DESIGN, FABRICATION AND PREOPERATIONAL TESTING OF A TRANSPORTABLE VOLUME REDUCTION AND SOLIDIFICATION SYSTEM

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ABSTRACT

In June 1982 Duke Power Company gave Associated Technologies, Inc. (ATI) the authority to proceed with design and fabrication of a Transportable Volume Reduction and Solidification System (TVR) to provide radwaste volume reduction services for one or more Duke Nuclear Stations.

This paper will describe the selection criteria used in evaluation, the Duke specification requirements, and station interfaces required. It will also describe the general design, the fabrication sequence and schedule, and the shop testing that was accomplished after the completion of fabrication. In addition, included is a description of testing to be performed after shipment to Duke which will address performance optimization and 10CFR61 requirements.

SELECTION CRITERIA

The criteria for selection of the TVR were developed from Duke experience with vendor systems and services and the Utility's nuclear power system needs for radwaste service.

The factors involved were:

1. Volume reduction capability
2. Binder acceptability at burial sites
3. Portability and adaptability to the power station
4. Economic feasibility and savings
5. History of proven operability
6. Simplicity of design, operation and maintenance

SPECIFICATION REQUIREMENTS

Based on review of nuclear station radwaste system requirements and the necessary regulatory codes and standards for radwaste system design, Duke Power Company developed a specification for design of a transportable radwaste system and services. This specification required the system to be designed in accordance with the following codes, principles, and utilization requirements.

Codes, Regulations and Standards

1. ANSI B16.5, B31.1
2. NRC Regulatory Guides 8.8 and 1.143
3. ASME, Sections VIII and IX

Requirements

1. The system should include spill containment and control provisions.
2. The system must have its own integral fire protection, heating and cooling, and gaseous effluent control systems.
3. The system would have to be designed for remote operation and ease of decontamination.
4. The system would have to include two large waste holding or batch tanks and have a complete distillate treatment and monitoring system.
5. Selection of materials for all equipment, piping, valves, etc. would have to be of stainless steel.
6. The process had to be capable of volume reducing and solidifying ion exchange resins, boric acid concentrates and steam generator chemical cleaning wastes.
7. The system had to fit into space available and have interfaces located in a controlled area.

PROJECT SCHEDULE

Engineering was initiated in July 1982 and shop functional testing of the system occurred in November 1983. The design, procurement, fabrication, startup and testing of a "first of a kind" system required less than 18 months.

During the engineering phase, the following sequence of events occurred. Initially a flow diagram and process calculations were prepared. Process and instrumentation diagrams (P&IDs), an equipment list, valve lists and an instrument list were then prepared. The next phase was preparation of procurement specifications which included general technical requirements, painting, electrical motors, steel fabrication, piping, etc. During this phase, preparation of detailed equipment procurement specifications was initiated resulting in the procurement of major equipment such as tanks, pumps, valves, instruments, and material handling equipment.

All major equipment was placed on order as of November 1982. During October and November a series of specifications were prepared for assembly, erection, and installation of all equipment including the structure, equipment supports, piping, valves, instruments, electrical cables, and HVAC.

Manufacture of major equipment occurred from September 1982 through January 1983. Deliveries began in February 1983 and were completed in June 1983. In January 1983 a contract was awarded for assembly, erection and installation of all mechanical and electrical equipment.

Fabrication of the structure and equipment supports was initiated in February 1983 and completed in April. During May, June, and July major equipment was set and piping/valve spools were fabricated. From August to October all piping, valves, pipe supports, instruments, and other electrical equipment and cables were installed. (See Figs. 1 through 5.)

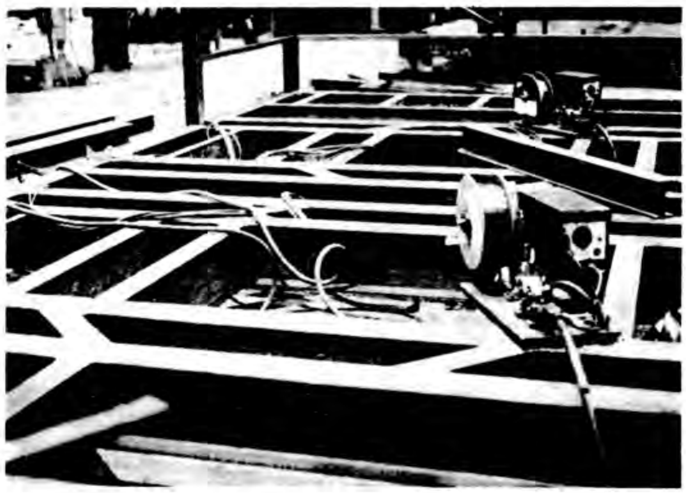


Fig. 1. March 1983, Structural Steel Fabrication. 15" I-Beam Module Base.

Fig. 2. July 1983, Equipment Being Set.

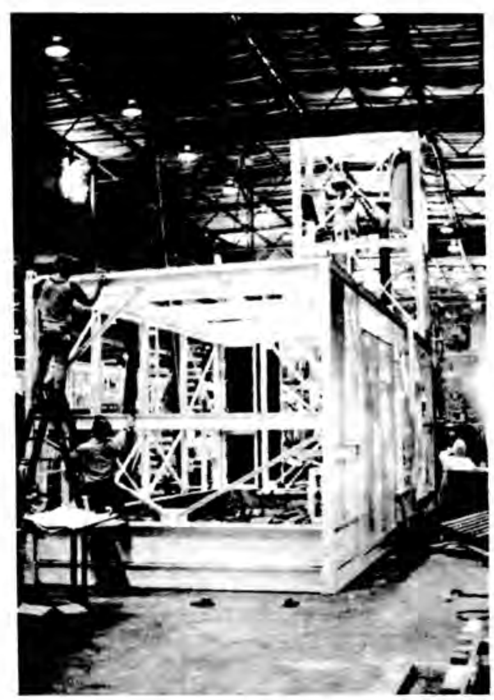


Fig. 3. July 1983, Tanks and Pumps Set in Waste Module.

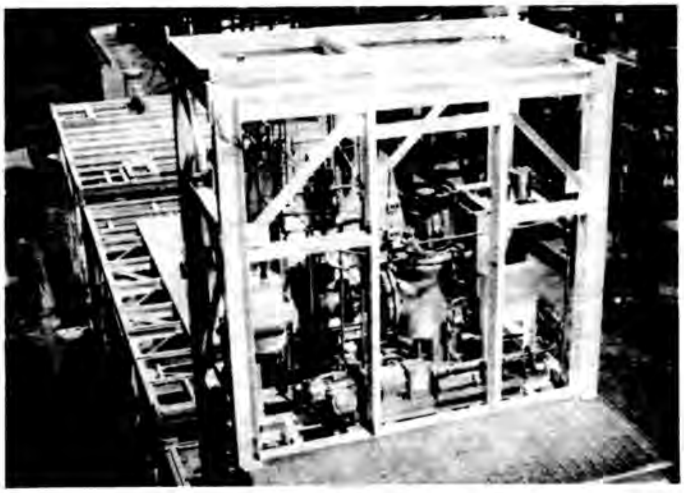


Fig. 4. September 1983, TVR Fabrication (75% complete). Evaporator Superstructure.

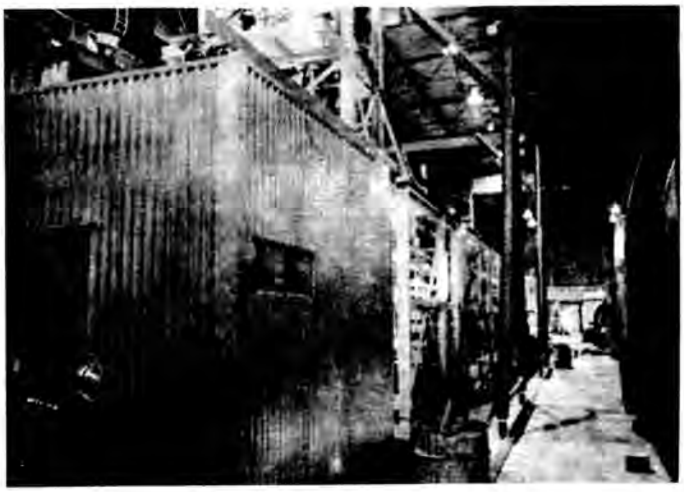


Fig. 5. October 1983, Siding on Control Room Module.

During September and October a series of tests were performed to meet specification and code requirements and verify that fabrication was in accordance with the design. During the month of November 1983 the startup occurred and a complete system functional test was *performed. The* shop functional testing was performed over a period of three weeks, and upon completion the system was disassembled and prepared for shipment.

SYSTEM DESIGN DESCRIPTION

The TVR System is self-contained in enclosed structural steel modules. The modules are transported by truck. The system, which is a complete and operable volume reduction and bitumen solidification system, is prewired and prepiped to the maximum extent possible to minimize the number of field connections required.

A material handling system is provided for handling empty and filled drums.

Figure 6 is an equipment arrangement of the Duke TVR System. A smaller, trailer-mounted system with only one batch tank is shown in Fig. 7.

The system process was developed in France in the early 1960's. The process, a one-step volume reduction and bitumen solidification, is proven and has been operating in both BWR and PWR nuclear power plants for a number of years. In addition to operating power plants the system is being used in research, military and fuel reprocessing centers.

The concept is a chemical and mechanical process for reliably and economically reducing radwaste volumes and incorporating it into a solidified bitumen matrix. The process uses a Luwa Thin-Film Evaporator, which operates at a waste product temperature of 320^{o}F (160^{o}C). This results in the evaporation *of all* free water from the waste influents. The remaining solids are homogeneously dispersed in a bitumen matrix. Solidification of the end product occurs upon the natural cooling of the binder.

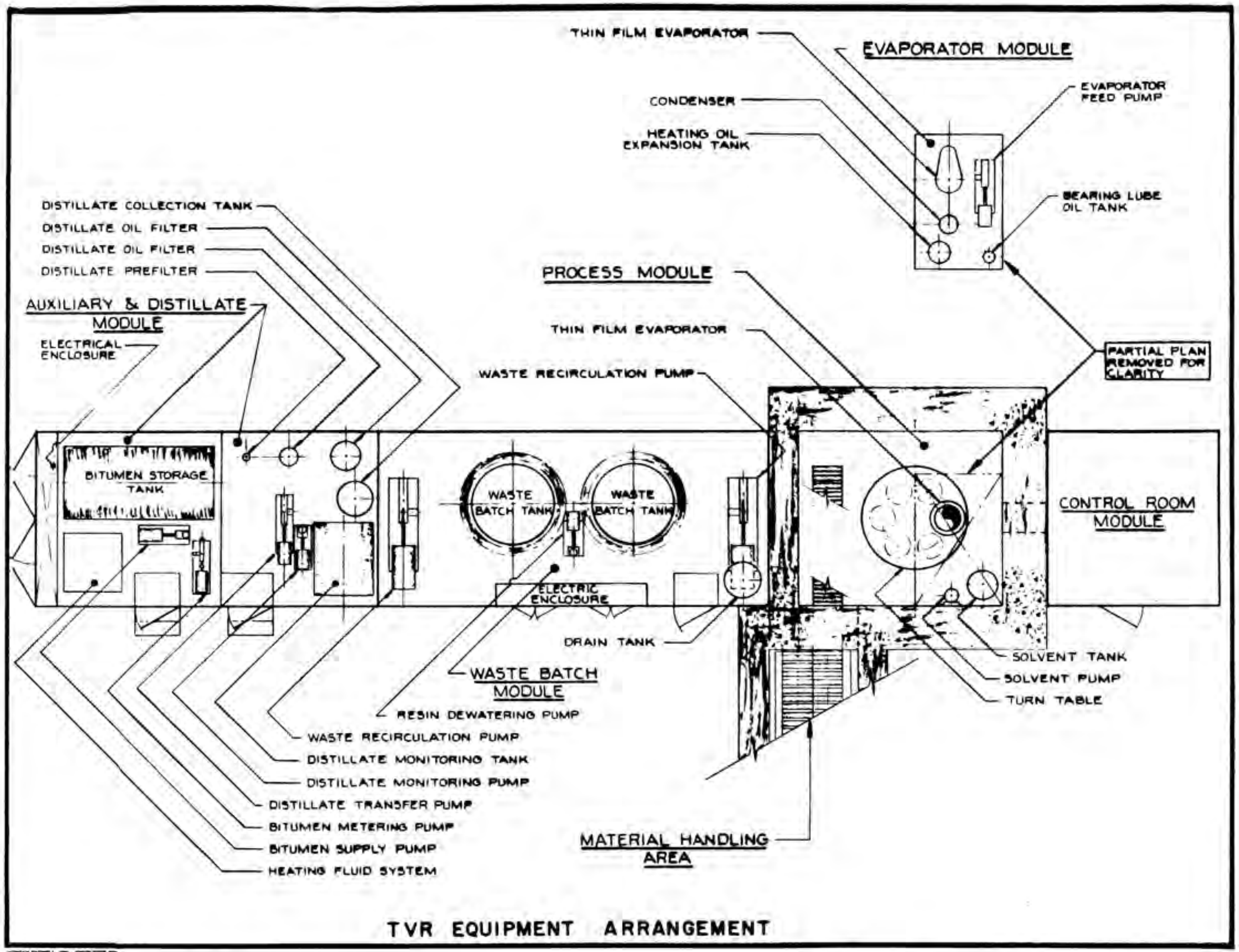
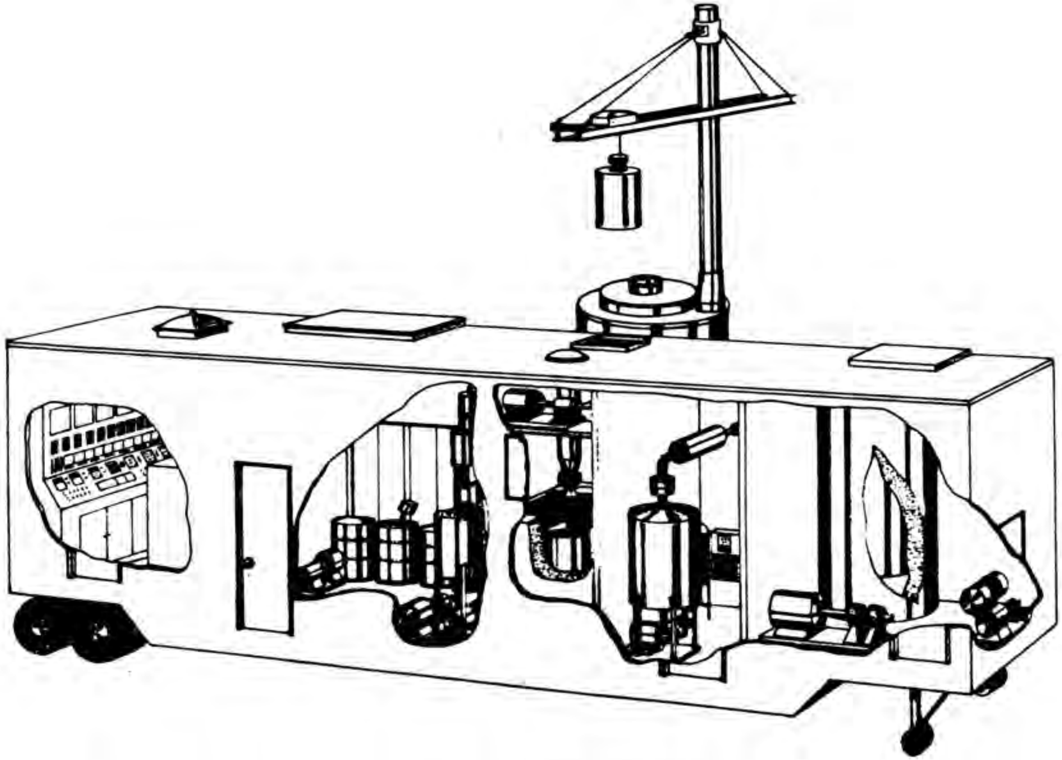


Fig. 6. TVR Equipment Arrangement



TRAILER-MOUNTED TVR SYSTEM

Fig. 7. Trailer-Mounted TVR System

Figure 8 is the Basic Flow Diagram for the TVR System.

Waste to be processed is charged into one of the Waste Batch Tanks. There it is sampled and chemically pretreated to prepare it for processing. Water is decanted or added as required to obtain the desired concentration when processing resins or sludges.

When the waste has been conditioned for processing, it is fed at a controlled rate to the Luwa Thin-Film Evaporator. Molten bitumen is also fed into the Evaporator through a second feed nozzle. The Evaporator is heated by means of a hot thermal fluid flowing through an external jacket.

The Evaporator rotor rotates within the cylindrical, heated body, maintaining the waste and bitumen in a thin, turbulent film against the heating surface. The action of the rotor and the force of gravity create a spiral flow path of waste/bitumen mixture as it flows from the top to the bottom of the Evaporator. As the waste flows through the Evaporator, water is evaporated and the water vapor flows countercurrently upward and out of the Evaporator. The waste solids, which are mixed with molten bitumen, exit the bottom of the Evaporator, flowing into a waste container. Upon cooling, the waste/bitumen mixture solidifies into a free-standing, monolithic, water-free solid.

The water vapor leaving the Evaporator is condensed in a shell-and-tube Condenser and flows into the Distillate Collection Tank. When this tank is filled, the distillate is pumped through a series of filters to remove any light oils that may have been vaporized from the bitumen in the Evaporator. The cleaned distillate then enters the plant's liquid waste system.

Station Design and Interfaces

Station modification for acceptance of the TVR System is outage-related since required personnel resources are of a diverse nature. For example, connection to present plant radwaste systems requires piping and welding in radioactive areas; therefore, there is a need for health physics technicians, welders, pipe support and design, and other maintenance personnel. Once station modification is complete, the TVR can easily be installed and ready for start-up within a few weeks.

Additionally, to properly interface with the station, the TVR, as specified for the Duke installation, was designed for conservation of plant utility resources (e.g. demineralized water, instrument air, etc.). All of the system was designed to fit within the space allocated for this purpose.

TESTING

Two different sets of tests were conducted at the shop prior to disassembly for shipment: Preoperational Checkout and Shop Functional Test.

Preoperational Checkout

The following set of tests was conducted to meet code requirements, verify that fabrication was in accordance with design, and ensure that equipment was operable for startup.

1. The welds of the Spill Containment Basins were tested using liquid penetrant.
2. All fabricated piping was inspected and tested in accordance with the requirements of ANSI B31.1 and NRC Regulatory Guide 1.143. All welding was subjected to visual inspection.
3. Equipment was rotated by hand before starting to ensure binding and misalignment were not present.
4. The direction of rotation of all motors was checked by a brief on-off flick of the switches.
5. Equipment was run and monitored for noise, vibration, binding, loose drives, and misalignment.
6. Safety devices and features were tested for proper operation.
7. The Turntable Assembly was run for a minimum of ten complete revolutions. Alignment with the centerline discharge of the Evaporator was set within 1/4 inch and checked for each station on the first, fourth and tenth revolution as required to ensure proper alignment.
8. The equipment associated with the Turntable and Drum Manipulation (hoist, monorails and conveyors) was run through ten repetitive trouble-free cycles of drum handling.

Testing of the instruments and electrical (I&E) equipment was expected to fulfill three basic needs:

1. Verify that electrical and pneumatic interconnections have been made according to drawings.
2. Verify that the I&E equipment items are functioning properly and can be calibrated.
3. Confirm that the instruments and controls function to control and monitor the process as desired.

The Fabricator made all interconnections, both electrical wiring and pneumatic tubing, between modules.

Ring-out of all instrumentation and power wiring in the modules and control panels was performed. The integrity of the power and instrumentation grounding networks was verified during the ring-out.

The functional testing of all electrical equipment was accomplished. This included breakers, starters, switches, lights, and outlets.

Shop Functional Test

A shop functional test was performed. This included individual testing of five subsystems followed by a series of integrated system process tests. For the integrated system process test nonradioactive anion ion exchange resins were used to simulate low level radioactive waste. The binder used was a straight distilled, viscosity graded asphalt, commercially available as AC-20.

The five subsystems tested were the Heating Fluid Subsystem, the Bitumen Storage and Metering Subsystem, the Distillate Collection and Treatment Subsystem, the Waste Preparation and Feed Subsystem, and the Evaporator Subsystem.

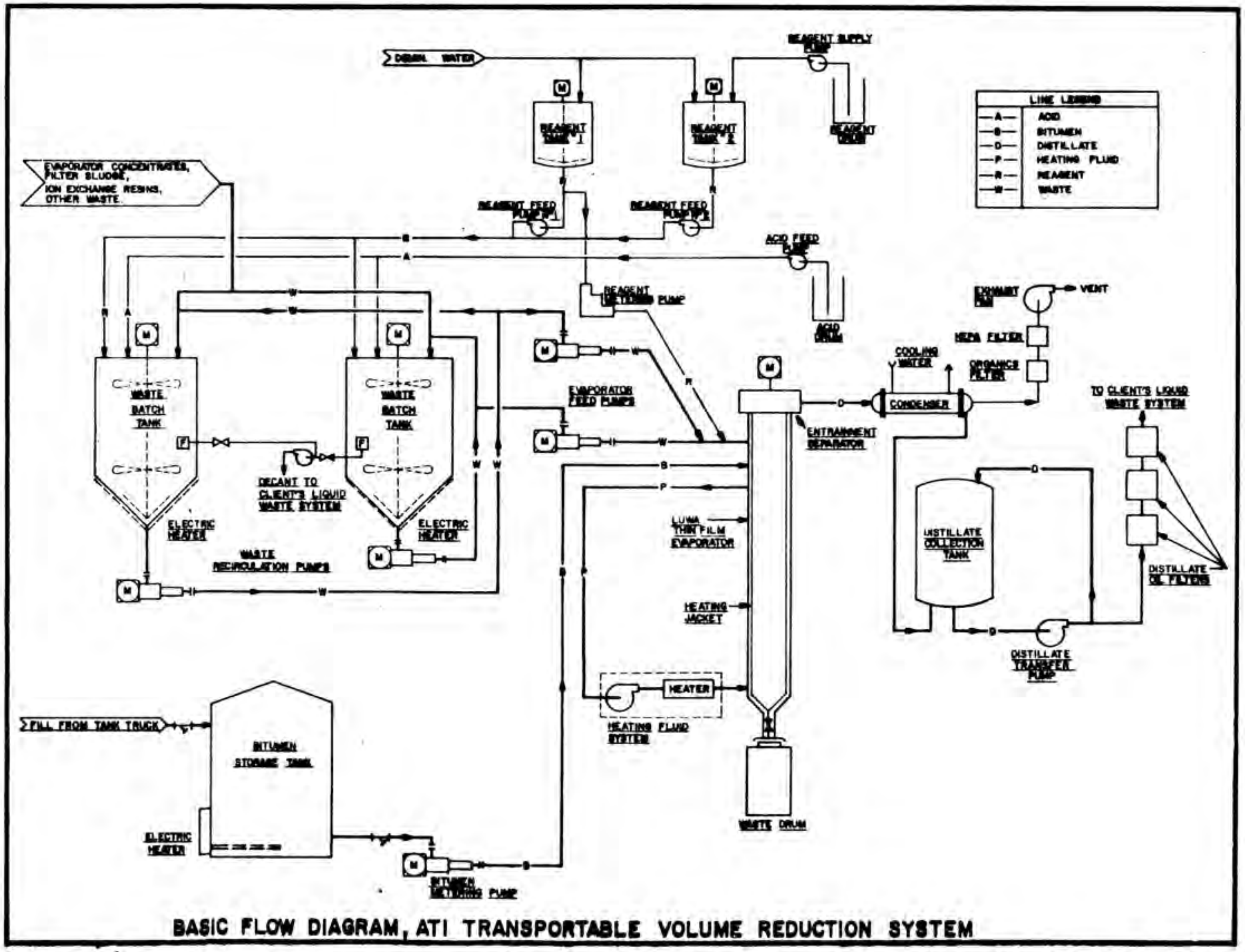


Fig. 8. Basic Flow Diagram

For the integrated system process test, 20 cubic feet of dewatered anion ion exchange resin was placed in waste batch tank B along with 112 pounds of reagent and about 500 gallons of water. The slurry concentration was about 15% by volume resin or about 22% by weight.

The system was started and one drum of product was produced. The evaporator removed free water from the slurry and chemically bound water in the resins. The drum was filled to a level 6 inches below the top of the drum. The filling took 2-1/2 hours and the product contained 30-40% by weight dry solids. At 40% this amounted to a loading of 9 cubic feet of dewatered resin into a filled drum. This calculates to a volume reduction (VR) factor of about 1.2. Higher loadings are achievable with resins. A VR factor for 12% boric acid would be 4.75 and one for 15% Na_2SO_4 would be 3.1.

Twelve hours after the system was shut down the level of product in the drum dropped 2 inches due to shrinkage from cooling. After adding another 10 cubic feet of resin to the waste tank, the system was started again and the first drum of product was "topped off" to a level 2-1/2 inches below the top of the drum. After this another empty drum was positioned under the evaporator. The second drum of product was filled to 1-1/2 inches from the top rim of the drum. It took 2-3/4 hours to fill the second drum. The system was then shut down. During the following weeks the system was started up and shut down three more times. During these periods ion exchange resins were processed.

In order to determine the quality of the product, the first two filled drums were placed in a walk-in freezer and frozen for five days. After the drums were removed from the freezer, they were cut with a grinder and then split in half with a wedge and hammer.

In both drums, the product was homogeneous and monolithic, and no voids were present. The bituminized bead resin had a grainy texture with all beads having a good coating. In both drums the product was very hard with no water present. (See Figs. 9 and 10.)

In the drum that was "topped off" there was no visible interface between the two fills. (See Fig. 9.)

Fig. 9. Drum No. 1 - Two Pass Fill, Bitumen Ion Exchange Resin.

Fig. 10. Drum No. 2 - Single Pass Fill.

During the three week shop test a number of other components were run and tested.

The turntable, jib crane, drum grapple and process module door were operated a number of times. The process module camera was tested for proper operation of its pan, tilt, and zoom functions. The camera operated properly.

Additional Testing

Upon completion of all fabrication activities, the TVR system will be shipped to Duke and temporarily installed at Duke's Riverbend Steam Station near Mount Holly, North Carolina. At Riverbend it will undergo additional nonradioactive testing for six to nine months in conjunction with training of operators from Duke's Oconee, McGuire, and Catawba Nuclear Stations for potential future TVR operation at any station. Completion of additional testing within this time frame leaves the TVR ready by the end of 1984 for its first application at Oconee for processing/solidification of liquid radwaste resulting from Chemical Cleaning of Unit 2 Steam Generators, which may be required as early as February 1985.

The selection of Riverbend as the demonstration site was influenced by several factors. Riverbend has exhibited previous success in testing various systems and components for nuclear stations at a lower cost due to minimal site modification requirements and the availability of space, installation and maintenance, personnel, and support services. Vendor and industry access is assured with installation at Riverbend, due to the difference in security level between a fossil and a nuclear station. Riverbend's proximity to Charlotte is also a plus for both Duke and ATI.

Additional testing of the TVR system which will be performed at Riverbend includes the following:

1. Site Integrated Functional Testing

   Upon completion of the preoperational mechanical and electrical checkout to verify proper assembly, the TVR will be operated with those auxiliary systems not tested at the time of the previously discussed shop tests (the chemical feed system, HVAC system, air compressor, and emergency generator) to demonstrate integrated functional operation of the system. The performance of the entire system will also be demonstrated during this testing phase to verify fail-safe features of the TVR and to assure that for each waste type - boric acid concentrates, spent resins, chemical cleaning solvent - the process yields an acceptable solidified product within both the limiting conditions defined by Duke's specification and operating parameters guaranteed by ATI in the contract.

2. Process Optimization Tests

   After demonstration by Site Integrated Functional Testing that the TVR meets or exceeds all specified criteria and contract guarantees, Duke will perform process optimization tests to further enhance the economic and technical advantages to be gained by the system. This will be performed by determining the *maximum and minimum* operating points achievable while producing an acceptable solidified product. Examples of such optimization will be:

   a. maximum weight ratio for solidified product for each waste type.

   b. maximum transferable resin slurry concentration.

   c. maximum evaporative capacity for each waste type.

   d. minimum reagent and chemical feed concentrations required.

3. 10CFR61 Testing

   As a result of recent regulatory changes concerning the land disposal of low-level radwaste, outlined in 10CFR61 and accompanying Branch Technical Position (BTP) on radioactive waste form and classification, it has become necessary that the TVR undergo additional process testing to verify the stability of the solidified product. Product stability is defined in the aforementioned BTP as follows:

   a. ANS 16.1 Leachability

   b. Compression after Thermal Cycling

   c. Compression after Irradiation

   d. 0.5% Free Water and Free Standing Monolith

   e. Compression after Biodegradation

   f. Compression after Immersion

   It is necessary that these tests be performed on samples of solidified product of each waste type to be processed, i.e., boric acid concentrates, spent resins, steam generator chemical cleaning waste, laundry and floor drains, etc. The data generated by this testing will supplement existing data provided by SGN in order to demonstrate compliance with 10CFR61 regulation.