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MODULARIZATION AS AN AVENUE TO ECONOMIC COMPETITIVENESS

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ABSTRACT

There are many features of the emerging next generation of nuclear power which impact the competitiveness of the facilities. We will focus on the equipment fabrication and erection phase of the work.

Utility plants, like other complex facilities, require comprehensive program management skills. While any project is sensitive to cost, schedule and quality control, nuclear plants have strict and regulated requirements associated with quality control, and its associated materials source and record keeping. The industry has developed an increasing interest in the adaptation of prefabrication, or modularization, to the design, engineering and construction of power plants.

Avondale Industries has been actively involved for the past several years with the DOE/EPRI sponsored Westinghouse design for an advanced passive 600MWe PWR nuclear power plant (the AP-600). The Westinghouse team is currently working on the detailed design and NRC licensing/design certification phase. This program is a part of the current industry advanced light water (ALWR) efforts aimed at re-establishing the nuclear power option to meet U.S. electric generation needs in the 1990s and beyond. The Westinghouse program has the objective of developing the conceptual design of a greatly simplified 600MWe pressurized water reactor plant with major improvements in safety, licensing certainty, life cycle cost, and construction schedule.

One of the major tasks of the program is the development of an optimized plant arrangement and construction approach using modular construction to assist in achieving a short construction schedule and cost-effective plant configuration. Although the finite effect of modularization has yet to be tested in the dynamics of the erection of a commercial nuclear power plant, we feel that there is sufficient evidence from experience in other major manufacturing areas to warrant its application to future construction programs. In order to focus on the potential for modular construction, we will first review its evolution from marine construction into the industrial arena.

Shipyards are ideally suited for diversification into modular construction of industrial, commercial and utility facilities. Our large inventory of heavy materials handling equipment contributes significantly to the efficiency of the fabrication operation. This coupled with automated materials preparation facilities, allow major projects to be constructed in a manufacturing environment. Major shipyards have the sophisticated infrastructure, and the flexibility of its application, needed to support the manufacture of single modules or large complex systems with comparable efficiency.

We will give you a brief history on the evolution of modular construction as applied to major construction projects. While many of the illustrations will naturally be associated with the activities of Avondale Industries, they are also representative of other major manufacturing organizations. Prefabrication, or modularization, has been practiced for many decades by the marine construction industry. The WWII Liberty Ships are a prime example. Non-marine modules also have a long history. The latter were primarily prompted by remote

sites, with attended shortage of skilled labor or hostile environmental conditions, and historically associated with the oil or petrochemical industry.

Avondale Industries employs a comprehensive system of modular construction to build its projects. In general terms, this means that large projects are subdivided into efficiently managed sizes. These subdivisions, or modules, are designed, fabricated and managed as "zones." Our approach is not merely the structural design and construction of discrete modules. It is a comprehensive construction management system that begins in the planning, design and engineering phases and carries through into material procurement, zone outfitting, site erection, start-up, operation and maintenance. A key element of the planning and design functions is the emphasis on constructability.

We employ production lanes, or areas, where the various fabrication activities are performed on the zones. Unlike traditional field construction, we take the work to the workers, not the workers to the work. A typical ship might have 150-200 zones. The application of the marine building procedures to non-ship projects was a logical evolution. For example, a major ship requires upwards of 300,000 individual items of material and equipment to be in the right place, at the right time and of the right specification and design in order to expeditiously complete a project. A modern container ship will require about 10,000 pipe spools, 350,000 feet of electrical cable, and 2,200 drawings.

The fundamental steps in the fabrication process are essentially the same for marine vessels and industrial facilities. Instead of transporting the outfitted zones several hundred yards, or up to a few miles, for incorporation into a ship, the zones may be shipped thousands of miles to the permanent plant or facility site. The size and dimension of the transportable zones is a function of the plant site location. Sites accessible by navigable water systems can incorporate large outfitted zones. The following are a series of slides which illustrate some of the studies and projects utilizing modular construction.

ILLUSTRATIONS

You will note in Fig. 2-1 that the zone has been outfitted to the fullest practical extent. The outfitted module is surface cleaned in a large climate controlled building. Final painting, or

FIGURE 2-1: A Typical Ship Module

FIGURE 2-2: A Typical Prefabricated System

surface treatment, except at the interfacial joints, is completed prior to incorporation into the vessel. We endeavor to install all reasonable items in a module, and clean and test prior to transfer to its permanent location. Only installation of special instrumentation or equipment that is too fragile to handle the transportation activities, and cable pulling, are accomplished after the module has been incorporated into the project. We make extensive use of lifting equipment to orient the modules for "down-hand" welding.

Systems, such as shown in Fig. 2-2, are incorporated into ship modules. You can begin to see similarities between these marine systems and those that might be incorporated into industrial and utility plants. We generally refer to these systems as "packaged units."

Fig. 2-3 illustrates how the outfitted zones are integrated into the vessel. This procedure is generically very similar to the construction of industrial plants. Avondale has accomplished a series of non-marine projects through the application of our modular construction procedures. They have included sulfur recovery plants; large turbine/compressor and turbine/pump stations; toxic and hazardous waste treatment plants; cryogenic systems for gas separation plants; a surface condenser for retrofit of a nuclear power plant; a 192MWe low-head hydroelectric station and an 800-bed detention facility supported by a floating foundation.

Figs. 2-4, 2-5 and 2-6 show some of these projects in various stages of completion. Fig. 2-4 shows a sulfur recovery unit for a Saudi Arabian oil refinery designed by Ralph M. Parsons. We built this plant in five large modules which were shipped by freighter to the Middle-East. A similar unit was later built and shipped to Greece.

Fig 2-5 is a toxic and hazardous waste treatment plant that was designed and built in eleven truckable modules. This system incorporates a circulating fluidized bed combustion system licensed by the Pyropower Corporation.

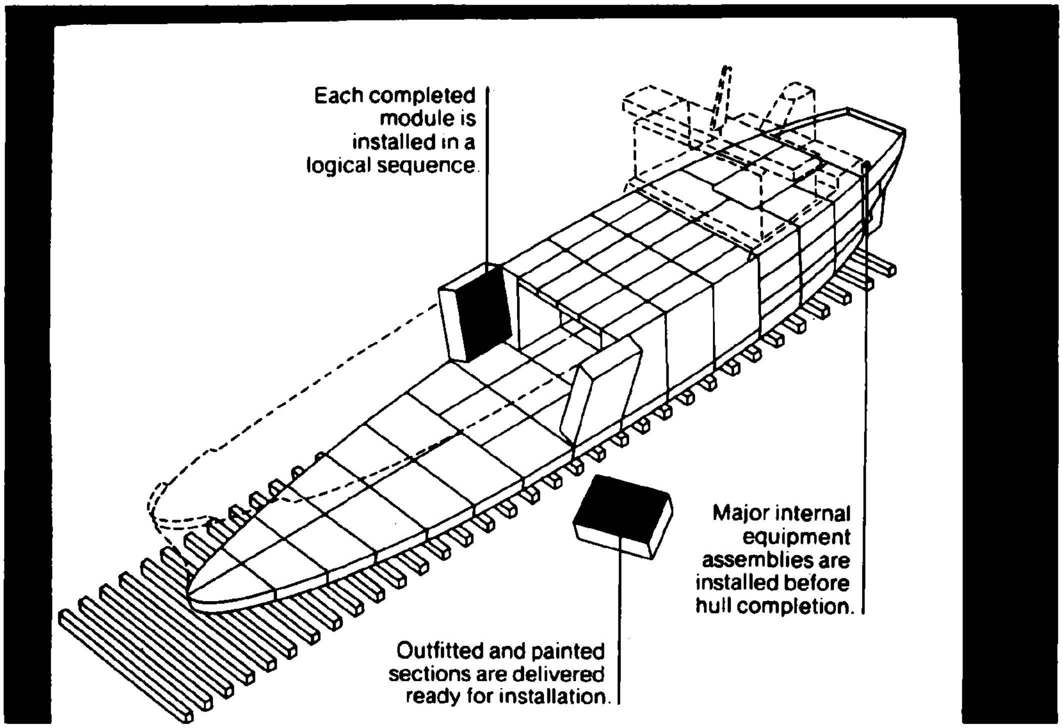

FIGURE 2-3: Modular Ship Construction

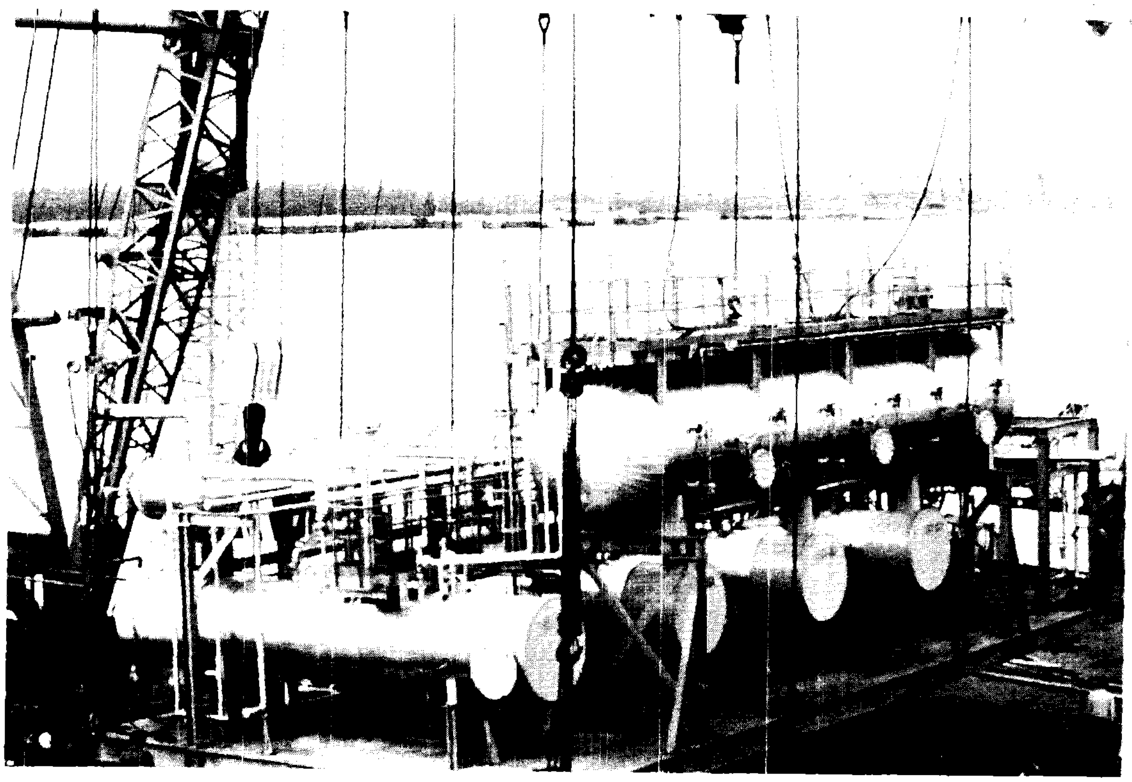

FIGURE 2-4: Sulfur Recovery Unit

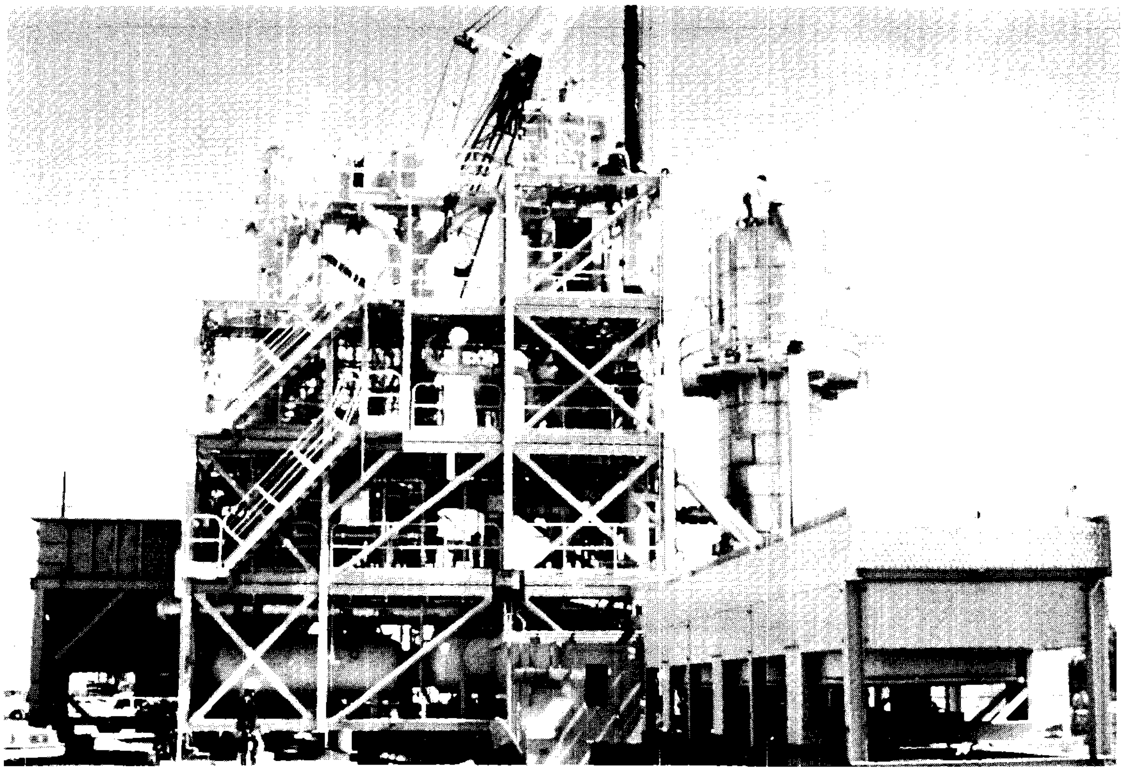

FIGURE 2-5: Toxic Waste Treatment Plant Based Upon CFBC

Fig. 2-6 is the 192MWe low-head hydroelectric power plant station under construction. The majority of the modules that went into this structure were fabricated at our Westwego yard about five miles down the Mississippi from the erection site. While admittedly unique, this project dramatically illustrated the impact of modular construction. Our competitively bid, fully bonded, and guaranteed fixed-price and schedule was $100 million lower and six months shorter than those based upon traditional field fabrication. This plant is currently operating after exceeding its performance guarantees.

Fig. 2-7 shows the completed power plant structure under tow for its 200+ mile journey up the Mississippi to the site on a canal between the Mississippi and the Atchafalia River basin. One of the many unique features of its design was that the module zones also served as the forms for about 120,000 cubic yards of concrete which was placed in it at the site.

The question is often asked about how large a prefabricated module is practicable. Shipyards routinely handle and move about modules that weigh several hundred tons. Ships weighing over 20,000 tons are moved on and off a floating drydock. The 192MWe hydroelectric station weighed about 25,000 tons when it was moved off the building ways onto the floating drydock and floated into the Mississippi.

Fig. 2-8 shows a module for an olefins plant. This module was fabricated in IHI's Japan yard and transported to Yanbu, Saudi Arabia. This module weighed about 1800 tons. Please note the similarity to portions of a power plant. Fig. 2-9 shows major modules for a fertilize plant being shipped from Anacortes, Washington to the Kenai Peninsula in Alaska.

We are also participating in a broad range of design, development and quotations for projects on all matter of structures, both land-based and supported by floating foundations. These include hotels, restaurants, prisons and detention facilities, repowering of fossil fueled electric power stations, cogeneration facilities, peaking power units, bus maintenance depots, iron ore reduction plants based upon coal gasification, solid waste and sewage sludge treatment facilities. Prominent among these is our involvement with the Westinghouse team for the licensing of the next generation of standardized Nuclear power plants–the aforementioned AP-600.

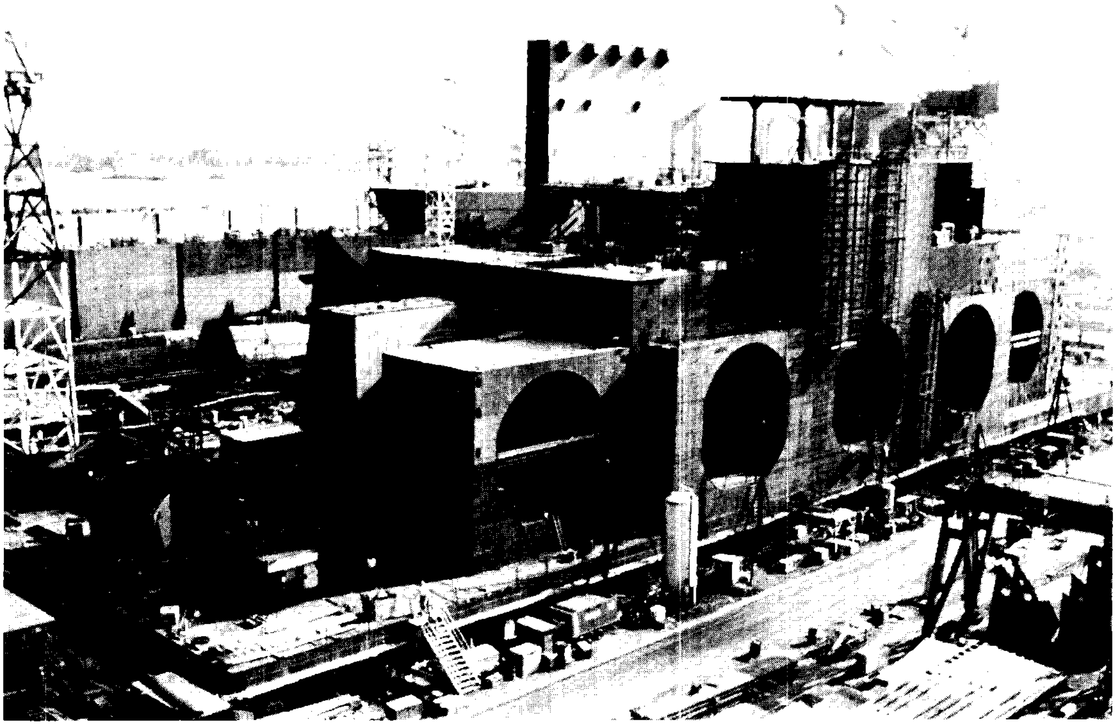

FIGURE 2-6: Hydroelectric Plant Under Construction

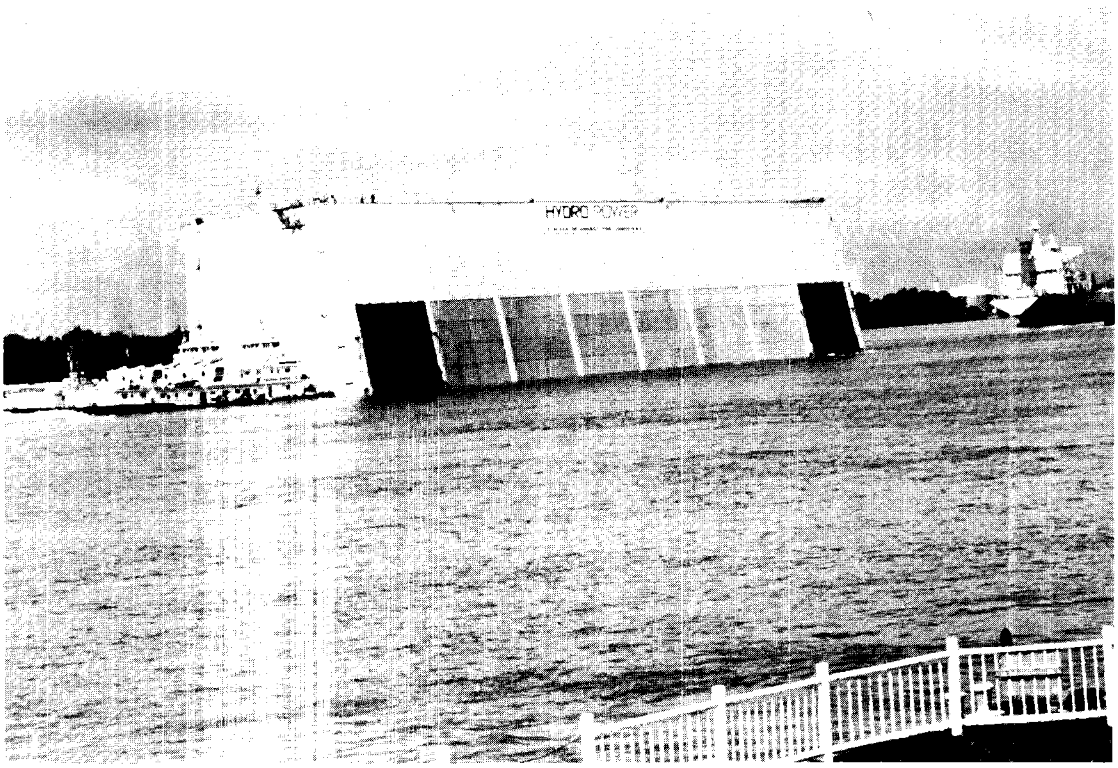

FIGURE 2-7: Completed Hydroelectric Plant in Transit to Site

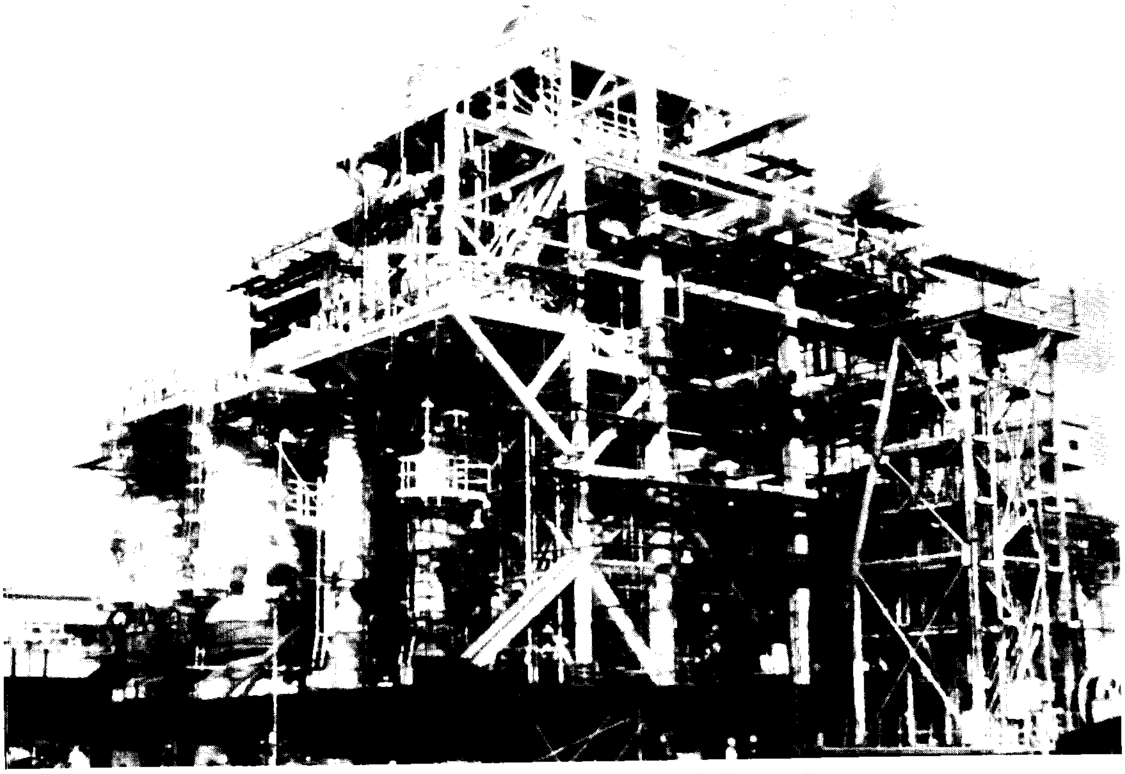

FIGURE 2-8: Module for an Olefins Plant

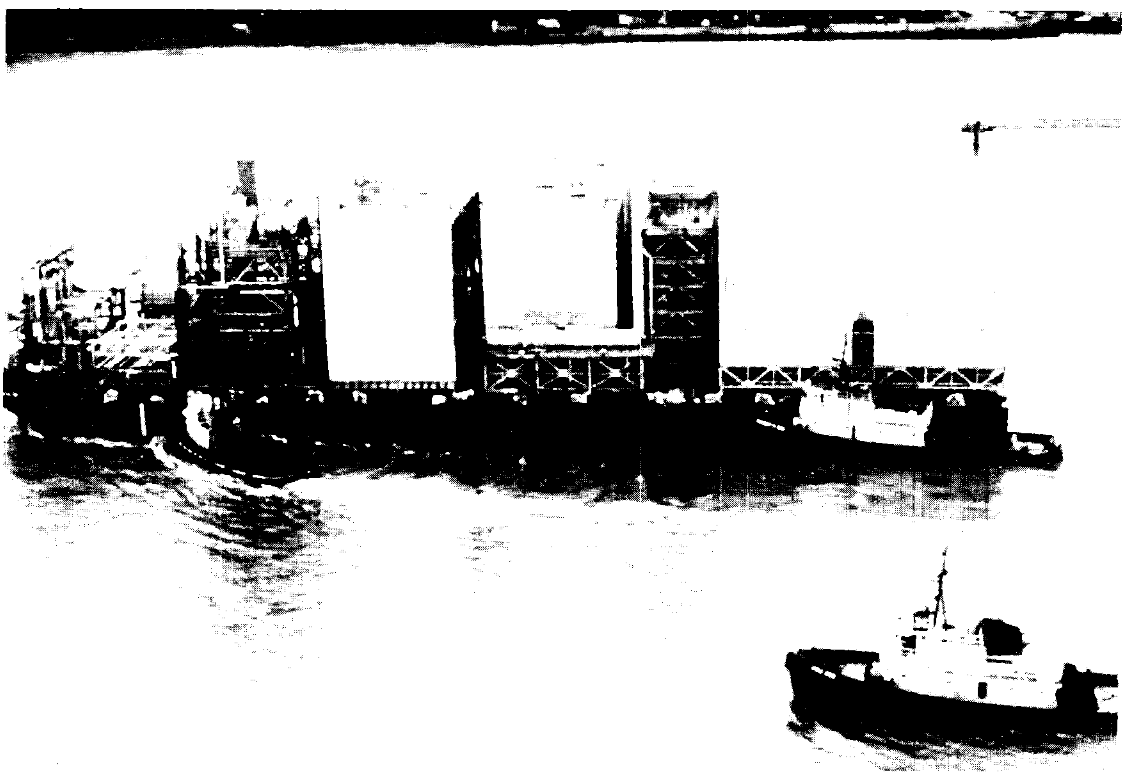

FIGURE 2-9: Fertilizer Plant Modules in Transit to Site

Fig. 2-10 illustrates a 150MWe circulating fluidized bed coal-fired generation unit based upon Pyropower technology. We worked on the project with Pyropower and the Bechtel Corporation for the repowering of a Wisconsin power station. The system was designed to be prefabricated in 21 modules. This approach appeared to be very competitive, however the project was indefinitely postponed. Fig. 2-11 shows a further breakdown of the combustion chamber, cyclone superheater, reheater, air heater and economizer sections, which illustrates the proposed modules.

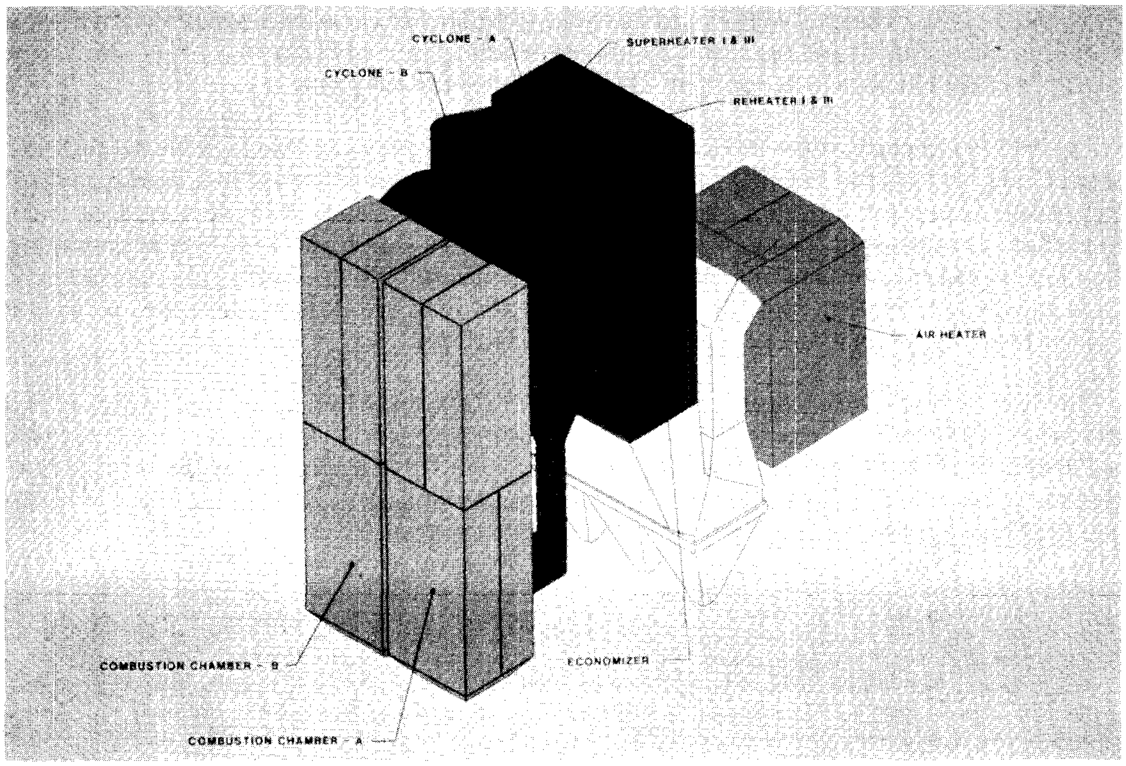

FIGURE 2-10: CFB Coal-Fired Power Plant

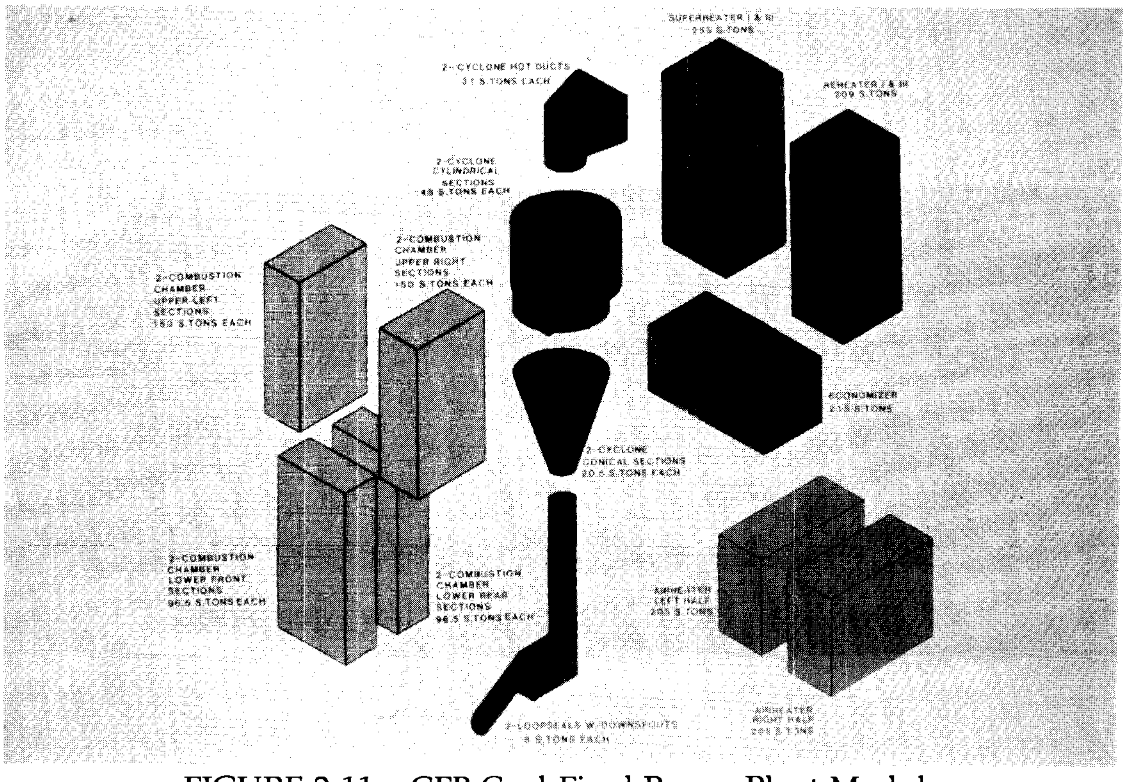

FIGURE 2-11: CFB Coal-Fired Power Plant Modules

We were also involved in an innovative proposal to build an 800MWe coal-fired power plant on the Bahamas and transmit electricity to Florida via an underwater direct-current cable. We developed a comprehensive modular construction approach which divided the plant into three types of zones. Zone type A would be essentially completed remote from the site. Zone type B would consist of pipe spools, packaged units, material and equipment that would be assembled into major modules at the site. Zone type C would be essentially constructed in the field; however, all necessary material and equipment for such zone would be kitted at a remote marshalling yard and dispatched to the site "just-in-time" for erection. Fig. 2-12 shows the plant depicted by blocks which approximate the modules for the plant.

Fig. 2-13 is a picture of the model of a portion of the systems associated with the turbine/generator. Fig. 2-14 is the turbine/generator area in block module form. This work provided valuable insight into the program management systems and logistics of implementing a major power plant. The apparent economic advantages from such an approach were very encouraging. It should be noted that for maximum effectiveness we must rethink the entire project structure to include equipment vendors, systems subcontractors and field erection organizations as well as the major module manufacture at shipyards, or like facilities.

Our involvement with Westinghouse on the AP-600 brings into focus the subject of this conference. We have been working with Westinghouse for several years to develop improved construction techniques for the AP-600 plant design with the emphasis on the efficiency of construction, operation and maintenance. The next series of slides are from our AP-600 model which is effective in illustrating modular construction applications.

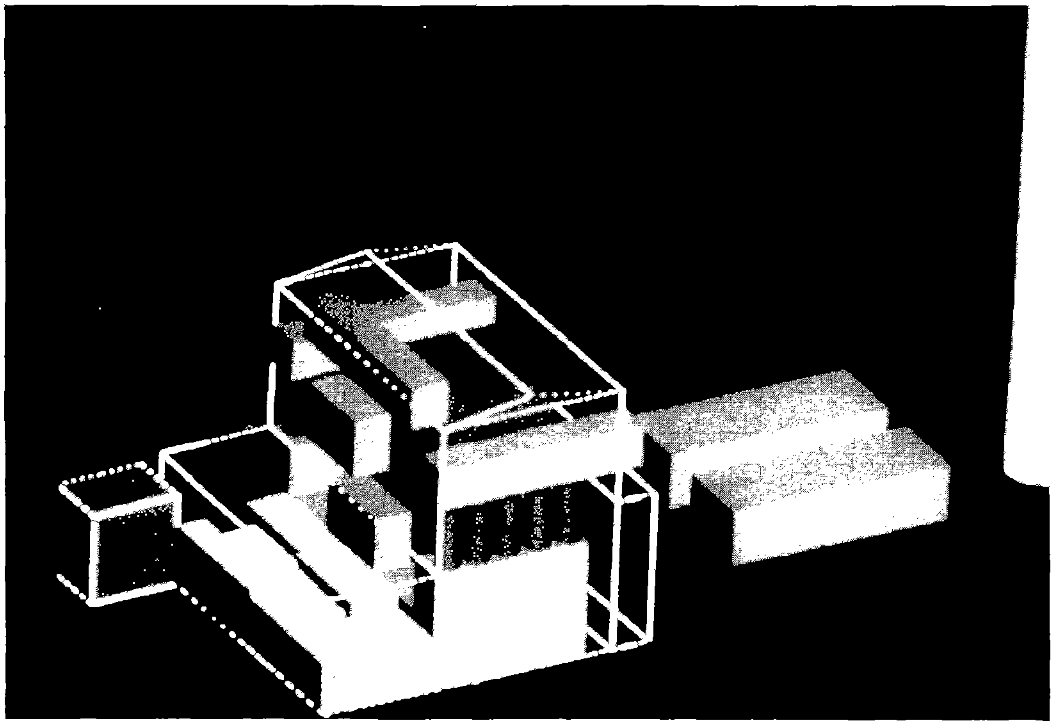

FIGURE 2-12: Plant Zones Simulated by Area Block

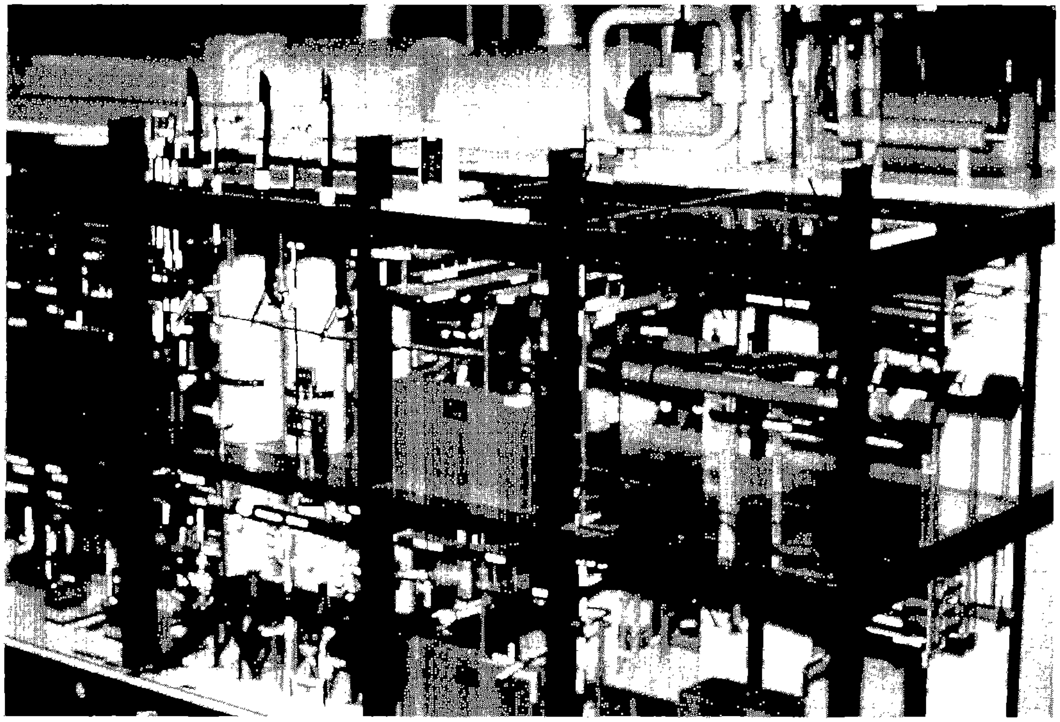

FIGURE 2-13: Turbine/Generator Area Model

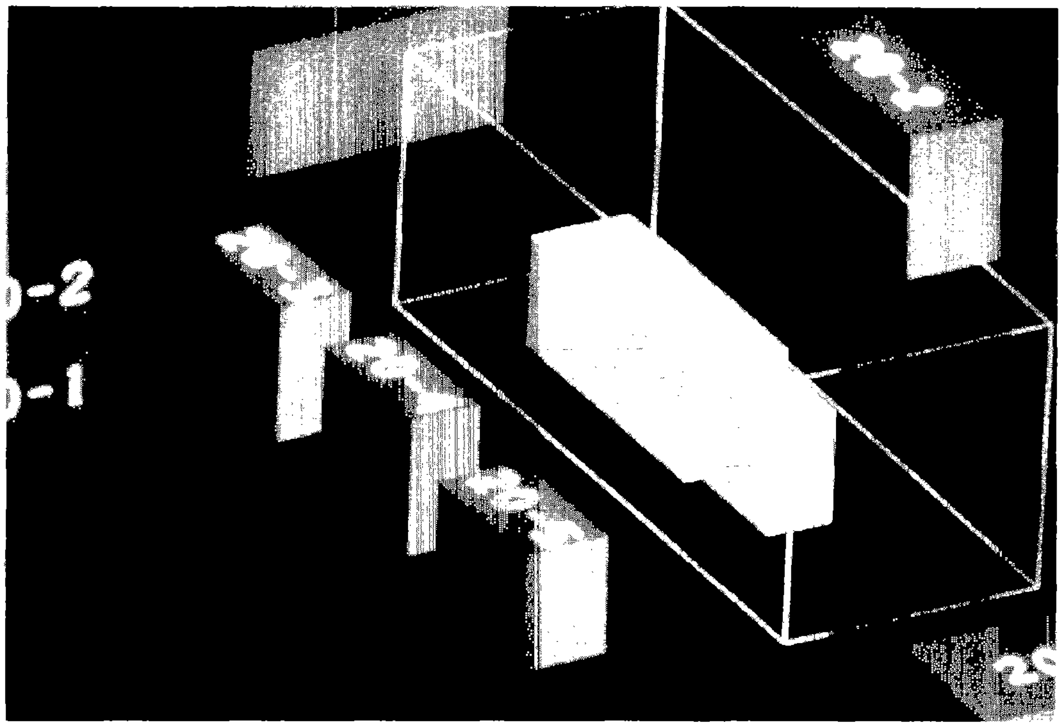

FIGURE 2-14: Turbine/Generator Area Modules

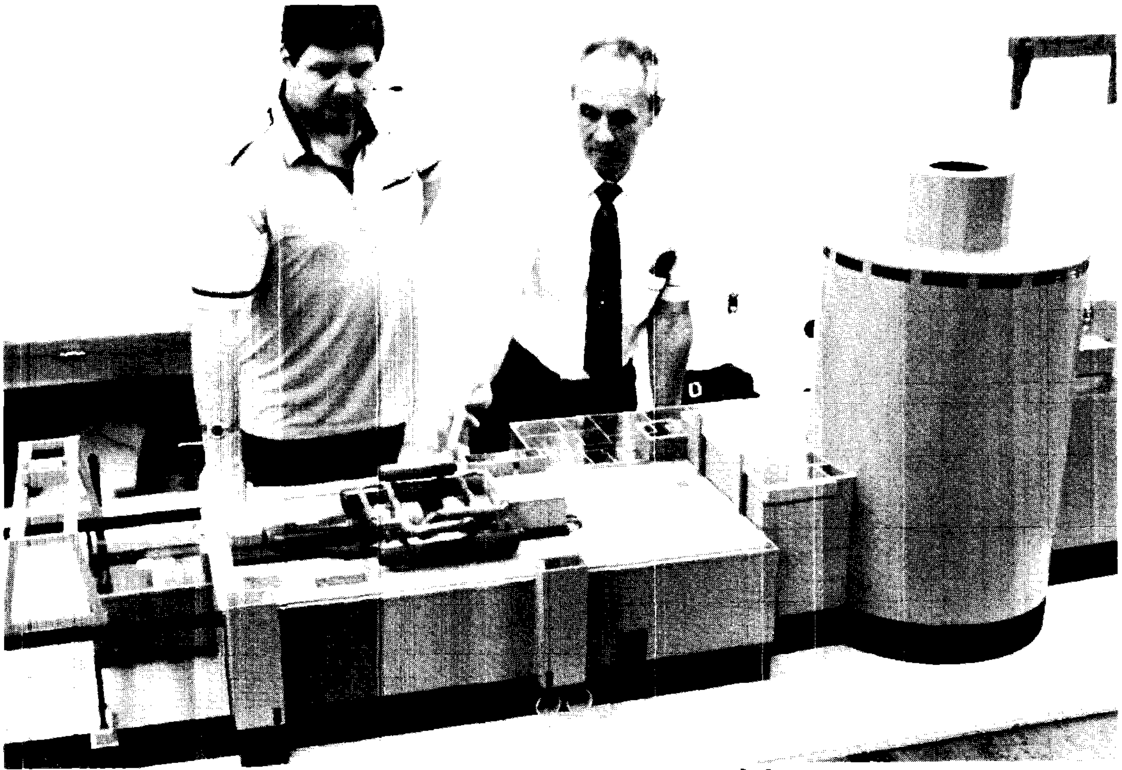

FIGURE 2-15: AP-600 Model

Fig. 2-15 is the assembled model with the nuclear island to the right and the turbine/generator building to the left without the enclosure for the turbine/generators.

Figs. 2-16 through 2-18 are plan views of the various levels in the nuclear island.

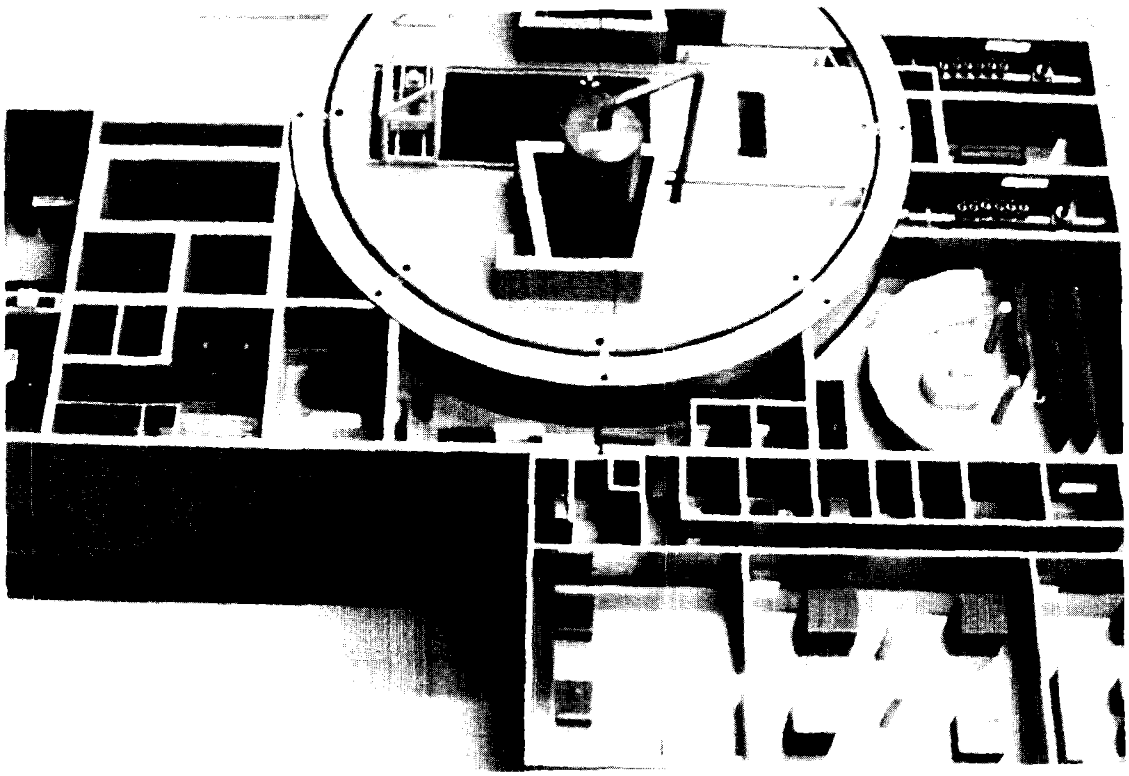

FIGURE 2-16: Level 3 of Annex and Fuel Buildings

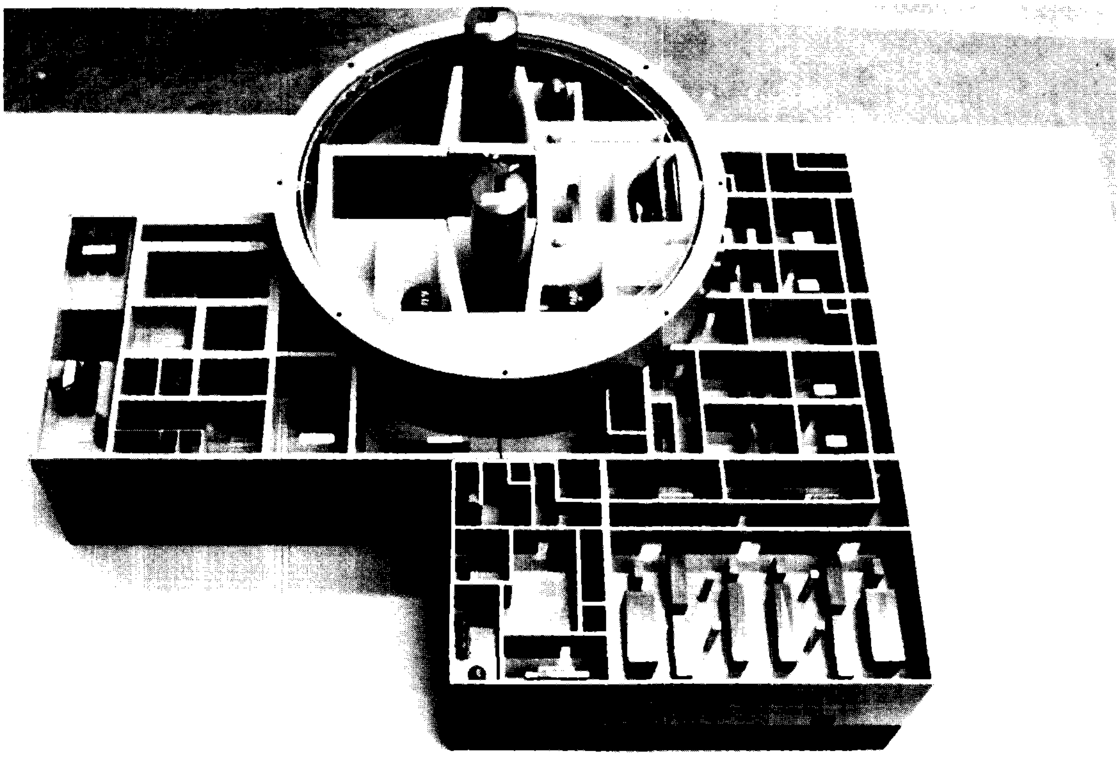

FIGURE 2-17: Level 2 of Annex and Fuel Buildings

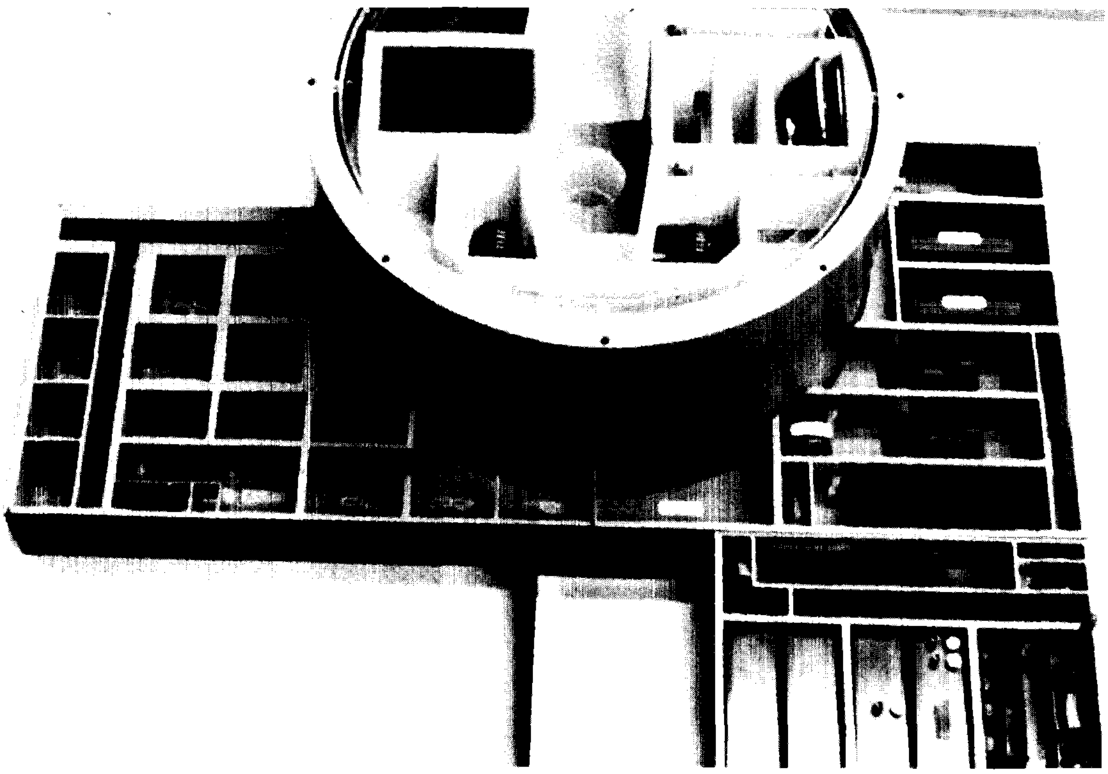

FIGURE 2-18: Level 1 of Annex and Fuel Buildings

Fig. 2-19 shows the turbine/generator building systems located under the turbine deck. You will note the many packaged units and modules that are included in the containment, annex, fuel and turbine/generator structures.

The program has included a rigorous evaluation of all aspects of the power plant. The primary emphasis has been on creating a fabrication environment where the most efficient construction methods can be applied consistent with the highest level of quality assurance and quality control. The current design parameters include the specification that the modules be rail shipable.

This means that discrete modules will be no larger than twelve feet in width & height and forty to eighty feet long. In the case where the plant site is accessible by navigable waterways, these rail shipable modules can be incorporated into larger modules at the fabrication site. They may also be assembled together at a site adjacent to their permanent placement.

As the dynamics of the development program unfold we have identified groups of module types. These include "L" modules, "M" modules and "E" modules. The "L" modules are steel liner modules which are placed within the containment structure and interface with each other, or field installed systems. These are left-in-place steel/concrete forms. The "M" modules provide steel structural systems that have stand-alone strength for the intended use, however they also will be designed and fabricated to act as the forms for concrete radiation shielding and missile protection.

"E" modules are equipment modules for a wide variety of services. They will be placed both within the containment and throughout the plant. These modules will be fabricated at equipment vendors, module fabrication facilities and plant fabrication areas. The primary goal is to have such systems assembled in areas where the craftsmen have the best working conditions and their supervision is most effective.

FIGURE 2-19: Turbine/Generator Building Below Turbine Deck

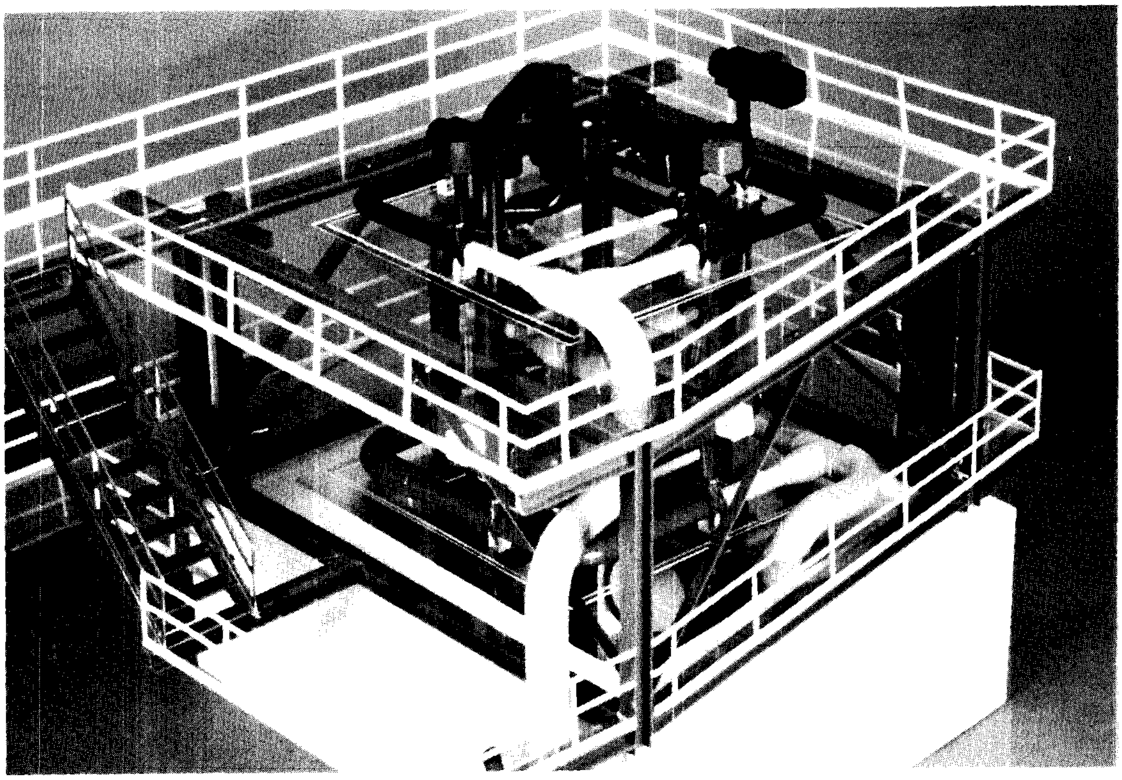

FIGURE 2-20: Depressurized Piping Module

The individual modules will generally weigh in the range of 10 to 650 tons. Each will be pre-outfitted to the maximum practical extent, including such things as equipment, piping, instrumentation, ventilation, cable trays (cable would be pulled after installation of the modules to minimize electrical interconnections, except where such cable would originate and terminate within the module), grating, valves, fittings, engineered equipment and the like. All surface treatment such as painting, insulation, sound proofing and the like would be completed on the module prior to permanent placement.

We have with us today two models which are part of the proposed AP-600. They are the chemical, volume, clean-up system (CVCS) and depressurizer piping module. The first represents two rail shipable piping and equipment modules, the latter is a piping module featuring two trains of let-down valves and piping. These modules will be installed within the containment structure, however they are typical of the ones being developed for the entire plant.

Fig. 2-20 shows the depressurizer piping module complete with decking and railings. Figs. 2-21 through 2-27 show the core of the depressurizer piping module without the decking and railings. The CVCS system is designed as two rail-shipable modules. One contains the demineralizer and the other the filters.

WHAT CAN WE CONCLUDE FROM ALL OF THIS WORK?

Modular construction of major plants such as nuclear power is technically feasible. The program management approach is different than traditional field erected plants, however well within the capabilities of experienced industry design/constructors.

Although the cost of planning, design, engineering, procurement, and program management phases of the project may be higher, as a percentage of the total project cost, the increase in the scope of this portion of the project will be significantly offset by reductions in the balance of

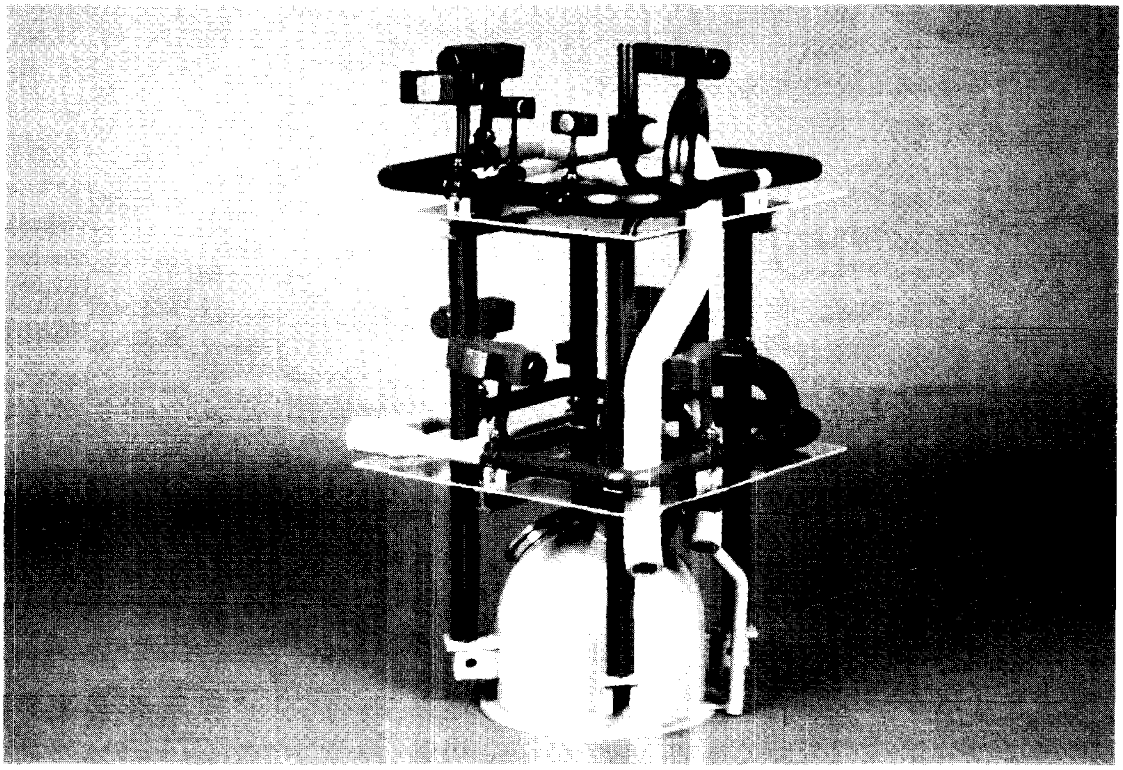

FIGURE 2-21: Depressurizer Piping Module Core System

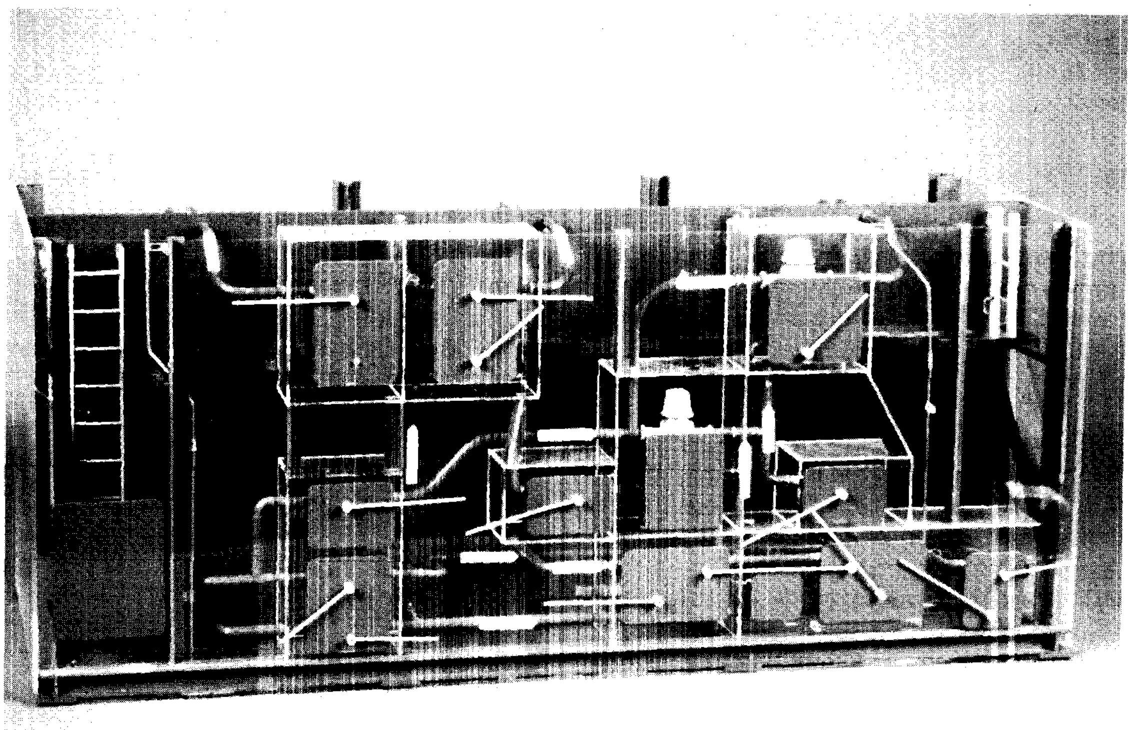

FIGURE 2-22: Demineralizer Valving

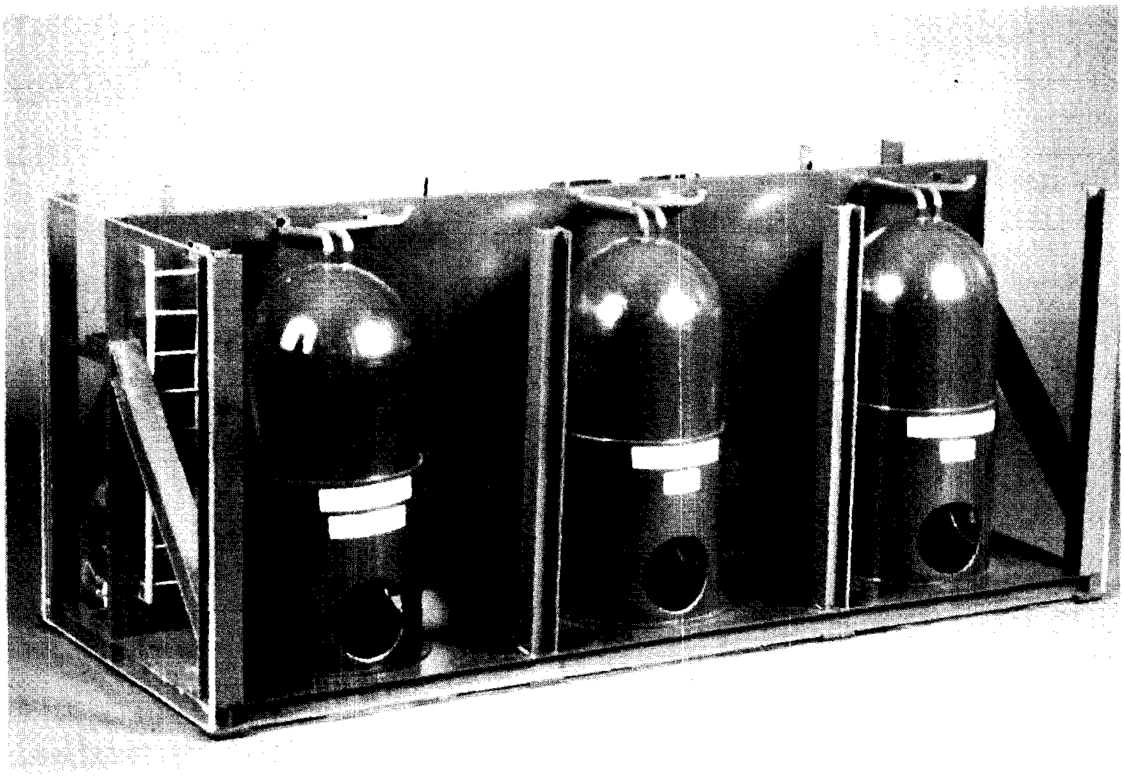

FIGURE 2-23: Demineralizer Reactors (Opposite Side to Valves)

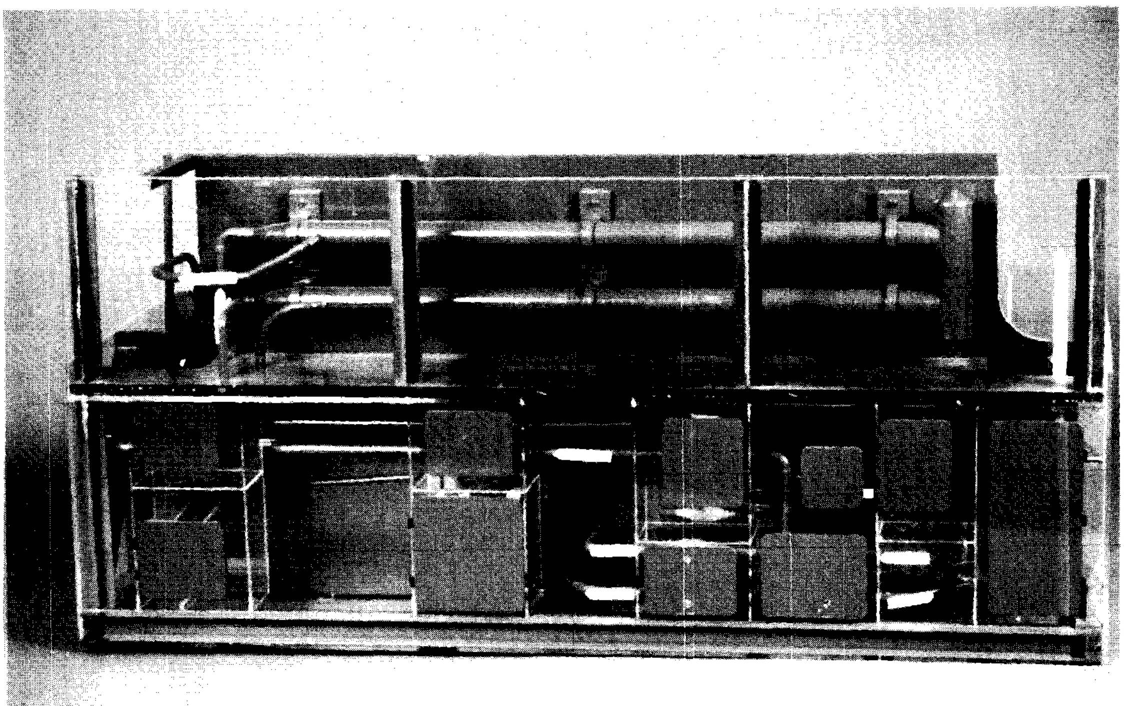

FIGURE 2-24: Filters Valving

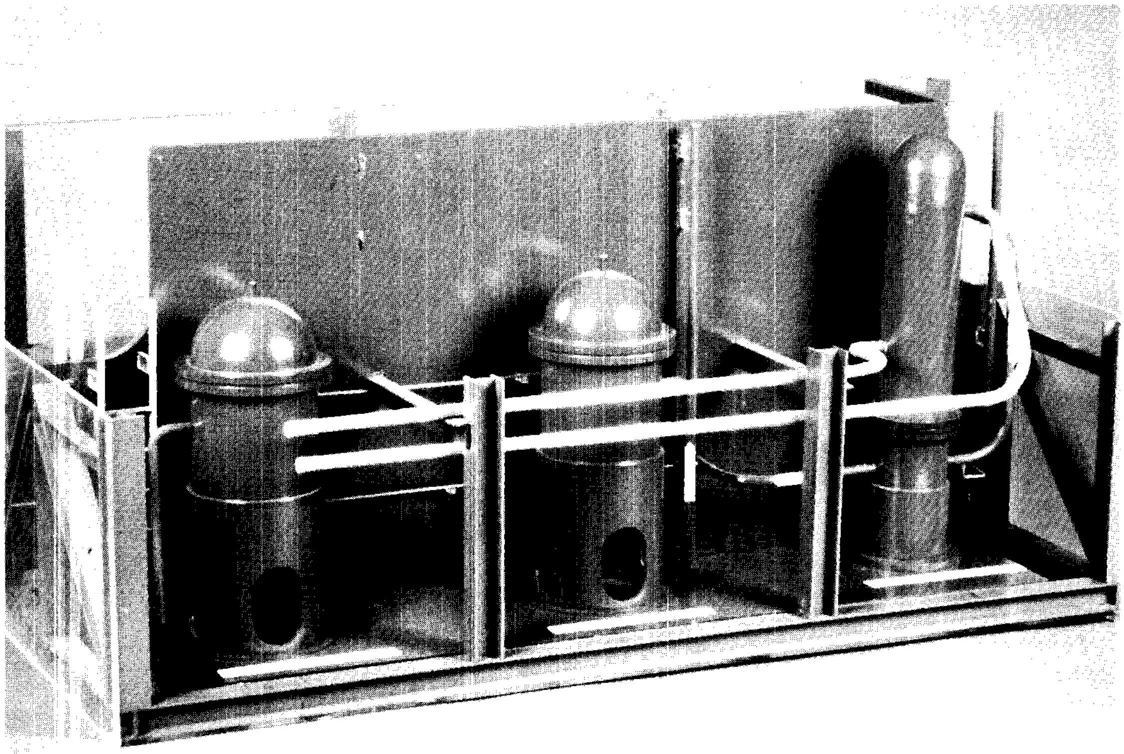

FIGURE 2-25: Filters (Opposite Side to Valves)

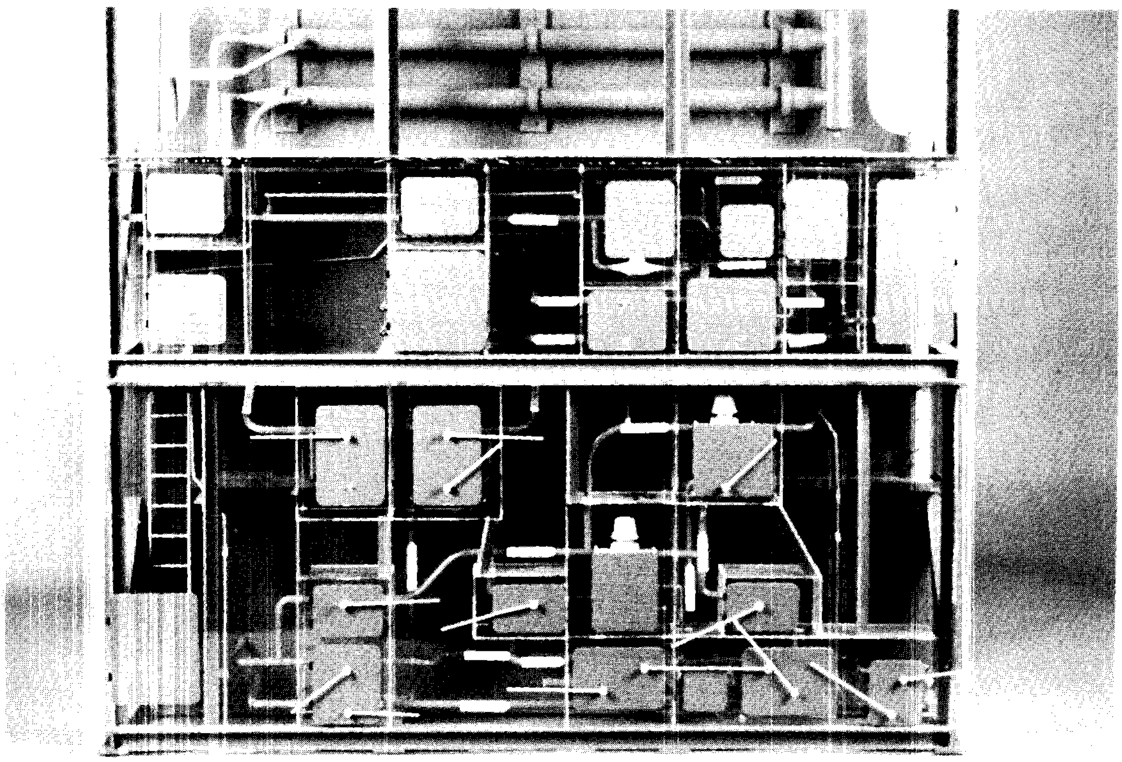

FIGURE 2-26: Demineralizers and Filters (Valving), Stacked

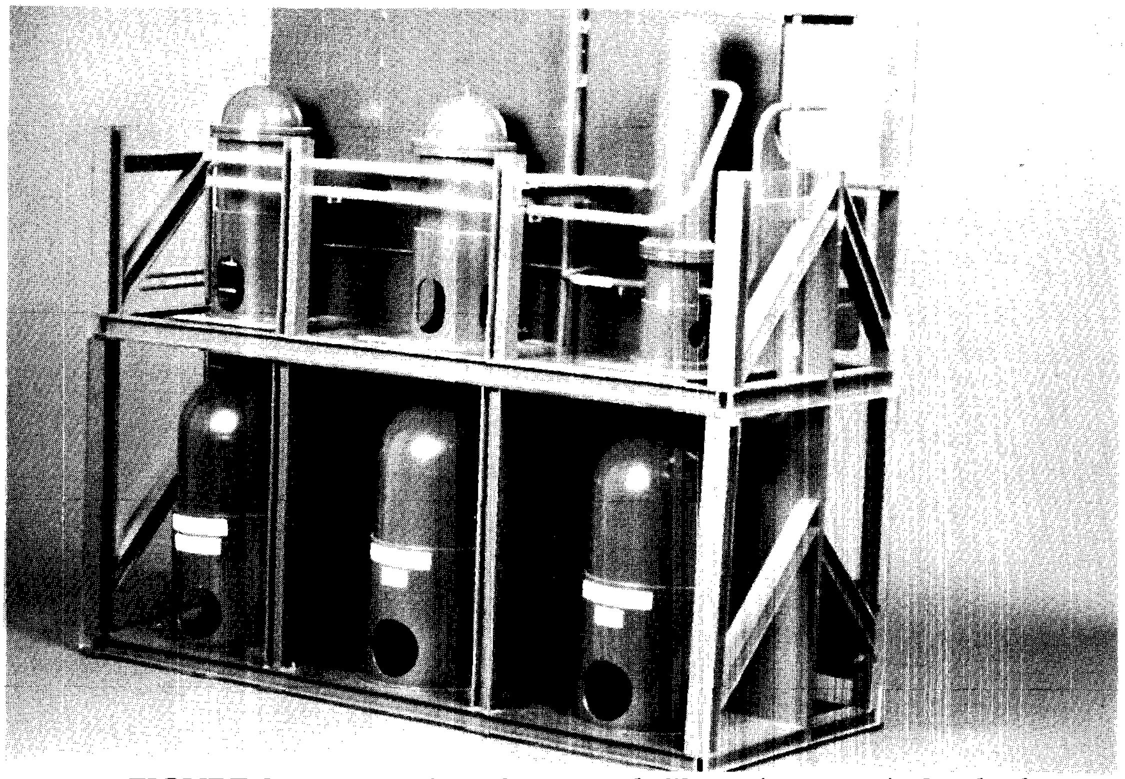

FIGURE 2-27: Demineralizers and Filters (Reactors), Stacked

plant costs. This is especially the case for the AP-600, which will be designed as a "standard" plant, and NRC design certification will be obtained prior to start of construction.

A substantial shortening of the overall project schedule is a key objective of the program. 600MWe conventional nuclear power plants have been brought on-line in five (5) years after contract signing. The current estimate of the Construction Schedule for the AP-600 is 36 months from first concrete pour.

The AP-600 economics derive from four basic sources: 1) plant simplification; 2) extensive use of modularization; 3) reference plant experience with operating PWRs; and 4) passive safety systems. Design simplifications have enhanced the overall safety of the plant while eliminating about 60% of the nuclear island valves, 35% of the total plant pumps and 75% of the nuclear island piping. The building volume is about 40% less than existing 600MWe plants.

These and other efficiencies brought about in a large part by the effectiveness of modular construction yield a 30% reduction in the total capital cost compared with the reference plant PWR. Modularization provides increased productivity, reduced field erection period, early starts on items that can be built in parallel, mitigation of the impact of weather-related delays and greatly enhanced quality control, inspection and documentation.

In summary, the fabrication techniques developed in the dynamics of shipyard construction are being applied to a broad range of industrial and commercial projects. The improvements over conventional field construction include:

(1) Maximum use of modularization for structures, equipment, and systems.

(2) Centralized manufacture and assembly of modules under modern factory conditions.

(3) Pretesting and inspection to quality-control specifications prior to shipment.

(4) Streamlined field installation, based on detailed work sequencing.

(5) Major reductions in bulk materials and field labor requirements.

(6) Efficiencies in plant arrangement that translate into compact size and ease of maintenance.

Last, but not least in the minds of the utility's financial officers, this approach opens the way for securing significant portions of the plant under firm price and schedule commitments.