The most acute APROS application for Loviisa studies is a comprehensive modelling of the plant auxiliary steam control system to enhance the reliability and operability of the turbine plant in different loading situations. Our aim is to optimize this closed loop control system, and thus improve automatic transient management. This will directly lead to a lower turbine shut-down probability.

CANDU 3 — MODULARIZATION

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Abstract

The CANDU 3 Heavy Water Reactor is the newest design developed by AECL CANDU. It has set as a major objective, the achievement of significant reductions in both cost and schedule over previous designs. The basic construction strategy is to incorporate extensive modularization of the plant in order to parallel the civil and mechanical installation works. This results in a target 38 month construction schedule from first concrete to in-service compared to 68 months for the Wolsong-1 CANDU 6 actually achieved and the 54 months envisaged for an improved CANDU 6.

This paper describes the module concepts that have been developed and explains how they contribute to the overall construction program and achieve the desired cost and schedule targets set for the CANDU 3.

1. BACKGROUND

In 1982, AECL started looking at the basic requirements for the next generation of reactor designs to follow up on the CANDU 6 which, together with the Ontario Hydro program had been the main product of the 1970's. After the initial studies, a small multi-discipline project team was established to develop concepts which would meet the overall requirements and prepare preliminary cost estimates and project schedules.

Following completion of their work, which showed that the CANDU 3 was technically feasible and that the cost and schedule were competitive with a similar sized coal-fired plant, AECL committed to proceed with the detailed design of the CANDU 3. This work was started in April 1988 and is about half way through the standard plant design program.

The major features of the implementation strategy are :

- Pre–engineering such that 95% of the engineering will be complete by first concrete
- Up front licensing to reduce the regulatory risk
- Division of the engineering into two parts, Standard Product Design (SPD) and Site Specific (SS). The SPD covers a generic plant which is designed to enveloping conditions and can be used with the minimum of changes on a number of sites. The SS work is the additional work to complete the project for a specific site.
- Preselection by suppliers to provide for an early commitment of detailed engineering information.
- Open top construction using a very heavy lift crane and extensive modularization
- Maximize modular construction and prefabrication of components.

Figures 1 & 2 show the overall station layout for the Standard Product on a generic site.

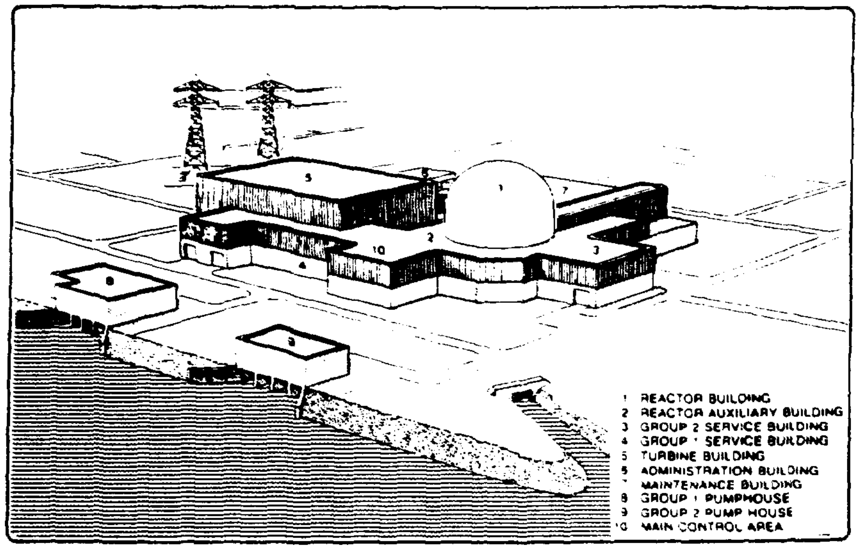

FIGURE 1 STATION LAYOUT

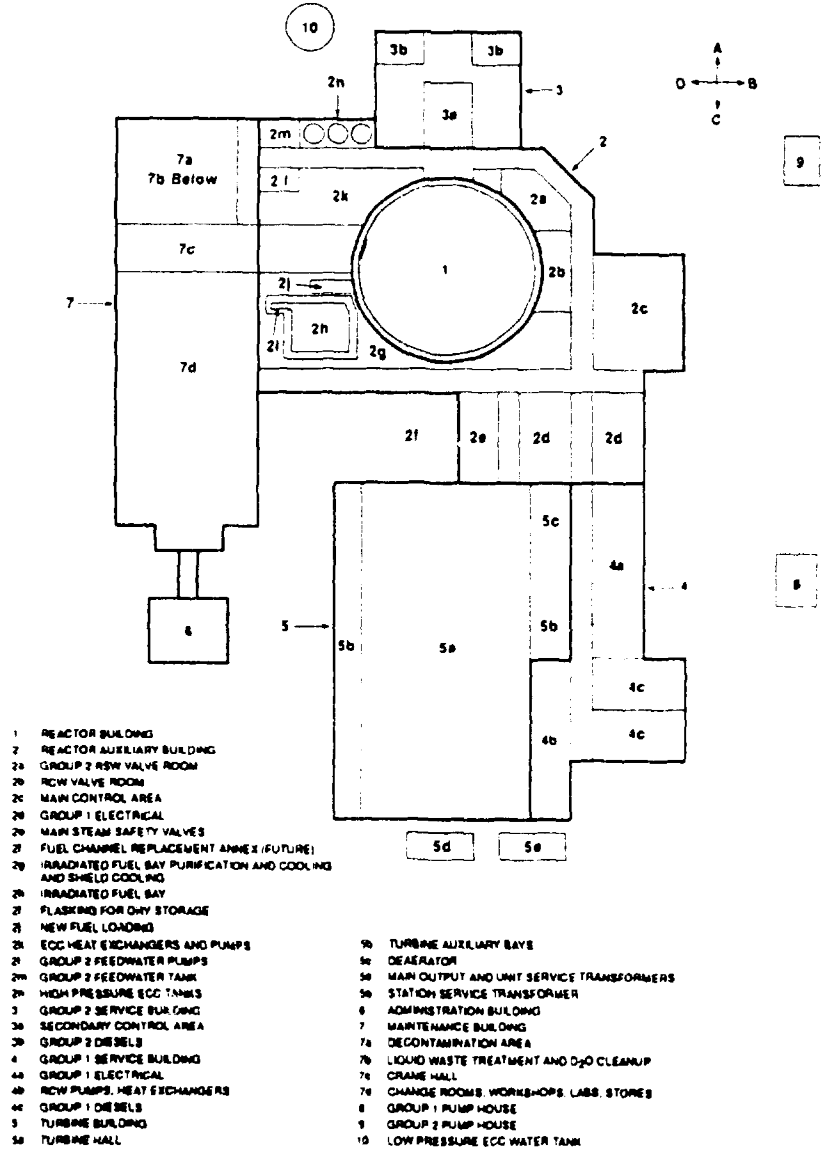

FIGURE 2 STATION LAYOUT - PLAN

2. PROJECT OBJECTIVES

The overall requirements which have been set for the CANDU 3 are :

- Enhanced plant safety
- Utilization of proven technologies and concepts
- 100 year plant operating life
- 94% lifetime capacity factor
- Any major rehabilitation within a 90 day outage and all components that cannot last 100 years to be easily replaceable
- 50% reduction in man–rem/MW(e)
- 38 month construction schedule for the first unit reducing to 30 months for later units
- Easily adaptable to site and client requirements
- Energy competitive with coal–fired stations.

3. CONSTRUCTION STRATEGY

a) Minimize construction schedule to reduce interest and overhead costs

b) A construction schedule to be competitive with alternative energy systems and hence maintain the CANDU 3 as an option where the ordering of power plants is delayed as long as possible

c) Reduce risks to the construction schedule

d) Minimize on–site construction work/maximize factory in–shop work

e) Minimize construction costs

These construction objectives cannot be met if they are not considered as an integral part of the design process. Consequently the CANDU 3 team has included from the beginning, construction specialists as key members of the organization. They provide an ongoing input to the development of the concepts and to the detailed design.

The following basic principles were established to guide the design team:

a) Provide maximum access for Construction and equipment installation
b) Simplify the Reactor Building Internals, for example the CANDU 3 has 62% of the concrete required for the CANDU 6 and only 37% of the formwork
c) Minimize the number of components, the size of the reactor permits a 50% reduction from previous CANDUs for Steam generators, coolant pumps, fuelling machines, etc. but there is also a significant reduction in process piping and components.
d) Simplify equipment installation by eliminating highly complex and precision activities. This has been achieved through component prefabrication and system modularization.
e) Maximize Shop Fabrication and Modularization which will be discussed in detail in the next section.
f) Separate Qualified Systems and Structures, eg. locate safety and safety support systems in a qualified area which is physically separate from those systems that do not require qualification.
g) Provide well defined construction interfaces which will allow the design and construction of the principle buildings and their contents to be readily allocated to different organizations.

The construction methods and techniques include "open top" construction for the Reactor Building, utilizing a very heavy lift crane to install large pieces of equipment and modules.

Composite Steel/Concrete walls and slabs are used on the modules to reduce the weight of modules for lifting and installation.

4. MODULARIZATION

4.1 Definitions

We have defined a module as a structural steel frame containing one or more systems and floor levels and weighing up to 500 tonnes. We also consider skid mounted assemblies made up of equipment and piping as modules; these typically do not exceed about 20 tonnes.

Other large pieces of equipment such as Steam Generators, Calandria Shield Tank, Fuelling Machine carriage etc are not considered as modules; however they are subject to the same considerations for handling and lifting. with the very heavy lift crane and will be discussed as part of the construction schedule and sequences.

4.2 Modularization Options

AECL has looked at a number of modularization schemes in conjunction with experienced module manufacturers in Canada and Europe. These include the medium sized modules (up to 500 tonnes) which are the basis of the reference plant design; and Large Scale Modules of whole buildings weighing up to 12,000 tonnes. Our studies indicate that both schemes are technically feasible and meet the cost and schedule objectives. To retain the maximum flexibility for potential site locations the design is proceeding on the basis of the medium size modules, however the plant layout and configuration is such that it could be readily adapted to Large Scale Modules if circumstances permit.

The medium sized modules are too large to be transported to the site by road or rail, and they need water access if they are built off site. However, they can be built on site and this is the reference approach for the Standard Plant Design so that inland sites with limited water access can be utilized.

The Large Scale Modularization scheme is based upon all manufacturing work being done off site in a shipbuilding or off-shore rig building facility. It therefore requires water access at both ends.

Our studies on Large Scale Modules have been carried out in conjunction with Grootint of the Netherlands who have successfully adapted their modularization knowhow from off shore oil platforms, refineries, etc. to the CANDU 3 and demonstrated the feasibility and the cost and schedule benefits of this approach.

The studies for the medium size modules were done in conjunction with the Saint John Shipbuilding Co. in New Brunswick, Canada and also demonstrated the feasibility and cost and schedule benefits of this approach.

4.3 The Reference Modules

There are a total of 14 modules identified in the Reactor Building. These are listed in Table 1 with a brief description of their contents and dimensions. There are an additional 8 modules in the remainder of the NSP, mostly skid mounted. These are listed in Table 2.

In general, the modules are designed to be as large as possible to minimize the number of interconnects that have to be made after they are installed in the Reactor Building. Also since the modules will be installed through the top of the Reactor Building, they are generally designed as a vertical section of the building to avoid stacking one on top of the other. This provides the maximum flexibility of installation sequences.

A nominal installation clearance of 200 mm between modules and adjacent structures has been used. This includes the allowance for normal construction tolerances for concrete and structural steel as well as for verticality of module during installation.

The maximum module weight of 500 tonnes has been established by the availability of Very Heavy Lift cranes, such as the Lampson Transi Lift II LTL 1200, a number of which are available in various parts of the world.

4.4 Module Description

Module RM 20 is the largest of all the modules in the Reactor Building and will be described as a good representative example of our approach. Fig. 3 shows the overall arrangement of this module together with the major systems.

TABLE 1

MODULE LIST FOR THE REACTOR BUILDING

	MODULE	
NO.	DESCRIPTION	L x W x H Approx. Dimensions(m)
RM10	Structural Module "A" Side from Base Slab to elev 115.2m (D_2O Purification, HPECC Valve Station, HVAC equipment	28 x 8 x 18 150 t
RM20	Structural Module "B" side, (Moderator HX & Pumps, SDC, Moderator Liquid Poison, DN Monitoring, HT Pressure and Inventory Control, GFP System)	22 x 18 x 10 475 t
RM 40	Structural Module "D" Side F/M Auxiliaries, D_2O Valve Station, Floors at elev. 115.1m and 122.5m, HVAC equipment	12 x 10 x 22 100 t
RM50	Structural Module "D" Side LISS equipment	8 x 2 x 14 20 t
RM51	Skid Mounted Module "D" side at elev 111.7m Moderator Cover Gas	8 x 2 x 3 10 t
RM52	Skid Mounted Module "D" side at elev 100.0m Annulus Gas System	6 x 3 x 3 10 t
RM 60	Assembly Module Inlet Vault Feeder Header Frame & Insulation Cabinet #1	6 x 3.4 x 13 50 t
RM61	Assembly Module Inlet Vault Feeder Header Frame & Insulation Cabinet #2	6 x 3.4 x 13 50 t
RM62	Assembly Module Outlet Vault Feeder Header Frame & Insulation Cabinet #1	7 x 6 x 13 64 t
RM63	Assembly Module Outlet Vault Feeder Header Frame & Insulation Cabinet #2	7 x 6 x 13 64 t
RM64	Assembly Module HT Pump #1, Shield Floor & Suction/Discharge Line Portion & Assembly HT Pump #2, Shield Floor & Suction/Discharge Line Portion	11 x 4 x 3 60 t
RM70	Assembly Module Boilers, Pressurizer Bleed Condenser Support Frame	13 x 11 x 4 200 t
RM80	Structural Module "A" side above elev. 115.1m (HT Pump Motor Supports, HVAC equipment)	17 x 14 x 15 100 t
RM 80	Structural Module Dome Liner plus reinforcing steel	38 dia. x 18 high 230t + Rebar 400t max.

The main loading bearing members are hollow steel walls which support structural steel and composite structural steel floors. The total thickness of steel walls and composite floors is determined by the shielding requirements during operation and they will be filled with concrete at site after installation. The steel for these structures is designed to withstand all loads during construction including shipping and handling and the dry weight of all installed equipment. After they have been filled with concrete

TABLE 2

MODULE LIST FOR REACTOR AUXILIARY BUILDING AND GROUP 2 SERVICE BUILDING

NO.	DESCRIPTION
AM 20	Main Steam Safety Valve Manifold
AM 30	Shield cooling
AM 31	I.F. Bay cooling
AM 32	New Fuel platform
AM 40	ECC HX's and valve manifold + G2FW pumps, valves and piping
AM 41	ECC pump support and suction piping
AM 50	Gr 2 RSW valve manifold
AM 51	Gr 1 RCW manifold

and attached to the internal structure, credit will be taken for composite action to withstand all of the design basis loads including seismic, live loads, differential pressures and temperatures, etc.

All of the mechanical equipment, piping and insulation will be installed during the manufacturing phase, together with cable trays, conduit, panels, junction boxes, lighting and local wiring, etc. All painting will also be complete.

Non structural shielding will be included in the form of hollow steel structures which will be filled with concrete at site after installation.

There is a total of about 670 cu meters of concrete to be placed in this module after installation. This concrete will be pumped into place using concrete distribution pipes built permanently into the forms. This will minimize the risk of damage to installed equipment. Note that this is the only module with such a large amount of concrete, two other modules require concrete, the maximum being 40 cu meters for the floor of the Fuelling Machine Auxiliaries Module.

The steel walls will be attached to the main internal structure by welding a filler piece between the vertical ends of the walls and embedments in the concrete. This work can be done from inside the structure since the walls are a minimum of 1.0 m thick.

The piping and tubing which penetrates the adjacent concrete wall will be connected by a field weld located inside the module at a convenient spot to allow adequate room for welding NDE, etc. There are a total of approximately 70 connections to be made at the periphery of this module. The piping connections vary in size from 20 inch to 3/4 inch diameter together with tubing for the DN monitoring system.

Cable trays and conduit will be run to the periphery of the module. There are approximately 250 cables to be pulled into or through this module after installation.

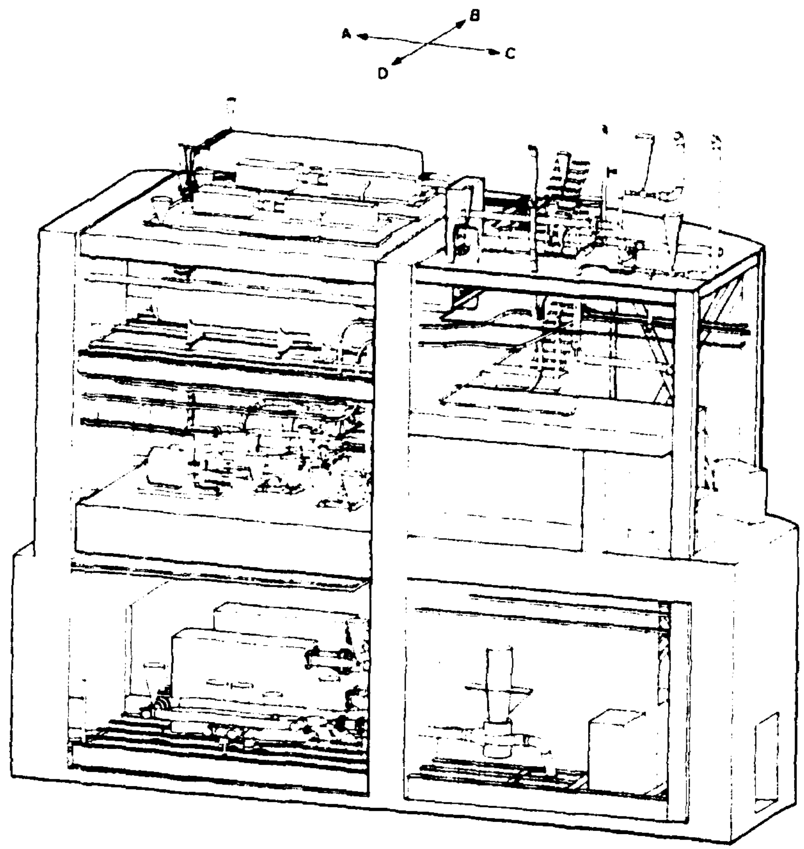

FIGURE 3 STRUCTURAL MODULE RM20 (Moderator HXs and pumps, SDC HXs and pumps, moderator poison)

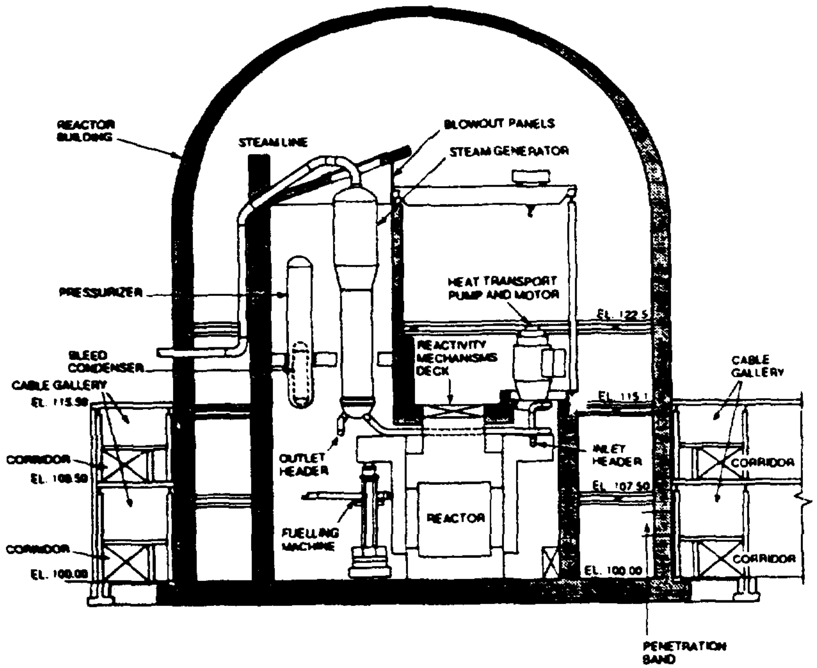

FIGURE 4 REACTOR BUILDING - SECTION

Light temporary enclosures of sheet metal or similar material will be used to protect the modules during shipment up to the time they will be lifted into position. Where sea shipment is involved, then more elaborate protection will be provided.

5. CONSTRUCTION SEQUENCES AND SCHEDULE

In this section, I will focus on the Reactor Building Construction, which is where the impact of modularization is the greatest with the result that it is no longer on the critical path for the Project. That honour now belongs to the Turbine Building and the main control centre.

5.1 Construction Sequences

The Reactor Building containment (Fig. 4) is a steel lined reinforced concrete structure, with the steel liner serving as the inside formwork for the concrete pour. We have a choice of pouring it before, in parallel or after the internal concrete (Fig. 5). The preferred route is after, except where we have a hostile climate where it may be preferable to quickly build the walls and provide a temporary cover to provide protection for the work inside.

The steel liner for the dome will be fabricated at ground level and will be lifted into place, together with the reinforcing steel after all of the modules and equipment have been placed into the Reactor Building.

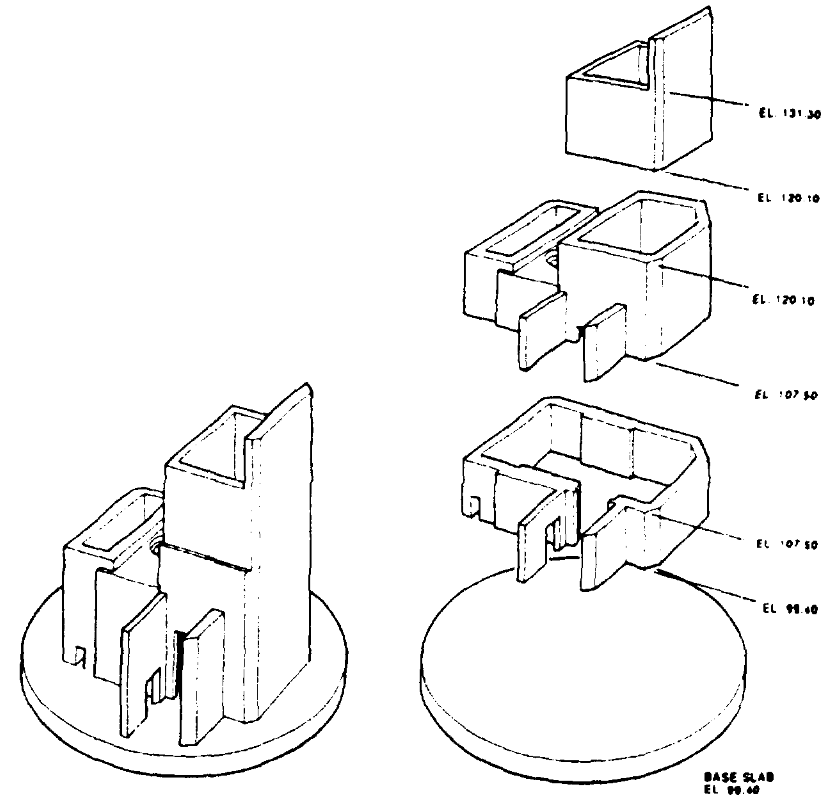

FIGURE 5 REACTOR BUILDING INTERNAL CONCRETE STRUCTURE
ASSEMBLED AND EXPLODED VIEWS

The first major component to be installed is the Calandria Shield Tank Assembly (CSTA) which is lowered down through the boiler box onto the base slab. It is then moved sideways into its final position and attached to its support pads. The Shield Tank Extension is then lowered into position and welded to the CSTA (Fig. 6). These two steps represent a significant improvement over previous CANDU designs since both vessels can be hydrostatically tested at the factory which simplifies and speeds up site work.

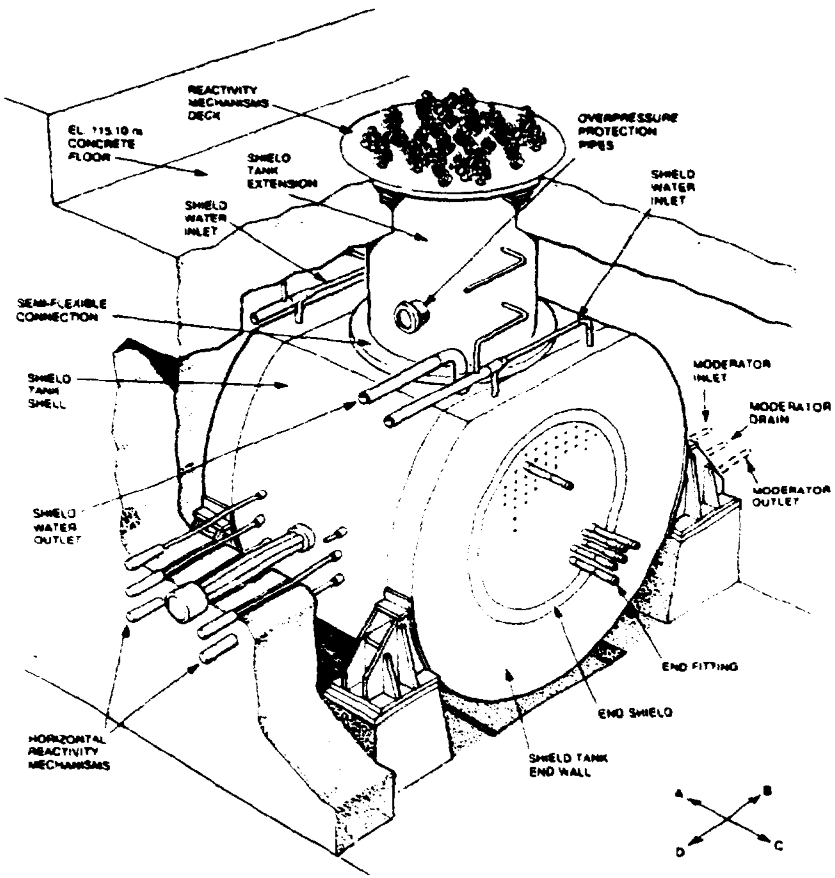

FIGURE 6 REACTOR STRUCTURES ASSEMBLY

The feeder header modules are then installed by lowering the outlet headers through the boiler box and the inlet headers through the opening which will later take the main Heat Transport System Pump Motor sets. The feeder/header modules are complete and include the insulation cabinet and instrumentation. On previous designs, all of the lower feeders were installed individually and welded to the upper feeders at site and took several months of time on the critical path.

Once the feeder modules and Calandria Shield Tank Assembly are in position, work can start on the installation of the Fuel Channels (FCA). Each individual FCA is inserted horizontally into the Reactor and welded into position using semi-automatic welding equipment. They are then mechanically attached to the feeder pipes using the traditional grayloc fittings. On previous CANDU's, the components that make up the Fuel Channel Assemblies were individually installed at site. The Fuel Channels are now a factory fabricated assembly which removes a large number of complex precision tasks from the construction site.

The remainder of the modules and large components such as Steam Generators, pressurizers can now be installed. Since the module breakdown is vertically oriented, there is some flexibility in the sequence in which they can be placed in the Reactor Building.

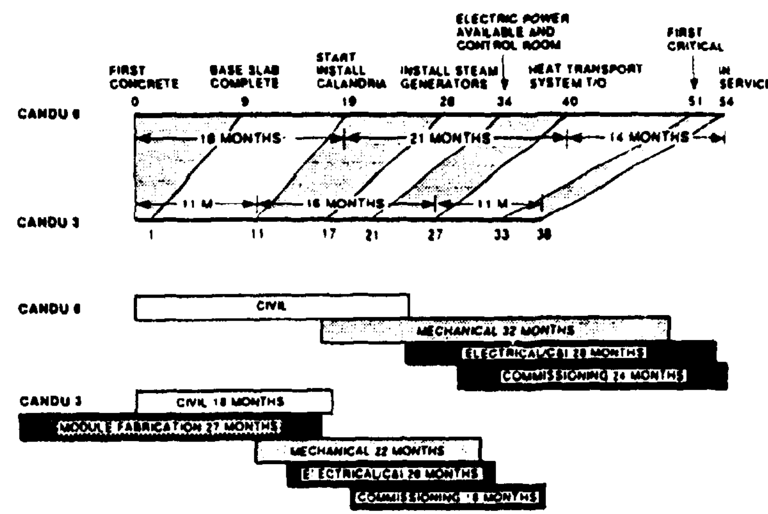

FIGURE 7 CONSTRUCTION SCHEDULE COMPARISON OF IMPROVED CANDU 6 AND CANDU 3

5.2 Schedule

The major benefit of modularization and component prefabrication is to allow the civil works and mechanical installation to proceed in parallel. Fig. 7 shows a comparison between the improved CANDU 6 and the CANDU 3 construction schedule. The durations shown for each of the major trade groups are consistent with past experience on the CANDU 6 program taking into account the reduced number of components and simplification of on site activities, particularly in the critical areas of Reactor installation. This schedule shows that module fabrication start 10 months before first concrete. For long delivery items, the first purchase orders need to be placed 18 months ahead of the start of module fabrication which results in a total project schedule of 66 months.

6. CONCLUSIONS

The CANDU 3 program established the reduction in construction schedule as a major objective. By incorporating modules and maximizing off site component fabrication into the basic design, the construction schedule from first concrete to in-service can be reduced by 30% from 54 months for an Improved CANDU 6 to 38 months for the CANDU 3.

The detailed design work done to date has confirmed the feasibility of this approach.

ACKNOWLEDGEMENTS

The following AECL staff have made a major contribution to the development of the ideas expressed in this paper.

R.S. Hart who is generally recognized within AECL as the father of CANDU 3 and whose ideas and concepts are the foundation on which it is built.

J.R. Candlish, senior construction specialist, who developed the modularization concepts and the construction approach which will allow the construction schedule objectives to be met.

COST REDUCTION IN THE ABB ATOM BWR 90 PROJECT

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Abstract

BWR 90 is a development of the ABB Atom design BWR 75. The latter was realized in two plants in Swelen, Forsmark 1 and 2, and two Finnish palnts, TVO 1 and II, and was further brought to maturity in Forsmark 3 and Oskarshamn 3, in operation since 1985/1986.

The present paper is reviewing one of the main goal of the project BWR 90 which consist in the ways how to reduce costs and facilitate a short construction time schedule

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After delivery of Oskarshamn 3 in 1986 we started a study of the design. The result of this study is called BWR 90. The main goal of the project BWR 90 was threefold

- to incorporate technological development
- to adapt to new safety requirements
- *to reduce costs and facilitate a short construction time schedule*

(Figure 1)

In this presentation I will concentrate on the third item. Design considerations can be summarized as follows.

The plant layout has been changed in several details. Figure 2 and 3.

- *The safety-related parts* have been concentrated to the immediate environment of the reactor building. This gives shorter pipe and cable connections to the reactor and those structures which have to be protected from outer impacts, earthquake, airplane, etc. are collected in a smaller portion and so the protective means are cheaper.