CURRENT STATUS OF DEVELOPMENT OF THE DEMONSTRATION FBR IN JAPAN

Tatsutoshi Inagaki, Masahiro Ueta, Masao Hamada
The Japan Atomic Power Company, Japan

ABSTRACT

The Japanese government and utilities promote the development of the demonstration fast breeder reactor (DFBR) following the prototype FBR "MONJU". The Japan Atomic Power Company (JAPC) has been conducting design studies of the DFBR since 1986, under the sponsorship of Japanese utilities. The main specifications of the DFBR were settled in 1994 and the conceptual design of the DFBR plant was finished in 1996 based on the main specifications. However, the sodium leak incident in "MONJU" and recent outstanding improvement in the economy of light water reactors require further enhancement of the reliability and economy of the DFBR. Therefore, JAPC has started the new design study for the purpose of achieving both improved countermeasures against sodium leaks and fire, and reduction in the construction cost.

WHY DO WE PROMOTE FBR?

Worldwide energy demand is increasing in proportion to economic development and population increases especially in developing countries, although many countries are putting a lot of effort into reducing energy consumption. If the consumption of fossil energy resources, such as oil and natural gas, increases in proportion to energy demand, they will run out of in the middle of the 21st century. In addition the greenhouse effect caused by carbon dioxide gas forces limited consumption of fossil resources below the current level.

In order to cope with both an increase in energy demand and prevention of the greenhouse effect, nuclear power generation is the most promising and effective measure. We are convinced that nuclear power generation will play an essential part in energy supply in the 21st century.

Since fast breeder reactors (FBRs) have the potential to utilize fuel much more effectively than light water reactors (LWRs) by more than 50 times, it is expected that FBRs can secure the energy supply for more than thousands of years. In addition, FBRs have the fascinating potential to be able to incinerate minor actinides which are radioactive wastes of ultra-long half lives originating from nuclear power plants. Therefore, the Japanese government and utilities have been promoting the development of the FBR since the initial stage of nuclear energy development.

WHAT IS THE STATE OF THE FBR IN JAPAN?

The sodium leak incident which occurred in the prototype reactor "MONJU" in December 1995 induced nationwide discussion about FBR development. The committee formed by the Atomic Energy Commission of Japan discussed the FBR development policy from wide viewpoints and reported the conclusions about FBR as follows in late 1997.

- FBR is one of the promising candidates as a future non-fossil energy resource.
- FBR development should be promoted according to a flexible plan to accommodate the trend of energy demand, achievement of innovative technologies and other factors.

- The restart of “MONJU” is expected to accumulate experience from operation and maintenance which should be reflected in the design of the demonstration fast breeder reactor (DFBR), and to promote research and development toward FBR commercialization.

The causes of the sodium leak incident in “MONJU” have been identified. A comprehensive safety review of the “MONJU” plant was conducted and a “MONJU” improvement plan was proposed, including strengthened countermeasures against sodium leaks and fire. Discussion about restarting “MONJU” has begun.

WHERE ARE WE IN FBR DEVELOPMENT?

Our company, The Japan Atomic Power Company (JAPC), has been conducting design studies of the DFBR since 1986 under the contract awarded by the nine Japanese electric power companies and the Electric Power Development Co., Ltd.

First, we studied economic improvement of the DFBR and confirmed the possibility that the construction cost of the DFBR can be reduced to about 1.5 times that of LWRs on the basis of 1000MW electricity output by simplifying systems and adopting innovative technologies.

The next theme is the selection of a reactor type for the DFBR. Japanese utilities selected the top-entry loop-type reactor system for the following reasons.

- Maintenance and repair of the primary components are easier in a loop-type system than those in a pool-type system because heat exchangers and pumps are separated from the reactor core and accessible for maintenance
- A top-entry loop-type system is more flexible to incorporate innovative technologies.
- A loop-type system can utilize experiences from “MONJU”.

Based on this selection, we affirmed the feasibility of the top-entry loop-type reactor system from technical and economic viewpoints because this type has never been applied to actual FBR plants. We performed scale-model tests of thermal hydraulics for natural convection under residual heat removal conditions, multi-surface sloshing caused by earthquake and gas entrainment from free liquid surfaces because they are important from both a safety standpoint and to determine the feasibility of the top-entry system, and are difficult to predict by analysis. We confirmed the feasibility of the top-entry system through the test results and the Japanese utilities settled the main specifications of the DFBR.

As the next step, we conducted a conceptual design study of whole DFBR plant from 1994 to 1997 and accomplished the following design targets.

- Safety is equivalent to that of the latest LWRs for sodium-related safety.
- The construction cost is below 1.5 times that of LWRs on the 1000MWe basis.

We have drafted the preliminary application document for approval of reactor installation and confirmed the licensability of the DFBR design on the basis of the latest LWRs in Japan.

We started the new design study in 1997 with two aims. The first, to improve the countermeasures against sodium leaks and fire, considering the sodium leak incident that occurred in “MONJU” which revealed that sodium leaks and fire should be prevented as much as possible from availability of the plant, although they might have no significant effects on plant safety. The second is to reduce the construction cost of the DFBR further, because the construction cost of Japanese LWRs is being reducing drastically to remain competitive with fossil power generations.

OUTLINE OF THE DFBR DESIGN

System

The main specifications of the DFBR are listed in Table 1. Figure 1 shows a bird's eye view of the reactor building and the cooling system of the DFBR. The DFBR is planned as a top-entry loop-type reactor with three loops. The primary cooling system has seven primary vessels, namely a reactor vessel, three vessels for intermediate heat exchangers (IHXs) and three vessels for pumps. The primary vessels are connected by inverted U-shape pipes which enter into vessels through roof decks and have no nozzles or attachments on their shell parts. The primary main pipes outside the vessels have no instrument wells or piping supports. The reactor building is horizontally seismically-isolated to reduce seismic loads dramatically.

Table 1 Main Specifications of the DFBR Plant

Item	Specification
Reactor Type	Top entry loop type reactor
Thermal Output	1,600 MW (Electrical output about 660 MW)
Number of Loops	3 loops
Reactor Outlet Temperature	550 ^{0}C
Core and Fuel Core Fuel Burnup	Homogeneous core Pu-U mixed oxide hollow pellet about 90 GWd/t (initial phase) about 150 GWd/t (high burnup phase)
Breeding Ratio	about 1.2 (with blanket) about 1.0 (without blanket)
Reactor Shutdown System	2 independent systems
Decay Heat Removal System	4 loops of DRACS
Reactor Containment	Rectangular reinforced concrete Containment with liner
Steam Generator	Once-through helical type
Fuel handling System	Rotating plug, manipulator type
Reactor Building	Horizontal seismic isolation building

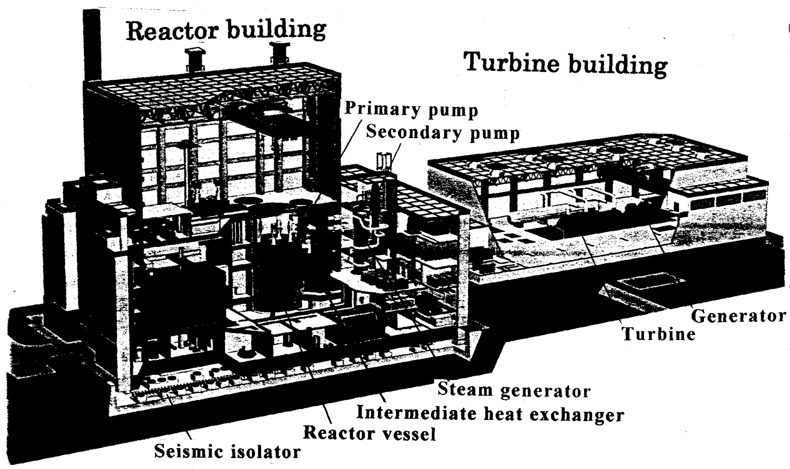

Figure 1 Bird's Eye View of Reactor Building

Core Safety

We are pursuing ultimate core safety of the DFBR to reduce the probability of a core disruptive accident (CDA) to an infinitesimal level. Therefore, the DFBR is equipped with multiple and independent reactor shutdown systems: the primary and the backup fast reactor shutdown systems using control rods, self-actuated shutdown mechanism (SASS) and gas expansion modules (GEMs).

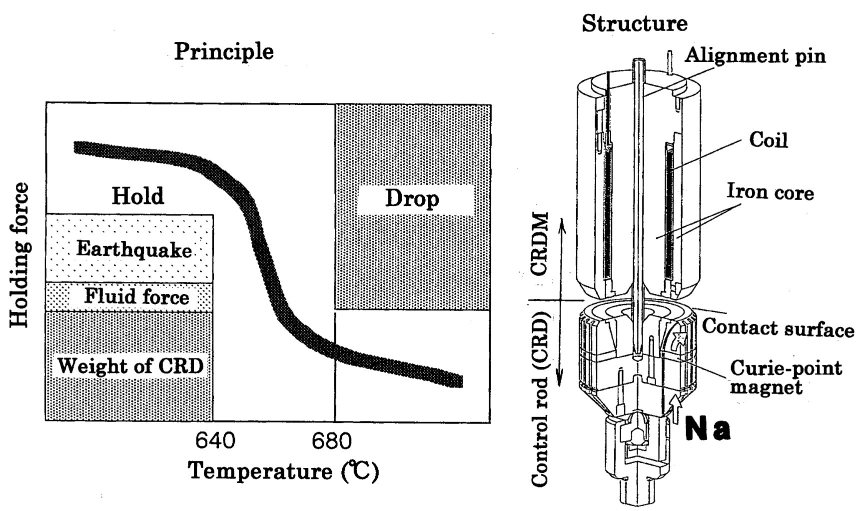

Figure 2 Principle of SASS

The SASS is equipped in the backup reactor shutdown system and can hold a control rod in contact with the bottom surface of the control rod driving mechanism by magnetic force. In an abnormal excursion where the coolant temperature at the core outlet rises with time, the magnetic force in the SASS steeply decreases with temperature (Figure 2) and a control rod naturally drops by its dead weight.

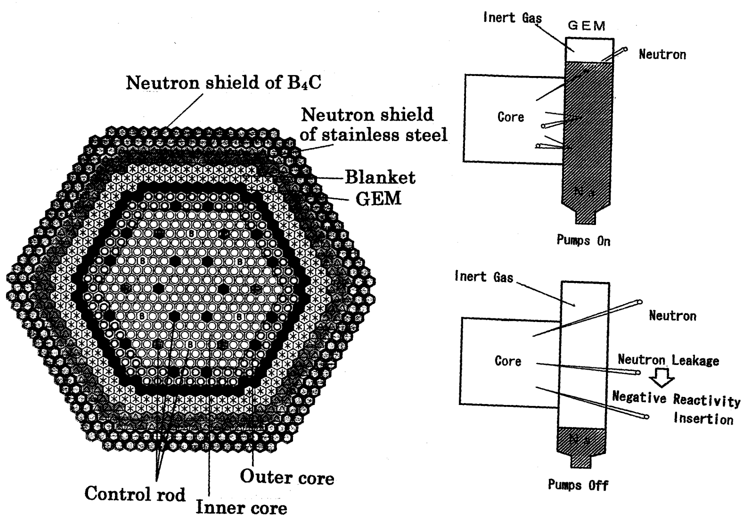

Figure 3 Principle of GEM

The GEMs are passive systems of ducts containing argon gas. A GEM is plugged at the top and opened at the bottom (Figure 3). During normal operation argon gas is pressurized by pump discharge pressure and sodium level is higher than the top of the core. In case of loss of flow by pump trip, pressure on the bottom of the GEMs drops, argon gas expands, and sodium levels in the GEMs are lowered below the bottom of the core. As a result, neutron loss through the GEMs increases and the negative reactivity is inserted. The GEMs are located around the periphery of the core and can prevent coolant from boiling and keep core safety even in an unprotected loss of flow event.

Decay Heat Removal

Decay heat from the core is usually removed to the environment through the cooling circuits and the turbine bypass line by forced circulation. In an emergency situation where these lines are not available, decay heat is removed through the direct reactor auxiliary cooling system (DRACS) of safety grade. DRACS is composed of four independent lines and can remove decay heat from the reactor vessel through heat exchangers immersed in the reactor vessel by not only forced circulation but also natural convection. DRACS can maintain core safety under the total loss of the alternating current source.

Containment

The DFBR has a double containment boundary of a containment vessel (CV) and a confinement area. The confinement area covers penetrations of pipes and cables through the containment boundary (Figure 4).

The CV is a rectangular concrete structure integrated with the reactor building and is leak tight by a steel lining on the inner surface of the concrete walls. The CV has the capability to resist the pressure caused by 1000kg of sodium burning under a hypothetical CDA.

The confinement area is ventilated to the atmosphere through the stack to maintain negative pressure and is connected to an emergency gas treatment system for suppressing radioactive releases to the environment by adsorption or radioactive nuclide on filters.

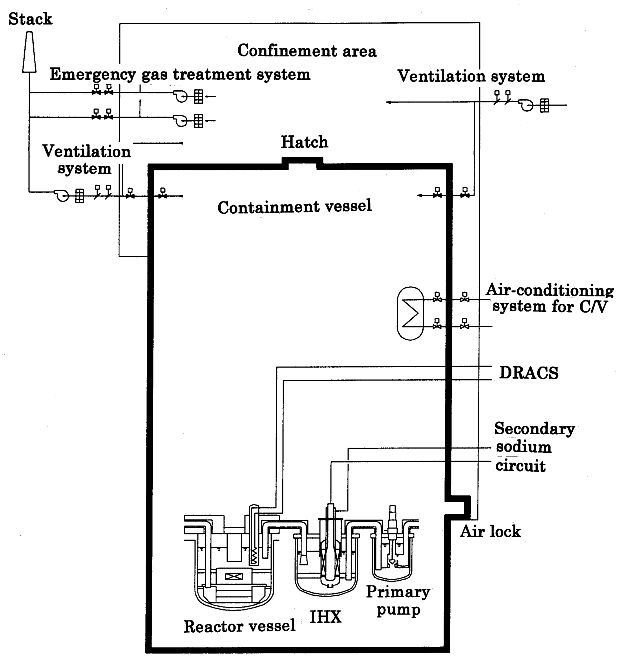

Figure 4 Concept of Containment Facility

Countermeasures Against Sodium Leak and Fire

The sodium leak incident in "MONJU" brought about a long-term plant outage which would not have been permitted in commercial plants from an economics point of view. Therefore, we are aiming in the DFBR design to reduce the potential of sodium leakage to a low level and to prevent sodium fires even if sodium leakage occurs.

The reactor vessel and other primary vessels containing sodium are equipped with guard vessels. Primary and secondary pipes in the CV are enclosed by guard pipes. Such enclosing structures confine sodium leakage and maintain the sodium level necessary for core cooling in case of a sodium boundary failure, and to prevent sodium fires. The enclosing structures are leak-tight and have the capability to resist thermal and mechanical loads caused by pipe failures. Therefore, large amounts of sodium leakage into the CV would not occur in the DFBR.

The secondary pipes outside the CV will also be enclosed (Figure 5). In order to do this, we will adopt electro-magnetic pumps (EMPs) as the main circulation pumps in the secondary circuits, and integrate EMPs with the steam generators (SGs). Pipes from the SGs to the pumps will be eliminated and the secondary piping will be much simplified. Penetrations and branch pipes will be also eliminated as much as possible.

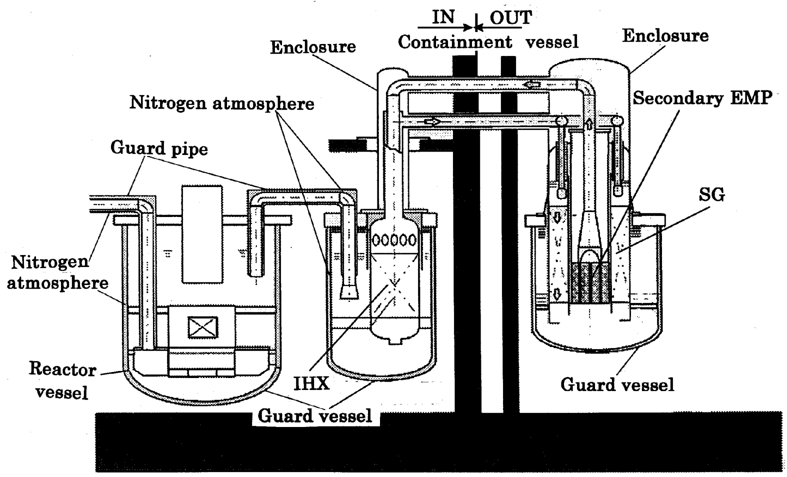

Figure 5 Concept of Measures Against Sodium Fire

PROSPECT OF COMMERCIAL FBRS

From a technical viewpoint, commercial FBRs should be safe and reliable equivalent to LWRs and therefore should be accepted by publics with ease. From an economical viewpoint, commercial FBRs should be competitive with other energy resources in terms of electricity cost.

To achieve these targets, the following innovative technologies and improvements are expected to improve safety and economy.

(Safety)

- Highly reliable reactor shutdown systems and inherent safety in core design.
- Highly reliable decay heat removal system utilizing natural convection.
- Highly reliable SGs adopting double-walled heat transfer tubes.

(Economy)

- EMPs integrated with IHXs and SGs in the primary and secondary cooling circuits.
- Seismic isolation building reducing not only horizontal but also vertical seismic loads.
- Simplification of the upper structure of the reactor vessel by eliminating rotating plugs.
- Elimination of the secondary sodium circuit after the high reliability of SGs adopting double-walled heat transfer tubes will be demonstrated
- Standardized twin plants where some facilities are commonly used for the two plants.

Figure 6 shows a rough estimation of plant construction cost toward commercial deployment of FBRs. We believe FBRs can be economically competitive with LWRs in future, and therefore we will continue FBR development toward their commercialization around 2030.

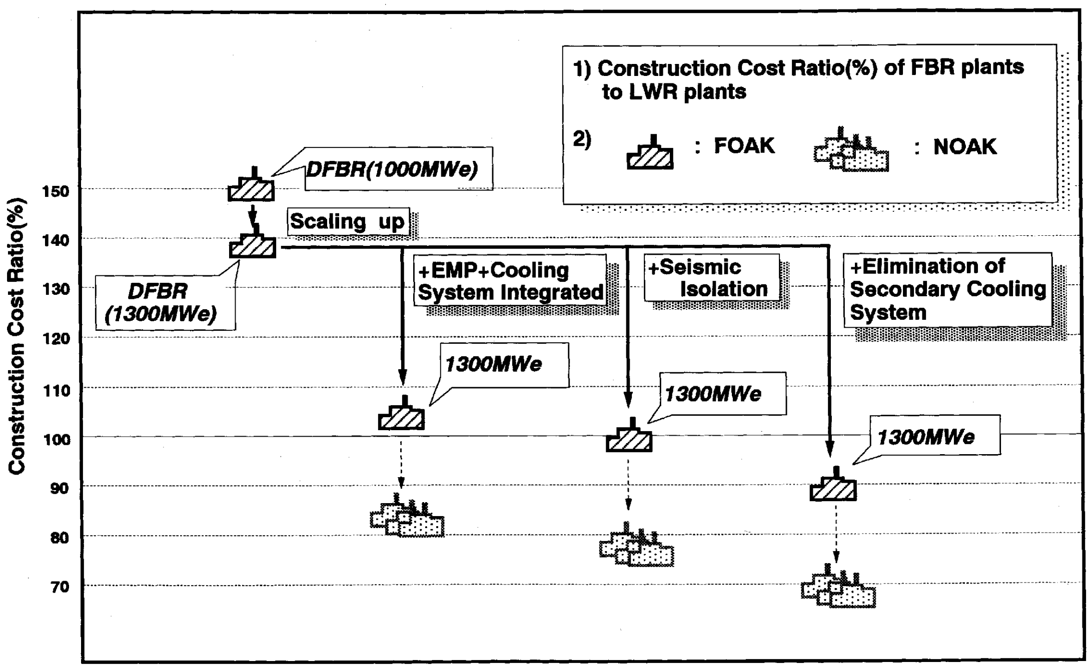

Figure 6 Prospect of Construction Cost Reduction of FBR Plant

CONCLUSIONS

The Japanese government and utilities have been promoting the development of the FBR which will play a significant role in energy supply in the 21st century. The Japan Atomic Power Company (JAPC) has been conducting the development of the demonstration fast breeder reactor (DFBR) since 1986 and finished the conceptual design study in which we achieved safety equivalent to that of light water reactors (LWRs) and accomplished a plant construction cost below 1.5 times that of LWRs on the 1000 MWe output basis. JAPC has started a new design study aimed at both improving countermeasures against sodium leaks and fire, and reducing plant construction cost further, considering the sodium leaks incident in "MONJU" and the recent drastic cost reduction of LWRs.

KEY WORDS

Fast breeder reactor, FBR development, Design study, Core safety, Measures against sodium fire, Prospect of FBR commercialization