THE ABWR IN FUTURE POWER GENERATION PLANNING

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ABSTRACT

Advanced nuclear technology has reached the point of commercialization. Two advanced nuclear plants (ANPs) have been constructed in Japan and are reliably generating large amounts of low cost electricity. Taiwan is now in the process of licensing and constructing two more ANPs. Other countries have similar strategies to deploy advanced nuclear plants and the successful deployment of ANPs in Japan, Taiwan, China, and South Korea, coupled with international agreements to limit CO2 emissions, will only reinforce these plans.

Because they have a proven track record, ANPs will play an important role in meeting the conflicting needs of developing economies for more massive amounts of electricity and the need worldwide to limit CO2 emissions. Use of advanced nuclear technology, in other words, provide these economies with a proven means to promote sustainable development.

INTRODUCTION

Sustainable development has been defined as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. The concept embraces the idea that investments in the production of energy be made wisely, so that they contribute to long term economic development without charting a course to environmental ruin.

Nuclear energy meets the test of sustainability. We have seen, repeatedly, that countries which have invested in nuclear programs have been demonstrably rewarded with low cost electricity, economic growth, and remediation of the deleterious effects of burning fossil fuels. Moreover, the use of nuclear energy is not a dead end street. Even when U-235 resources are consumed, future generations are not precluded from using this valuable technology should they choose to deploy fast reactors.

In order to develop sustainable economies, advanced nuclear technologies must be transferred from industrialized to developing countries. This requires a recognition by both sides of the responsibilities involved. For a nuclear program to take hold and flourish, the host country must have a stable political and business climate, an effective nuclear regulatory body, and a nuclear liability regime that encourages international suppliers to participate in the program. Developing countries wishing to use advanced nuclear technology have the responsibility to put these elements in place. On the other hand, developing countries have a legitimate need for local participation in the project, technology transfer, and financing. Suppliers, therefore, must be willing to work with local businesses and to transfer technology. Industrialized countries must, furthermore, provide help in financing projects, including nuclear plants, that promote sustainable development.

NUCLEAR ENERGY’S CONTRIBUTIONS

Nuclear energy already plays a major role in meeting the world’s energy needs. At the end of 1996, there were 442 nuclear power plants operating in 32 countries. These plants account for 17% of the world’s electricity. The industry remains dynamic as evidenced by the fact that five new plants entered operation in 1996 and another 36 are in various stages of construction in 14 countries. (For more information, visit the IAEA website at http://www.iaea.or.at)

The need for additional capacity remains strong, particularly in Asia where the consumption of electricity in some countries continues to grow by more than 10% a year. Figure 1 shows GE's forecast of new orders in the next 10 years.

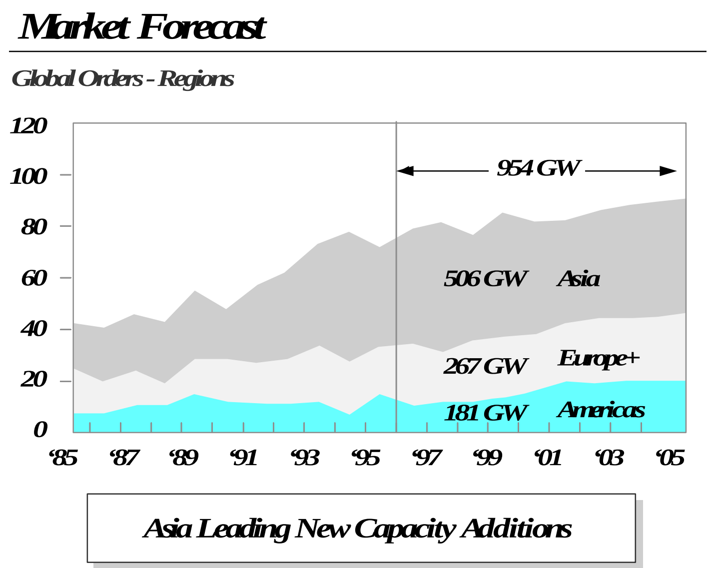


Figure 1 Need for new power plants

Generating electricity with nuclear energy permits all of this economic and social development to be sustainable, that is, not limited by encroaching environmental concerns. A non-nuclear, baseload plant generates electricity by burning fossil fuels day in and day out and releasing the byproducts to the environment. A nuclear plant generates large amounts of electricity with virtually no impact on the environment. In quantitative terms, if we were to replace the world's nuclear plants with coal-fired plants, global CO_2 emissions would increase by 8% every year. This would amount to 1600 million tons per year at a time when the world is trying to reduce emissions by 4200 million tons per year. Similarly, if the world's growing appetite for new electricity is met without nuclear energy playing a key role, CO_2 emissions would quickly rise to levels that curtail economic growth.

This point was recently underscored when a panel of ministerial advisory groups recommended that Japan build 20 more nuclear power plants as planned, rather than enact a carbon tax, which is seen to have a potentially dampening effect on the economy. Japan has pledged to reduce CO_2 emissions to 5% below 1990 levels.

For this and other reasons, countries in the Pacific Basin have systematically developed nuclear energy programs. A snapshot of such programs in Asia is given in Table 1.

Table 1 Nuclear Energy in Asia

Nuclear Energy in Asia

	Japan	Korea	Taiwan	China
Operating plants	51	11	6	3
Percent generation	30	50	20	2
Under construction	3	9	2	4
Units planned	5-20	12	0	20-30

NUCLEAR ENERGY PROGRAMS IN DEVELOPING ECONOMIES

The economic forces that created the need for nuclear electricity in the rest of Asia are also evident in China and the ASEAN countries. Nuclear electricity is an economic alternative to fossil fuels and exhibits long term cost stability, important advantages for countries with export driven economies. It's use enhances fuel diversity, an important policy consideration for countries that import fossil fuels and hence are vulnerable to price increases and supply interruption. Nuclear electricity is environmentally sound and emits no NOx (urban smog), SOx (acid rain) or CO2 (global warming). Finally, nuclear electricity is viewed by developing economies as a source of new technology and local jobs.

There are several necessary conditions that must exist before a nuclear energy industry can take root and flourish. The first is a stable political and business environment that protects the substantial investment made in a nuclear power project. This in turn encourages off-shore suppliers to participate in the project. Japan and South Korea are notable examples of countries where government policy has helped create a suitable environment for nuclear energy.

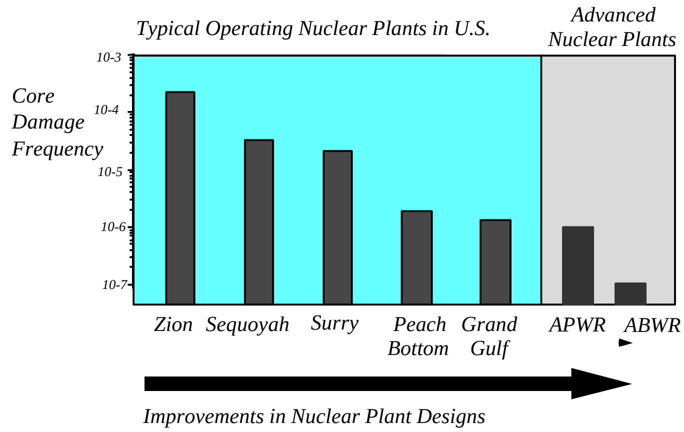
An effective nuclear regulatory body is a second necessary condition. Such an agency sets the requirements, regulations and standards necessary to ensure that nuclear facilities will be operated without jeopardizing the health and safety of the public. Concomitantly, industry must develop the know how and expertise to own and safely operate nuclear facilities.

In 1997, the Indonesian Congress passed and President Suharto signed a law that creates a nuclear regulatory body. The new law permits the private sector to undertake the construction and operation of a nuclear power plant and addresses the disposal of radioactive waste. BATAN will continue in its role of developing the level of nuclear expertise in the country. Mr. Habibe, Minister of Research and Technology, has indicated that the country's first nuclear plant could be constructed by the year 2006.

A nuclear liability regime which assures prompt, fair and reasonable compensation for off-site nuclear damage and provides industry participants with a clear-cut understanding of their obligations is also a necessity for U.S. suppliers. All industrialized countries that utilize nuclear energy have such a regime. The best regimes include national legislation that 1) makes the licensed operator of the facility solely responsible for damages caused to the public in the event of an accident, 2) includes a requirement that the operator carry substantial amounts of insurance to pay for such damages, and 3) includes a commitment by the government that it will compensate the public for any damages in excess of the insurance. Taiwan has a system that is generally consistent with international convention and provides for a government commitment. Prior to the start of the Lungmen project, Taiwan's 7th and 8th nuclear units, the legislature of Taiwan approved a bill which improves the system even further. Indonesia has recently enacted a law establishing a nuclear liability protection regime, the adequacy of which is still being analysed. China, which hopes to expand its use of nuclear energy based on Western technology, has not ratified any international convention and many suppliers are concerned about the adequacy of the available protection.

Features

- *Rugged and simplified design*
- *Modern C&I systems and control room*
- *Safety systems are more redundant and diverse*
- *Meet USNRC requirement for Severe Accidents*
- *Meet utilities' ALWR requirements*
- *Pre-engineered, pre-licensed total plant design*
- *Shorter, predictable construction schedule*
- *Reduced capital and O&M costs*



Source: "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," NUREG-1150, June 1989.

Assured Safety and Economics are the Keys

Figure 2 Features of Advanced Nuclear Plants Such as GE's ABWR

THE ROLE OF U.S. SUPPLIERS

Countries wishing to use US nuclear technology have the responsibility to put these elements in place. On the other hand, developing countries have a legitimate need for local participation in the project, technology transfer, and financing.

Developing economies see a nuclear power project as a way to create high paying jobs and infuse new technologies into its industry. Indonesia, for example, has indicated that it will require about 25% of the project's total supply to be local. This requires a willingness by US suppliers to work with local industry, including the transfer of necessary technology and training so that manufacturers can meet the high standards associated with the supply of components to a nuclear plant. US companies are generally agreeable to work in this way.

Financing of a nuclear project is a very significant undertaking especially for a developing country. A large nuclear plant (1300 MWe) costs about $2.5B. Such a large amount will need to be financed from outside sources, especially Export Credit Agencies. Utilities and governments see this as a responsibility of the supplier. A significant issue for US suppliers therefore is the availability of ExIm financing.

On the other hand, ECAs and commercial banks require government assurances of the highest order for a nuclear project. Governments are generally not willing to give such guarantees and Indonesia, whose ability to take on additional international debt is limited, is a case in point.

ADVANCED NUCLEAR PLANTS

The new generation of nuclear power plants, such as GE's Advanced Boiling Water Reactor (ABWR), have design features which lead to improvements in safety, economics and performance. These are summarized in Figure 2 below.

SAFETY

The ABWR has improvements which reduce the chances of an accident occurring and to mitigate the consequences should one occur. Because of this, the chances are vanishingly small that any radiation will be released to the public, even if an accident worse than Three Mile Island should occur.

A measure of safety commonly used by regulatory bodies is "Core Damage Frequency" (CDF), which is the probability of an accident occurring which results in some damage to the reactor fuel or core (which is what occurred at Three Mile Island). As Figure 2 shows, the CDF of nuclear plants has declined over time as new plant types were introduced. This figure also shows that Advanced Nuclear Plants have CDFs that are 10 times (for the ABWR type plants) better than any existing nuclear plant.

The reasons why an accident leading to core damage are much reduced for ANPs are:

Plant and Equipment Are More Rugged

ANPs have greater design margins, more reliable equipment, modern control and instrumentation systems using digital technologies, and are designed to be easier for humans to operate. This reduces the number of malfunctions and abnormal conditions which lead to the activation of safety systems.

The Design Has Been Simplified

The ANP designs have simplifications that enhance safety in a significant way. For example, the ABWR uses a new "Reactor Internal Pump" that obviates the need for major piping found in earlier BWR designs. As a result, there is no pipe break and therefore no accident in this plant which could result in a loss of water covering the reactor core, ultimately leading to core damage.

Safety Systems Are More Redundant & Diverse

Safety systems are even more redundant and diverse than before. For example, GE's ABWR has three completely separate divisions of safety. Each division, in turn, has two safety systems, each of which is sufficient to keep the reactor core safe. Each division has a dedicated source of power, a dedicated source of backup power, and is physically separated from the others by fire walls and flood barriers. In the event, therefore, of a fire, flood or some other accident that disables one division, the other two divisions are not affected. Each division has a heat removal system to ensure that the core remains in a safe condition after the accident has occurred and the plant has been shutdown. Finally, ANPs have been designed to ensure that safety systems work even in the event that all offsite power to the plant has been lost.

Severe Accident Mitigation

ANPs furthermore are designed to meet the USNRC's new requirements for "Severe Accidents". This means that ANPs have features which prevent the release of radiation even in the unlikely event that the core and plant are "severely" damaged. Furthermore, in the case of the ABWR, these features do not require operator action. Such features are referred to as “passive” safety features because they use natural forces such as gravity or convection to work. These features have been fully approved by the USNRC.

Because ANPs have features which mitigate the consequences of a severe accident, there is virtually no chance that any radiation will be released to the public, even should an accident worse than Three Mile Island occur. This provides a high degree of assurance that the public’s health and safety will never be jeopardized by the operation of the plant.

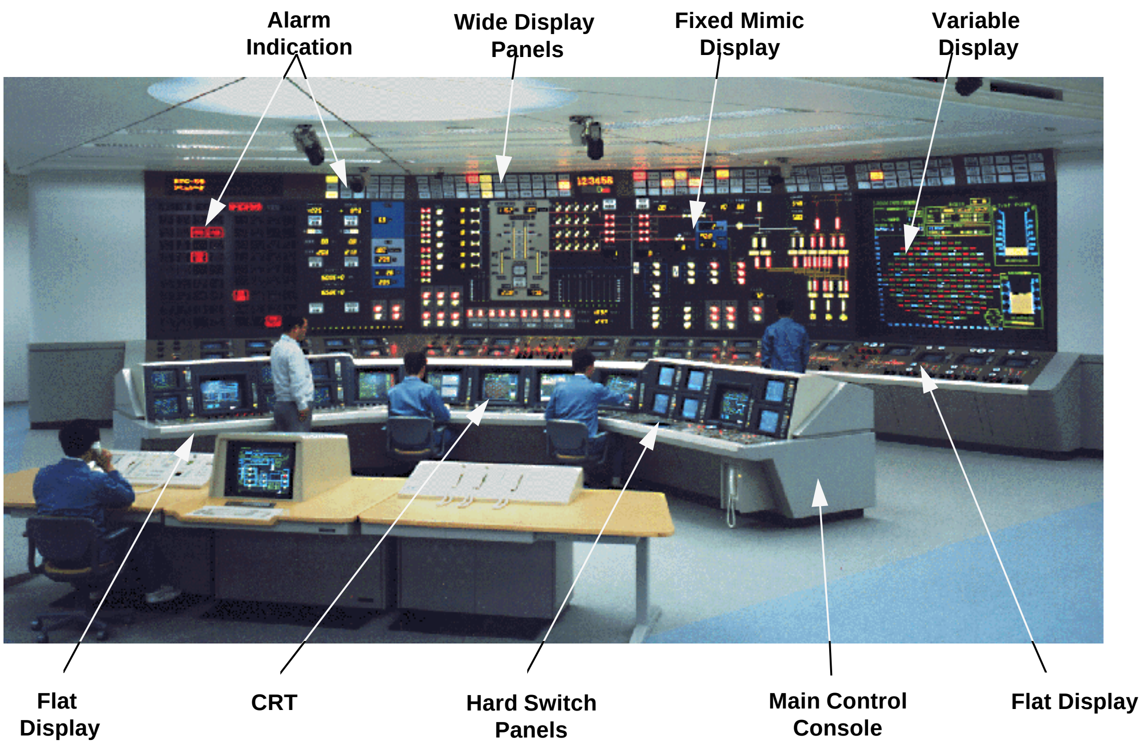


Figure 3 The ABWR control room which features the use of digital control and instrumentation systems in conjunction with MMI and modern alarm scheme.

Competitive Capital Costs

The ABWR has proven itself in to economically competitive as evidenced by the construction of two ABWRs in Japan, both of which were completed on schedule and under budget. The ABWR was also selected from many competing design by Taiwan Power Company for its Lungmen project based largely on the ABWR’s cost competitiveness.

Capital costs of a nuclear power plant are determined by the design, which determines the amount of equipment and materials, and the construction of the the plant, which is also influence by the design but also depends upon construction techniques and the capability of the “delivery” or project team.

Less Equipment and Quantities

Design simplification and the use on new technology has reduced the amount of equipment and construction quantities in the ABWR compared to the previous generation of BWRs. For example, the ABWR uses

Reactor Internal Pumps (RIPs) mounted directly to reactor vessel to recirculate core flow. Pump speed is controlled by adjustable speed motors or drives (ASDs).

Use of RIPs and ASDs eliminates the large external recirculation loops found in previous

BWRs. This has many cost benefits. The large recirculation pumps, flow control valves, jet pumps, piping and pipe supports have all been eliminated. Also, the containment and reactor building is more compact, thereby reducing the amount of material quantities need to construct them. Finally, because there are now no large nozzles below the top of the core, the safety systems can keep the core covered with water with less capacity. For example, the low pressure systems of the ABWR have a flow capability of 19,000 gallons per minute compared to 29,000 gpm for BWR/5 and BWR/6, a 35% reduction. This is an example of improving safety and reducing costs.

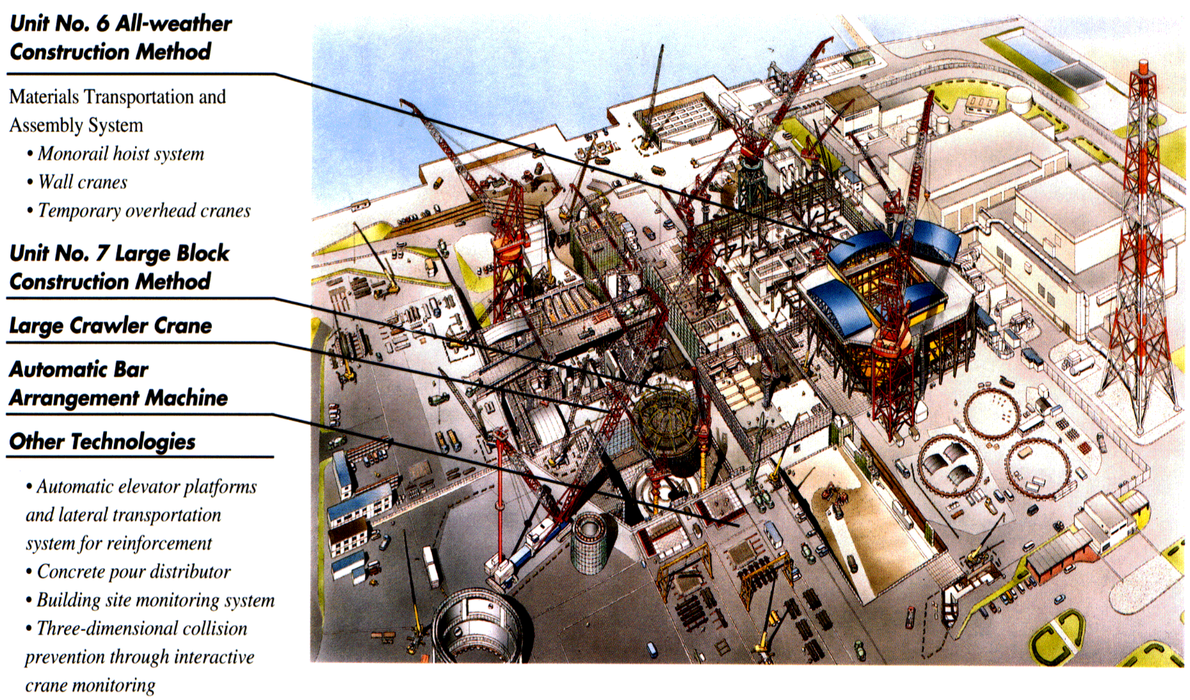


Figure 4 ABWR construction technology

The design of the control rod systems has also been simplified. Fifty percent of the hydraulic control units (HCUs) in the control rod drive systems have been eliminated. Because the new Fine Motion Control Rod Drives discharge water directly into the reactor during a scram, the scram discharge volume and the accompanying piping have also been eliminated.

The use of new technology further reduces the amount of plant equipment and construction quantities. The use of fiber optic networks, which carry substantially more information, instead of copper cabling has eliminated 1.3 million feet of cabling and 135, 000 cubic feet of cable trays. Use of microprocessors and solid state devices in the control networks has reduced the number of safety system cabinets in the control room from 17 to only 3.

The ABWR containment is a Reinforced Concrete Containment Vessel (RCCV). This technology was first introduced in a limited number in Mark III containments. The advantage of re-introducing this technology is that the containment can be made more compact, especially in comparison with the free standing steel version of the Mark III design. The ABWR containment volume is over 50% less compared to that design.

Shorter, Predictable Construction Schedule

Use of the RCCV has another important advantage–it reduces the construction schedule. Use of this containment and modular construction techniques reduces the overall construction schedule by an impressive seven months.

In constructing steel containments, the containment vessel is completed first, then the outer biological shield is erected, and finally the reactor building is constructed. For the RCCV, however, the construction of the containment vessel can take place concurrently with the construction of the floors and walls of the reactor building so that the entire construction schedule of the whole plant can be shortened. Also, RCCVs can be built in any shape. In the case of the ABWR, this is generally a right circular cylinder, which was chosen because it is easier to construct.

The use of fiber optic cabling also reduces the construction schedule, in this case by one month, because there is less cable to install.

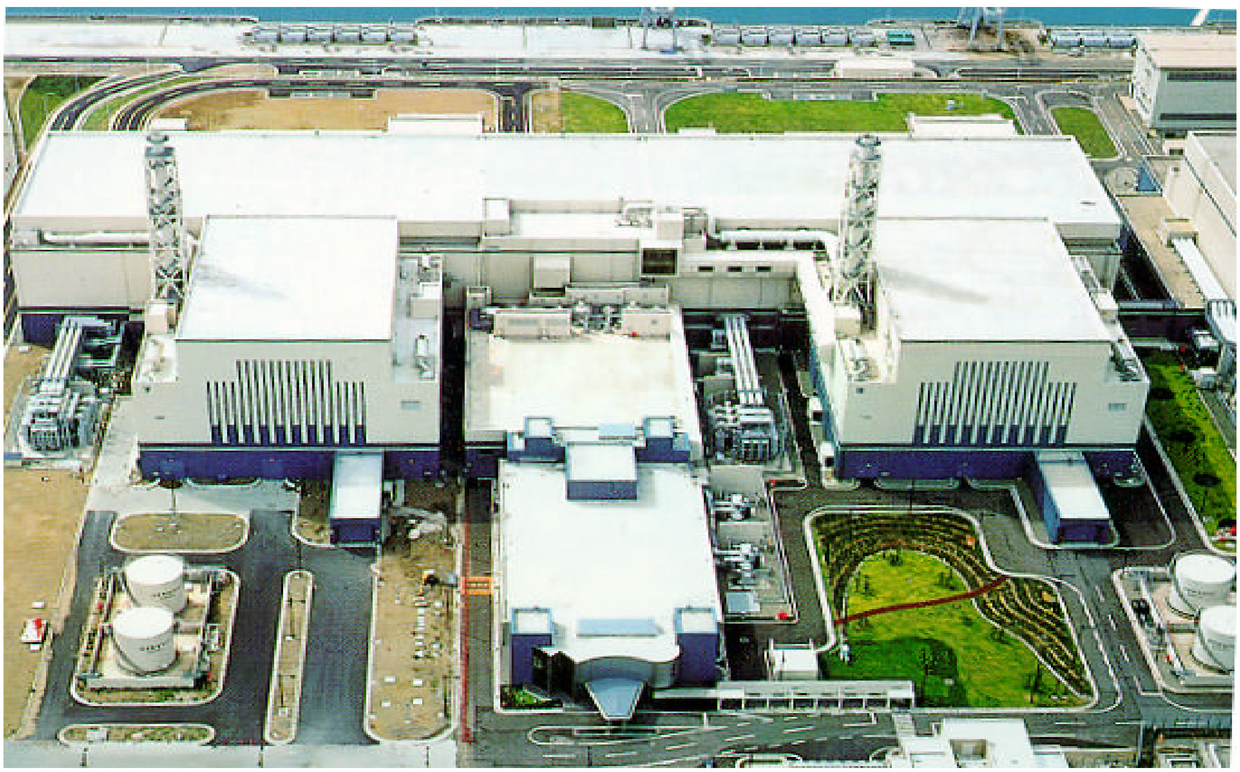


Figure 5 The world's first fully constructed advanced nuclear plants, the Kashiwazaki ABWRs

It is perhaps not generally appreciated that the ABWR has been designed for extensive use of modular construction, in particular large modules. The entire control room (400 tons), the steel lining of the containment, the reactor pedestal, the turbine generator pedestal, and the upper drywell structure with piping and valves are notable examples.

ABWR IS LICENSED AND CONSTRUCTED WORLDWIDE

When it comes to lowering the capital cost of a nuclear plant, there is no substitute for experience. The ABWR is unique in that respect. Not only is the ABWR the only Advanced Nuclear Plant to have been constructed, it is licensed in two countries--soon to be three--and is fully engineered. In 1998 and 1999, construction will begin on the third and fourth ABWR units.

The ABWR Enters Commercial Operation

The ABWR units in Japan are now constructed and fully operational. Kashiwazaki-Kariwa Unit 6, the world's first Advanced Nuclear Plant, began commercial operation on November 7, 1996. Unit 7, the second ABWR, followed shortly thereafter with commercial operation commencing on July 2, 1997. These are at the sixteenth and seventeenth nuclear units operated by The Tokyo Electric Power Company--all BWRs and are the first of many ABWRs to be built in Japan over the next 10 to 20 years.

Both units set world records for construction schedule. From first concrete to fuel load, it took just 36.5 months to construct Unit 6 and 38.3 months for Unit 7, which was about 10 months less than the average time for the previous BWRs constructed at the Kashiwazaki site. Likewise, both units were built on budget. This is an impressive record of performance especially since these were first of a kind units. The fully constructed Kashiwazaki ABWRs are shown in Figure 6, shown on the previous page.

The ABWR in the United States

The licensing of the ABWR has been described as the most exhausting review ever undertaken by the U.S. Nuclear Regulatory Commission. The efforts of the NRC and GE came to fruition on May 2, 1997 when the Chair of the NRC, Ms. Shirley Jackson, approved and signed the Design Certification for the US version of ABWR. This was rightly hailed by the US industry as a significant accomplishment, one that has been envisioned for a long time--pre-approval of a standard design of an advanced nuclear plant.

The successes continued when the ABWR First-of-a-Kind Engineering (FOAKE) program was completed in September, 1997 to the praise and satisfaction of the utility sponsors. FOAKE is an equally significant accomplishment because it represents a major step toward the US industry's other goal--to have a (pre-licensed) design 90% complete prior to the start of construction. At the conclusion of the FOAKE program, approximately 65% of the engineering of the US version of the ABWR is complete with the remaining engineering to be completed for the two ABWRs to be licensed and built in Taiwan.

The ABWR in Taiwan

The ABWR project for the Taiwan Power Company, known as Lungmen, is now well along. The project officially started in October, 1996 and the first major milestone was quickly reached in October, 1997, when the Preliminary Safety Analyses Report (PSAR) was submitted to Taiwan's Atomic Energy Agency. Other important milestones for Unit 1 are:

- First concrete — Dec. 1998
- RPV set — Mar. 2001
- FSAR submitted — Nov. 2002
- Fuel load — Nov. 2003
- Comm. Operation — May 2004

The schedule for Unit 2 is approximately one year later.