THREE MILE ISLAND UNIT 2 DEFUELING WATER CLEANUP SYSTEM

W. H. Bell, Bechtel National, Inc., Oak Ridge, TN
and
K. B. Rao, North American Power Corp., Gaithersburg, MD

ABSTRACT

During the defueling operations of the damaged TMI-2 reactor, it will be necessary to fill the reactor vessel, refueling canal and spent fuel pool with water in order to conduct fuel transfer operations. This water must be maintained at a Cs-137 concentration of .02 uCi/ml and a clarity level of 1 NTU. These criteria were selected to ensure that radiation dose rates to workers on the fuel handling bridge above the reactor vessel and in the fuel handling building are maintained as low as reasonably achievable (ALARA), and to maintain sufficient water clarity to enable workers to see underwater components in the reactor vessel, refueling canal and spent fuel pool during defueling operations.

In order to meet these objectives a defueling water cleanup system (DWCS) has been designed which consists of two separate subsystems. One system processes the water within the reactor vessel and a cylindrical contamination barrier to be placed above the reactor vessel with a design basis filtration system flow rate of 400-gpm and a soluble fission product removal ion exchange system of 60-gpm. The other system processes the water in the refueling canal and spent fuel pool with a 400-gpm filtration system and a 15-gpm ion exchange system.

INTRODUCTION AND BACKGROUND

Because of the damage done to the TMI-2 reactor during the accident of March 28, 1979 the potential for high radioactivity concentrations and high turbidity levels within the reactor vessel, refueling canal, and spent fuel pool are much greater than ever experienced in previous commercial power plant defueling operations.

During the fuel transfer operations of an undamaged reactor, the refueling canal is flooded with water that serves as a radiation shield for the workers on the fuel handling bridge. A common problem involved with many refueling operations is the turbidity of the canal water. If the water is turbid, components in the canal may not be sufficiently visible to allow planned refueling operations. Generally suspended corrosion products in the refueling water cause the visibility problem. Suspended particles in the few-tenths micron diameter range effectively scatter incident light, and a cloudy appearance results.

Thus, it is clear that if an undamaged reactor may be subject to turbidity problems, then TMI-2, with quantities of loose debris estimated to be as high as 128,000 lb, could have substantial problems with turbidity in the reactor vessel and refueling canal during defueling and disassembly operations.

In addition to the existing debris fines, it is anticipated that a substantial amount of additional debris will be generated because of cutting operations during disassembly of fused and deformed components in the core. Cutting operations and fuel and debris removal may also cause a significant degree of water agitation in the reactor vessel that could suspend previously settled particles.

Radiation exposure to personnel on the fuel handling bridge above the refueling canal and in the fuel handling building near the spent fuel pool will be primarily due to soluble Cs-137. A Cs-137 concentration of 1 uCi/ml will result in a dose rate contribution from the water of approximately 1R/hr at a distance of 1 foot above the water.

The objective of the defueling water cleanup system will be to maintain the dose rate contribution from the water at approximately 10 mr/hr to 20 mr/hr, which corresponds to a Cs-137 concentration of 0.01 uCi/ml to 0.02 uCi/ml.

Prior to the commencement of disassembly and defueling operations the head and plenum of the reactor vessel must be removed. During head removal the refueling canal will gradually be filled with borated water as the head is lifted. When the head has been removed it will be replaced by the internals indexing fixture (IIF). The IIF is a cylinder approximately six feet high with a diameter slightly larger than the reactor vessel head which is used to assist in plenum removal. During plenum removal operations the IIF will be filled with borated water. Prior to the actual removal of the plenum water quality within the reactor vessel and IIF will be maintained with a temporary processing system designed to maintain acceptable water clarity and radionuclide concentrations. This system will remain in operation until the plenum is actually removed at which time the refueling canal must be filled requiring the defueling water cleanup system to be operational.

After plenum removal, a cylindrical contamination barrier will take the place of the IIF. This contamination barrier will isolate the high quality water in the refueling canal from the contaminated water in the reactor vessel during disassembly and defueling operations. The contamination barrier effectively divides the water volumes involved with defueling operations into two separate bodies.

One body of water is contained within the reactor vessel and contamination barrier and the other consists of the water in the refueling canal, located in the reactor building, and the fuel pool located in the fuel handling building. The canal and fuel pool will be continuously connected via two fuel transfer tubes. Figure 1 illustrates this arrangement.

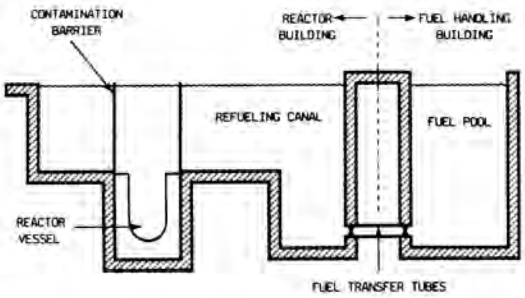

Fig. 1 Defueling Operations General Arrangement

The following is a list of the criteria used as a basis for the evaluation of various processing options for the defueling water cleanup system:

- Potential combinations of processing equipment have been evaluated to determine the optimum configuration for the defueling water cleanup system that will use existing equipment and procedures to the maximum extent practical.
- All soluble fission product ion-exchange media will consist of zeolites and shall be used in such a manner that will ensure that spent zeolites can ultimately be disposed of using current shipping and handling procedures and will be suitable for temporary onsite storage in the TMI-2 interim waste storage modules.
- Reactor vessel/contamination barrier filtration systems will be designed to be compatible with the material handling techniques developed for transporting solids into fuel canisters. These filters will be capable of removing fuel fines and debris above a nominal 0.5 micron rating using commercially available filtering equipment.
- Filtration systems will be capable of maintaining the steady-state turbidity in the quiescent reactor vessel/contamination barrier and spent fuel pool at 1 nephelometric turbidity unit (NTU) or less. The effluent from all water processing systems shall also be less than 1 NTU.
- All soluble fission product processing systems shall be designed to maintain the dose rate contribution from Cs-137 in the water to 20 mr/hr above the refueling canal water surface. This corresponds approximately to a Cs-137 concentration of 0.02 uCi/ml during defueling and disassembly operations.
- Processing system suction will be taken from and effluent returned to the reactor vessel/contamination barrier in such a manner as to promote downward flow above the core. This will keep a relatively clean water barrier in the upper section to aid in shielding and visibility and will help minimize particulate and soluble fission product transport to the refueling canal.
- To support continuous flow processing, provisions for in-line monitoring of boron concentrations and pH will be employed in addition to periodic sampling of all water chemistry parameters.
- Water chemistry requirements for the reactor vessel have been developed to ensure materials compatibility. Chemistry for the reactor vessel, refueling canal, and spent fuel pool shall be based on the following limits:

Boron	3,500 - 4,500 ppm
pH	≥ 7.5
Na	700-800 ppm (typical to maintain pH)
Cl^-	< 5 ppm
F^-	< 1 ppm

- In order to maintain dose rates at an acceptable level on the refueling bridge, it will be necessary to ensure that the system will be able to process the reactor vessel/contamination barrier water at a continuous flow rate of 20 gallons-per-minute (gpm). In order to ensure the maintenance of 20 gpm, sufficient equipment redundancy must be incorporated into the system to ensure that no single component failure will render the system inoperable.

The defueling water cleanup system will be required to maintain water quality with respect to turbidity and radiation exposure to personnel working near the following bodies of water:

Reactor vessel/contamination barrier	78,000 gal
Refueling canal	324,000 gal
Spent fuel pool	440,000 gal

The reactor/vessel contamination barrier was treated as one volume of water. This volume consists of an estimated 42,000-gallon reactor vessel volume plus a 36,000-gallon volume attributed to a contamination barrier. At this writing, the contamination barrier has not as yet been completely described. For evaluation purposes, the contamination barrier was assumed to be a vertical cylinder sitting on the floor of the refueling canal centered directly above the reactor vessel. The barrier was assumed to be 16-feet in diameter and 24-feet high, which extends it to the water surface. The purpose of the contamination barrier is to reduce the transfer of particulate and radioactive contaminants to the refueling canal and spent fuel pool to the lowest extent practical. For the purpose of determining a contaminant source term to the refueling canal, a leak rate of 10,000 gallons-per-day from the barrier to the canal has been assumed.

It should be noted that the selection of barrier dimension is not critical to the results of this study. It has been suggested that only a partial height barrier that does not reach the water surface might be used. This would result in a smaller reactor vessel/contamination barrier volume. A smaller volume results in a lower processing flow rate requirements for a given concentration of contaminant. However, a given spike of radioactivity or suspended solids results in a higher concentration of contaminants. These two effects tend to cancel each other out over the range of volumes related to the contamination barrier configuration currently under consideration.

All processing alternatives evaluated will be based on continuous flow systems rather than batch type bleed-and-feed operations. Continuous flow systems will allow the fastest recovery time from upset condition and will require less equipment and space because large intermediate tankage is not required.

Since the defueling water cleanup system (DWCS) will be treating two essentially separate bodies of water, it has been divided into two distinct subsystems. One subsystem will treat the water in the reactor vessel and contamination barrier and will be designated the vessel/barrier subsystem. The other system will process the water in the refueling canal and the spent fuel pool and will be called the canal/pool subsystem.

DEFUELING WATER SOURCE TERMS

The selection of water processing equipment required to maintain water clarify and dose rates within acceptable limits will necessarily consider the quantities of fine particulate debris and soluble fission products currently contained within the reactor coolant system. These substances are the primary contaminants that the defueling water cleanup system will be required to control. The rate at which fine particulates and fission products (particularly Cs-137) are released to the reactor vessel/contamination barrier, refueling canal, and spent fuel pool will determine the processing flow rates required to maintain water quality.

Unit operations that will be used to maintain water quality will consist of filtration and ion exchange equipment. Filters will be used to remove particulate debris and maintain water clarity while soluble fission products are removed by ion exchange in order to maintain dose rates above the water ALARA. The defueling water source term used to size these unit operations has therefore been based on a water clarity source term and a water radioactivity source term.

Water Clarity Source Terms

During defueling and disassembly operations, it will be necessary to maintain water clarity at 1 NTU to ensure adequate visibility in all bodies of water. The major inhibitor to clarity will be the large quantity of fine debris believed to be in the reactor core. As the debris is agitated, some of it will undoubtedly be suspended and transported throughout the defueling water bodies. It is currently believed that if a suspended solids concentration of 1 ppm can be maintained, the turbidity requirement of 1 NTU can be satisfied.

It is therefore necessary to design filtration systems with sufficient flow capacity and micron rating to maintain these conditions during relatively quiescent periods, or to be able to return the system to these conditions in a reasonable amount of time after spikes of suspended solids occur.

It has been estimated that up to 128,000 lb of loose debris exist in the core. Of this total, the portion with particle size of approximately 40 microns or less will have the greatest impact on water clarity, as that portion is the easiest to place in suspension. This debris consists primarily of UO_2 and ZrO_2, with UO_2 being approximately 72% of the mass and ZrO_2 the remainder. Of the UO_2 in the fine debris, approximately 18% of the 92,000 lb is below 40 microns for a total of 16,500 lb. Approximately 39% of the ZrO_2 is 40 microns or less in size, which results in 14,000 lb of fine debris. The total quantity of fine debris is then approximately 30,500 lb.

The impact that these solids have on defueling operations is dependent on the total quantity of solids suspended in a body of water at any given time. Because the amount of suspended solids is impossible to predict, calculations have been performed to determine the amount of time required to return a given volume of water to a suspended solids concentration of 1 ppm after a variety of spikes in suspended debris. These calculations have been done for the reactor vessel/contamination barrier (78,000 gallons), the refueling canal (324,000 gallons), and the combined refueling canal and spent fuel pool (764,000 gallons). The latter has been done to account for the fact that the transfer tubes between the canal and pool may be open, which requires that the two bodies of water be treated as one.

These calculations have been done for solids loadings representing between 100% and 0.01% of the total of 30,500 lb of fine debris being suspended at one time in the reactor vessel/contamination barrier. Filtration system flow rates between 100 gpm and 600 gpm were evaluated. All filters were assumed to have a decontamination factor (DF) of 1000.

Based on the results of these calculations, filtration system flow rates of 400 gpm for both the vessel/contamination barrier and canal/pool subsystem have been selected. This is based on a compromise between acceptable recovery times and reasonable equipment sizes. Table 1 represents the results of a typical calculation performed for the volume of water in the reactor vessel/contamination barrier system (78,000 gallons) while being processed at a flow rate of 400 gpm during the recovery from spikes in suspended solids varying from 0.01 to 100 percent of available reactor debris less than 40 microns in diameter. Results are expressed in the amount of time required to return the system to a suspended solids concentration of 1 ppm.

% of Available Solids	Suspended Solids Concentrations (ppm)	Recovery Time (hours)
100	47,000	35
50	23,500	33
10	4,700	28
5	2,350	25
1	470	20
.1	47	13
.01	4.7	5

Table 1 Vessel/Barrier Clarity Recovery Time

Water Radioactivity Source Terms

The major source of radiation exposure to disassembly and defueling personnel from the defueling water will be from soluble Cs-137 in the water. The objective of the defueling water cleanup system is to maintain the Cs-137 concentration at 0.02 uCi/ml or to return the water to this concentration as quickly as practical.

For the purpose of predicting Cs-137 loadings on zeolite ion-exchange media, a Cs-137 appearance rate scenario has been selected. It will be assumed that Cs-137 will be generated at the rate of 2 Ci per day with a 20 Ci spike occurring every 20th operating day. It must be clearly understood that this source term has been selected essentially as an accounting tool to aid in the selection and sizing of ion-exchange equipment. It does not imply that spikes of 20 Ci are the only spikes possible or that they will occur at all. Spikes of higher or lower size are certainly possible, but they are impossible to accurately predict.

The steady state value of 2 Ci per day is based on the Cs-137 appearance rate that has been observed in recent years. It is anticipated that this base rate will continue to occur during defueling with occasional spikes resulting from cutting and grinding operations.

To maintain the 0.02 uCi/ml concentration in the reactor vessel/contamination barrier with a steady-state generation rate of 2 Ci/day, a continuous flow rate of 20 gpm is required. If it can be assumed that the concentration of 0.02 will be maintained, then the refueling canal and spent fuel pool do not require a continuously operating ion-exchange system because the water leakage from the barrier is already at the desired concentration. Ion exchange will be required, however, whenever a spike occurs in any body of water.

In addition to the capability to maintain the desired Cs-137 concentration of 0.02 uCi/ml during steady state operation, the ion exchange system must also be sized to allow the system to recover from spikes in radioactivity. For this reason, a maximum flow rate of 60 gpm has been chosen for the vessel/barrier subsystem while a maximum flow rate of 15 gpm has been chosen for the canal/pool subsystem.

Figure 2 illustrates the amount of time required to recover from a variety of spikes in Cs-137 radioactivity in the vessel/barrier system when processed by an ion exchange system at 60 gpm. For the condition of a 20 Ci spike and a 60 gpm flow rate recovery is achieved in about 38 hours.

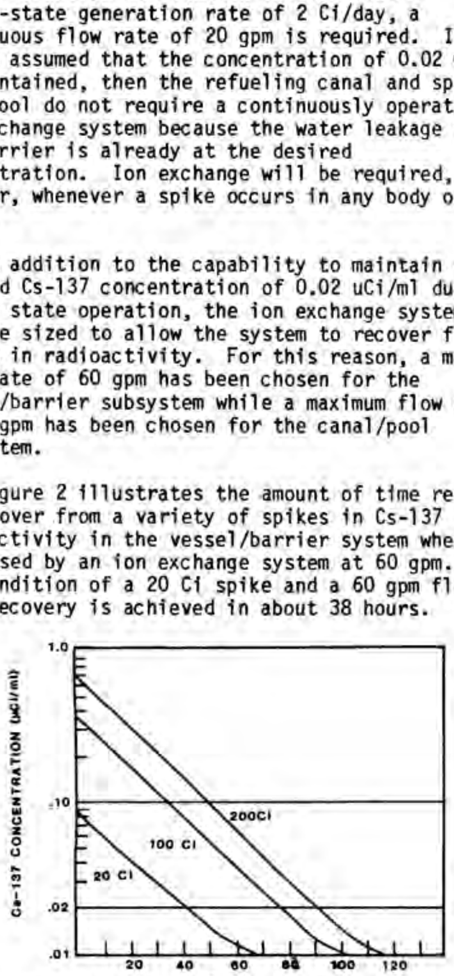

Fig. 2 Vessel/Barrier C^5-137 Recovery Time

SYSTEM DESCRIPTION AND EQUIPMENT SELECTION

The DWCS is not the first major water processing system to be installed at TMI-2. The removal of most of the radioactive water that existed in the TMI-2 reactor containment building as a result of the accident has been accomplished using a specially designed system called the Submerged Demineralizer System (SDS). This system derives its unique name due to its configuration. It is located underwater (submerged) in an auxiliary fuel pool. This water processing system immobilizes the major long lived fission products Cs-137, Cs-134, and Sr-90 on zeolite sorbents. Inorganic zeolites were chosen as the ion exchange medium as they have high radiation resistance and their sorptive capacity is not exhausted by the high sodium and boron content of the waters to be decontaminated.

The high sodium and boron concentrations in the TMI-2 RCS is due to the high boric acid concentrations used for criticality control and NaOH which is added to neutralize part of the boric acid and maintain pH at 7.5 or greater in order to prevent corrosion and fuel leaching.

It is due to these unique chemistry conditions that zeolites were selected as the fission product removal media for the DWCS.

In addition the the special requirements for the ion exchange system, the filtration system used to maintain water clarity by removal of fine debris also has some unusual criteria to meet.

Given the special nature of the fuel debris from both a criticality and shielding point of view, no existing plant filtering system was considered for use in the vessel/barrier subsystem. Unit operations such as hydrocyclones and centrifuges have been ruled out because the solids collected in these systems would still require another intermediate operation to transfer the retained solids to spent fuel canisters. Therefore, an investigation was made of a means of placing a filtering system directly into a spent fuel canister so as not to involve any other transfer equipment.

The particular equipment selected for this application is a filter consisting of a bundle of sintered metal tube filter elements placed directly within a spent fuel canister. The canisters will be placed under water in the refueling canal and spent fuel pool. Water will be pumped into the inside of the sintered metal tubes until a specified pressure differential across the filter is reached. After flow has stopped, a hydraulic bump will be applied in the reverse flow direction to knock the filter cake off the tubes. After the filter cake has been dislodged, sufficient time will then be allowed for the solids to settle at the bottom of the canister. After setting is complete, filtering operations may resume.

A sufficient number of canisters will be arranged in parallel to develop the required 400-gpm flow rates; when the canisters are full, they will be dewatered and disposed of in the same way as spent fuel.

System Description

The defueling water cleanup system concept that has been chosen for detailed design is illustrated in Figure 3. This concept consists of two separate subsystems to maintain acceptable water clarity and radioactivity concentrations in all the above water volumes. One system treats the reactor vessel and contamination barrier volume with a design basis particulate filtration system flow rate of 400 gpm and a soluble fission product removal, zeolite-based, maximum ion-exchange system flow rate of 60 gpm. The other system treats the refueling canal and spent fuel pool with a 400-gpm filtration system and a 15-gpm ion-exchange system.

This concept separates the processing equipment for the vessel/barrier from the refueling canal and spent fuel pool. This has the major advantage of separating the two distinctly different sources of water. The canal and fuel pool both contain large volumes of water that will have relatively low rates of contaminant addition. The vessel/barrier is a smaller volume that will have relatively high rates of contaminant addition. By separating the processing systems for these two bodies of water, the processing rates and component selection can be tailored to these diverse sources.

Because the concept described here has a separate ion exchanger for the vessel/barrier, the required 20-gpm continuous flow rate can proceed without interruption due to conditions in the canal and fuel pool. The use of separate ion exchangers for these two bodies of water also prevents the potential of eluting Cs-137 from the zeolite medium caused by processing water of greatly different Cs-137 concentrations.

The defueling water cleanup system will be required during plenum removal. The vessel/barrier subsystem will be required to be in operation at the time of plenum removal. It may be required to treat the entire combined volume of the reactor vessel and refueling canal during plenum removal. This may be necessary if the contamination barrier is not in place. The system is designed to allow it to treat both vessel and canal water even after the installation of the contamination barrier. This has the advantages of the higher flow capacity of the 60-gpm ion-exchange system and the additional 400 gpm of filtration capacity in the event of unacceptably large spikes in the refueling canal.

The refueling canal and spent fuel pool subsystem will be required to be operational at the time the spent fuel pool is filled. While it is not required, it is desirable that the canal/pool subsystem be operational after the installation of the *contamination barrier* to treat defueling canal water. While the vessel/barrier subsystem may be used to process canal water, it has the following disadvantages:

1. Using the vessel/barrier subsystem ion-exchange system to process refueling canal water will allow the Cs-137 concentration to increase within the barrier.
2. To prevent elution of Cs-137 during the treatment of the canal water, it may be necessary to change out ion-exchange liners before switching the flow path from the vessel/barrier to the canal.

While neither of these reasons prevents the use of the vessel/barrier system to process canal water, it is clearly undesirable from an operational point of view.

Equipment Selection

The purpose of this section is to briefly describe the type of equipment that has been selected for each subsystem.

I. Vessel/Barrier Filtration System

A maximum filtration flow rate of 400 gpm has been chosen for the vessel/barrier subsystem. Given that this system will be processing significant amounts of fuel debris, no existing plant equipment was evaluated for this purpose.

The filtering system that has been chosen consists of a bundle of sintered metal tubes placed in a modified spent fuel canister. Water will be pumped into the inside of the tubes until the differential pressure set point is reached. At this point, a hydraulic bump will be used to knock the collected filtrate off the filters. The debris will then be given sufficient time to settle within the fuel canister at which time filtering may be resumed.

The number of modified spent fuel canisters that must be used in the filtering system as well as the number of sintered metal tubes required to achieve 400 gpm are to be determined during detailed design.

II. Vessel/Barrier Ion-Exchange System

A maximum ion-exchange system flow rate has been selected for the vessel/barrier subsystem of 60 gpm. The system will normally be operated at a continuous 20 gpm.

All ion-exchange media used in the defueling water cleanup system will consist of a homogenous 50/50 mixture of IE-96 and Linde A zeolites. The ion-exchange vessel that has been chosen as optimum is the 6X6 liner containing 100 ft^3 of mixed zeolites. The 6X6 liner has been chosen primarily because of economic and ALARA concerns. It will require fewer filter removals to process a given volume of water than smaller 4 x 4 liners.

The number and configuration of liners to be used will be determined during detailed design.

III. Canal/Pool Filtration System

A maximum filtration flow rate of 400 gpm has been chosen for the canal/pool subsystem.

The existing spent fuel filters have been extensively evaluated for this application and have been rejected for a variety of reasons, chief of which are:

1. The number of filter cartridges required for 2 years of operation could be 100 or more.
2. Dose rates as high as 3300 r/hr on contact could make filter removal a serious ALARA and shielding problem.

3. Filter cartridges will be contaminated with fuel and must therefore be disposed of in fuel canisters. The Department of Energy (DOE) has agreed to take only 256 fuel canisters. One hundred cartridges will require at least 25 canisters, seriously impacting the number of canisters available for other sources of fuel debris.

The filtering system that has been chosen is the same as that for the vessel/barrier subsystem. This will consist of sintered metal tubes in a spent fuel canister and will be operated in the same fashion as that for the vessel/barrier system. This system will be constructed under water in the fuel pool to minimize radiation exposure to operating personnel.

IV. Canal/Pool Ion-Exchange System

The canal/pool ion-exchange system will operate at a maximum 15 gpm. This system will only be required to operate when the Cs-137 activities in the refueling canal or the spent fuel pool exceed .02 uCi/ml.

The systems that were considered for this application consisted of new 4X4 and 6X6-based liner systems as well as the submerged demineralizer system (SDS). While the 6X6 liner presents a number of operating and cost advantages, the SDS has been chosen as the ion-exchange system for the canal/pool subsystem. This choice has been made for the following reasons:

1. The SDS is an existing system with proven capability.
2. The true cost of building a new system to replace the SDS is difficult to determine when considering unknown construction and licensing costs.
3. The SDS will require relatively minor modification and will not involve a major licensing effort.

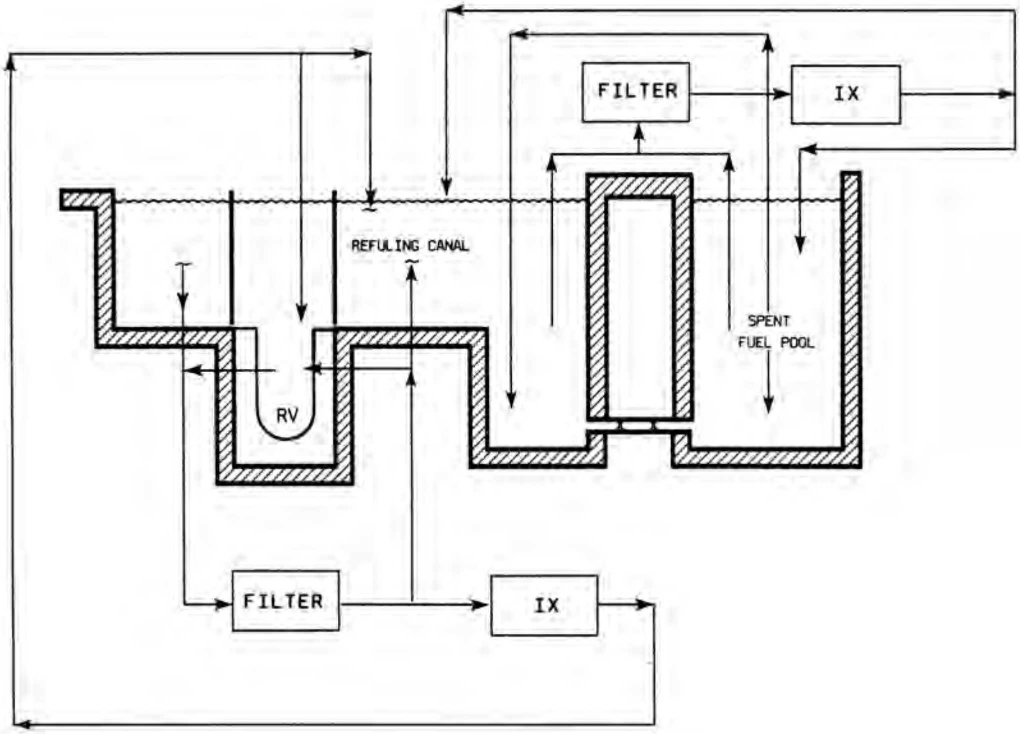

FIGURE 3 CONCEPTUAL DWCS FLOW DIAGRAM