 shows the method of replacement by means of a shielded flask. To ensure adequate sealing of the unit into the housing, all inlet and outlet ports and seals have been incorporated into one shield plug at the top of the cartridge.

Thixotropic Suspension

The ferric floc produced in the EARP precipitation process will contain only a few hundreds of ppm of iron in suspension, whereas up to 6-7 lbs/ft^3 is required for economic immobilization in cement. At these concentrations the suspension is thixotropic with an apparent viscosity of about 7 poise. Experimental work has shown that this dilute precipitated floc can be concentrated to about 6-7 lbs/ft^3 by ultrafiltration and that circulation of the concentrated floc (using a special pump) is perfectly feasible. In practice, the flocs from bulk effluent treatment will be concentrated in two stages. The much smaller volumetric arisings of concentrate is dewatered on a batch basis using a single stage ultrafilter.

Product Floc Packaging

The floc produced by the EARP process will be dewatered within the plant to a level appropriate for solidification with cementitious material without further treatment. A carefully predetermined volume of floc will be charged into a 17.5 ft^3 drum for immobilization in a separate facility. Based on experimental work to date, the operation of EARP is expected to result in the production of about 1200 drums of cemented wastes annually.

The EARP Building

The building housing EARP will be constructed mainly of reinforced concrete to provide the essential radiological shielding and will have overall dimensions of 206 feet long, 147 feet wide and 111 feet high. The top section and the two end sections of the building however will be steel-framed constructions, with maintenance areas accommodated in the top section and electrical and control equipment in the ends.

The two essential features of the building, which will require approximately 40,000t of concrete and 1700t of structural steel, are as follows. First is the reinforced concrete containment, which houses all the plant, vessels, pumps, and ultrafilters. The second is the upper service area which not only provides access for the removal, by flask, of

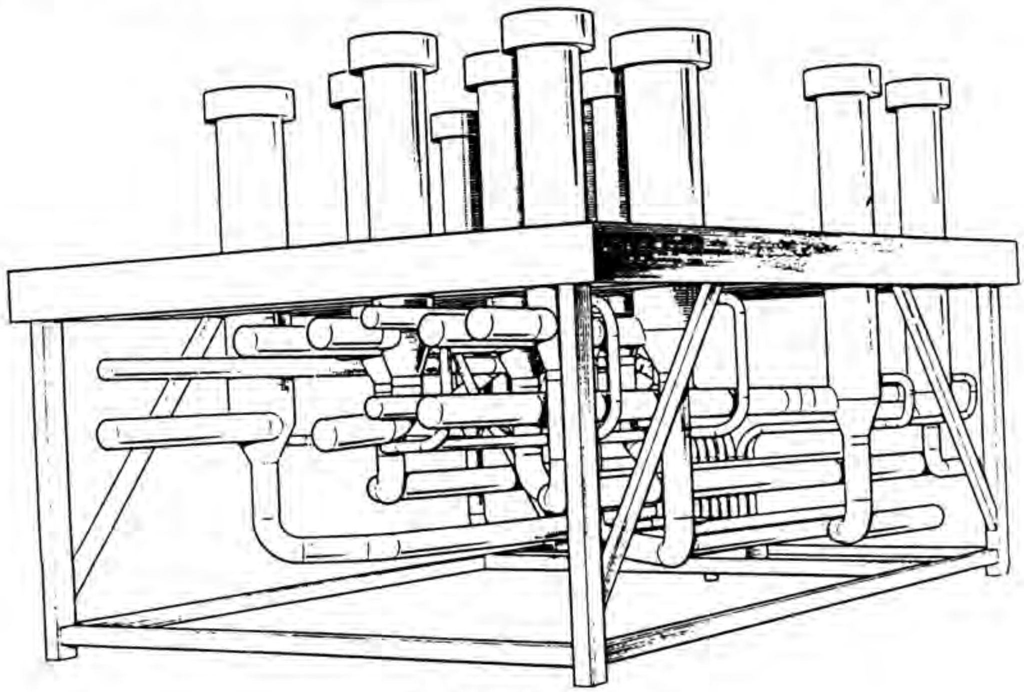

Fig. 6. Ultrafilter Module.

the remotely maintainable items, but also provides main routing for all inactive services.

A contract for the detailed design, construction and commissioning of the plant was placed at the end of 1987, and construction started in early 1988.

At the time of writing (December 1989), the basic design of EARP has been completed and the main civil work is essentially complete. Most of the larger vessels are already installed within the building. Handover for the plant is programmed for early 1992, with active operations commencing about mid-1992.