RAPID Reactor

By Mitsuru Kambe, Central Research Institute of Electric Power Industry.

1. What percentage of design of Central Research Institute of Electric Power Industry RAPID Reactor is complete?

Basic design work as well as research and development of the key components is almost completed. If specific design parameter from the customer is given, we could start the next design phase. Safety analyses for licensing procedure would be also requested in the design phase.

2. During the design phase are you taking advantage of system simulation and other computational tools to analyze safety and licensing issues?

Yes, safety analyses were done using plant dynamics code in which core physics and thermal-hydraulic behavior are taken into account. Plant dynamics analyses conducted were 1) fully automated reactor startup, and 2) unprotected loss of flow (ULOF).

3. Is this effort being undertaken in-house or it is subcontracted to another organization?

The RAPID project is undertaken by the following members:

1) Overall system design by Central Research Institute of Electric Power Industry (CRIEPI)
2) Core physics calculations and plant dynamics analyses by Mitsubishi Research Institute (MRI)
3) Reactor control systems development by KE Technologie GmbH of the Stuttgart University
4) Neutron radiography at JRR-3M test reactor by Kyoto University
5) Criticality test of Li-6 at Fast Critical Assembly (FCA) by Japan Atomic Energy Research Institute (JAERI)
6) Advanced material development for the thermoelectric system by Tohoku University

Responses to questions by Newal Agnihotri, editor of Nuclear Plant Journal.

Misturu Kambe

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4. Provide a spotlight on the digital instruments and controls of RAPID.

A significant advantage of RAPID is the introduction of the innovative reactivity control systems: lithium expansion module (LEM) (Fig. 1), lithium injection module (LIM) (Fig. 2) and lithium release module (LRM) (Fig. 3). These are not digital, but analogue instruments to ensure the inherent safety.

LEM is the most promising candidate for improving inherent reactivity feedback. LEMs could realize burnup compensation and partial load operation. LIMs assure sufficient negative reactivity feedback in unprotected transients. LRMs enable an automated reactor startup by detecting the hot standby temperature of the primary coolant. All these systems utilize liquid poison of 6Li and are actuated by highly reliable physical property (i.e. volume expansion of 6Li for LEM, and freeze seal meltdown for LIM and LRM). This concept enables operator-free reactor

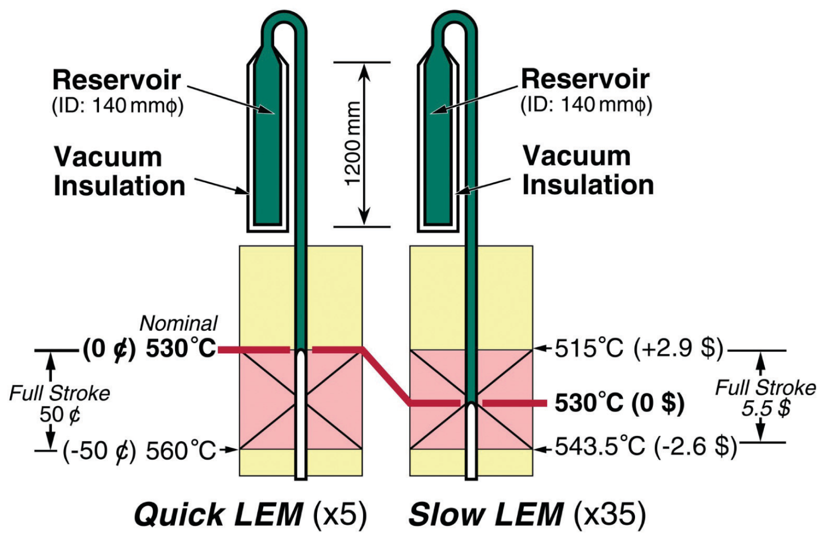

Fig. 1 LEM principle.

and exclude human error and terrorists' intervention. These operator-free reactors realize automated startup and nominal operation without operators. Partial load operation is also possible by adjusting the primary flowrate. Even in such a case, any fault handling by the operator would result in stable operation or automatic reactor shutdown.

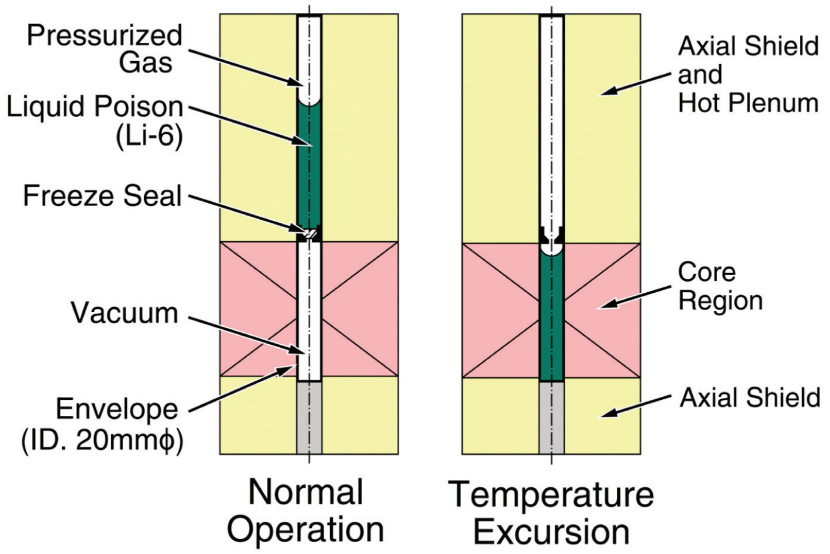

Fig. 2 LIM principle

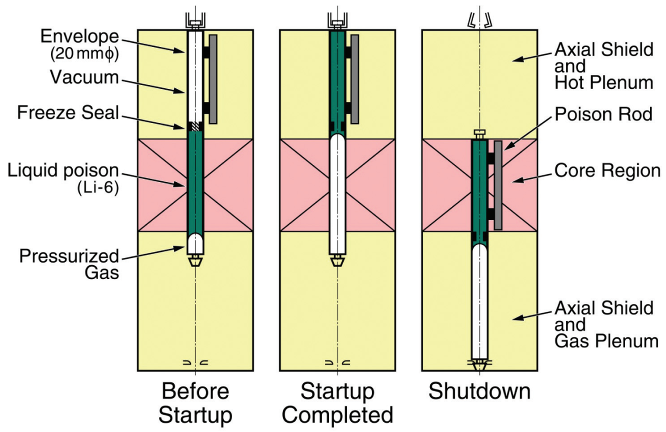

Fig. 3 LRM principle

5. Has Central Research Institute of Electric Power Industry chosen a vendor to supply the digital controls and instrumentation for RAPID?

Yes, KE Technologie GmbH could supply these devices.

6. Who is manufacturing the key components, such as reactor vessel, turbine, fabricated modules, steam generator (if applicable), diesel generators, piping, large valves, and large motors for RAPID?

It would be easier to manufacture large components such as reactor vessel for the factory of Japanese industries who manufactured the reactor vessel of the experimental fast reactor JOYO and the prototype fast breeder reactor MONJU.

Turbine, steam generator and diesel generator are not equipped in RAPID. Instead the thermoelectric system provides electricity. Thermoelectric modules could be provided by Hitachi Chemical Co., Ltd.

7. Who will be supplying the fuel for RAPID? Has Central Research Institute of Electric Power Industry, or one of its contractors done a fuel analysis to ensure the optimal efficiency and optimum safety?

U-Pu-Zr metal fuel is adopted for RAPID. It could be supplied by JAERI.

CRIEPI (Central Research Institute of Electric Power Industry) has started development of U-Pu-Zr metal fuel for fast reactors in 1986, and has been in collaboration with JAERI, the Department of Energy in the United States, Argonne National Laboratory, and Trans-Uranium Nuclei Research Center (EU). This research and development covers overall steps of the manufacturing processes including electrode precipitation, casting and recycling. Irradiation behavior of the fuel was also investigated in the uranium-plutonium hot facilities of above partners. In addition performance and safety analyses as well as cost evaluation are conducted.

8. What thermal hydraulic testing and analysis has been done on RAPID to ensure reactor safety and efficiency?

LIM injection test has been conducted at KE Technologie GmbH (Stuttgart, Germany) and JAERI (Tokai, Japan). This test data was used in the plant dynamics analysis of the reactor to demonstrate how the reactor may be safely shutdown by LIMs in the accident.

As for thermal hydraulic testing and analysis on the reactor structure and sodium circuits, nothing has been done because we are sufficient knowledge on this aspect in the development and operation of sodium cooled fast reactors in the past several decades.

9. Please summarize the results of serious accident analysis, including loss of coolant accident (LOCA) and Non-LOCA analysis that has been done on RAPID to ensure safety and reliability?

Because RAPID is a sodium cooled fast reactor, LOCA is excluded in the accident analysis. (In case of piping and/or reactor vessel rupture, coolant sodium remains in the reactor vessel to keep the core integrity because sodium coolant is not pressurized.) Accident analyses conducted were the followings.

1) Unprotected loss of flow (ULOF): The peak coolant temperature was lower than that of conventional fast reactors equipped with the pumps coastdown control systems. This is mainly due to moderate peak linear power of the fuel (43 W/cm at BOL core) of the RAPID.
2) Unprotected transient overpower (UTOP): A significant characteristic of the LEM reactivity control system is its redundancy. Because RAPID has no control rods, UTOP transients due to faulty handling of the control rods do not arise. However, a boundary failure of one of the LEM envelopes should be anticipated. The plant dynamics analysis demonstrated the passive safety features.

Passive safety feature is also expected in the less stringent ULOHS (unprotected loss of heat sink) incidents. This would results in only a slight decrease in the reactor power.

10. What are the different applications such as desalination, hydrogen generation, and other industrial applications which may utilize RAPID?

Potential uses for RAPID are in power plants for developing countries where remote regions cannot be conveniently connected to the main grid and where it is economical to provide local generation capacity. In addition RAPID can be used for power systems in islands where diesel generators are adopted so far. Other applications expected are power systems for ore deposits and sea water desalination plants in the desert. There are many ore deposits which are uneconomic because they are in very remote places, too far from the usual sources of energy. RAPID could make many projects economical, which would otherwise be abandoned. It would probably be more suitable for underground mining than the more environmentally destructive open-cut mining.

I feel PAPID is not suitable for hydrogen generation because the core exit temperature of RAPID (530 degree C) is not sufficient.

11. How will the sale of reactors in small countries such as Vietnam, Indonesia, Thailand, Angola, and others be supported financially?

I feel RAPID is suitable for such developing countries because of the following reasons:

1) RAPID enables operator-free reactor and exclude human error and terrorists' intervention; therefore no skilful operator is required.
2) Potential uses for RAPID are in power plants for developing countries where remote regions cannot be conveniently connected to the main grid and where it is economical to provide local generation capacity.
3) The integrated fuel assembly (IFA) has a definite proliferation resistance and economical advantage because the refueling in every 5 years could be achieved by the supplier (manufacture in Japan) and the spent fuels from the customers are sent back to the reprocessing plant in Japan.

We have got several inquiries from such countries and districts, including Mongol and Alaska.

12. How did you determine the material suitability for the reactor vessel and other components taking into account the corrosion, cracking, and other material degradation issues which have occurred in current light water reactors in the last 30 years?

In the sodium cooled fast reactor, austenitic steel (SUS316) is adopted as the construction material. As for the material compatibility of SUS316 with sodium coolant, we have sufficient knowledge based on the development and operational experience of the fast experimental reactor JOYO and fast prototype reactor MONJU.

13. What are the design features which makes RAPID a better reactor to withstand terrorism attack?

A significant advantage of RAPID is the introduction of the innovative reactivity control systems: lithium expansion module (LEM), lithium injection module (LIM) and lithium release module (LRM). The advantage of RAPID concept is illustrated in Fig. 4. The conventional reactors have several instrumentations to monitor the reactor. The process data available from such instrumentations are monitored, and the control /shutdown rods are actuated, if necessary. In this system, a failure of the system, human error and terrorist intervention would result in unnecessary reactor shutdown and reduce the plant availability. Maintenance of the instrumentation and monitoring system is therefore important. Such disadvantages are excluded in RAPID.

This concept enables operator-free reactor and exclude human error and terrorists' intervention. These operator-free reactors realize automated startup and nominal operation without operators. Partial load operation is also possible by adjusting the primary flowrate. Even in such a case, any fault handling by the operator would result in stable operation or automatic reactor shutdown.

14. How will RAPID minimize its per megawatt cost by making the thermal hydraulics and fuel more efficient?

The integrated fuel assembly (IFA) has an economical advantage as well as definite proliferation resistance because the refueling in every 5 years could be achieved by the supplier (manufacture in Japan) and the spent fuels from the customers are sent back to the reprocessing plant in Japan. (If the IFA is compatible with all RAPID reactors in such countries and the dimension and fuel enrichment of the IFA is identical.)

This plan possesses definite resistance to state-supported removal of plutonium for nuclear weapons production so long as the following measures could be undertaken:

1) Highly standardized RAPID reactors with compatible IFA design should be constructed. Construction recommended even in the nation(s) suspicious of state-supported removal of plutonium for nuclear weapons production.
2) The IFA reprocessing plant(s) should be constructed only in the nation(s) which undertake nonproliferation measures and accept international safeguards. A network of bilateral and multilateral agreements by those nations should be established.
3) The reactor power plants should be equipped with the IAEA containment/surveillance devices. They include the following: reactor power monitors, ultrasonic seals, thermal luminescent dosimeters, closed-circuit television and modular video systems, etc.

4) International network of the IFA shipment from the reactor site in any nations to the reprocessing plant(s) should be guaranteed.

15. What computational tools have been used to optimize the usage of fuel by providing assistance in design and in operation?

Core physics calculation to evaluate its criticality and burnup behavior is done by two-dimensional R-Z model neutron transport calculations by using TWODANT discrete ordinate multi-group neutral-particle transport code. JFS-3-J2 and ENDF-B/4 cross-section library with 70 neutron groups were employed for the analysis.

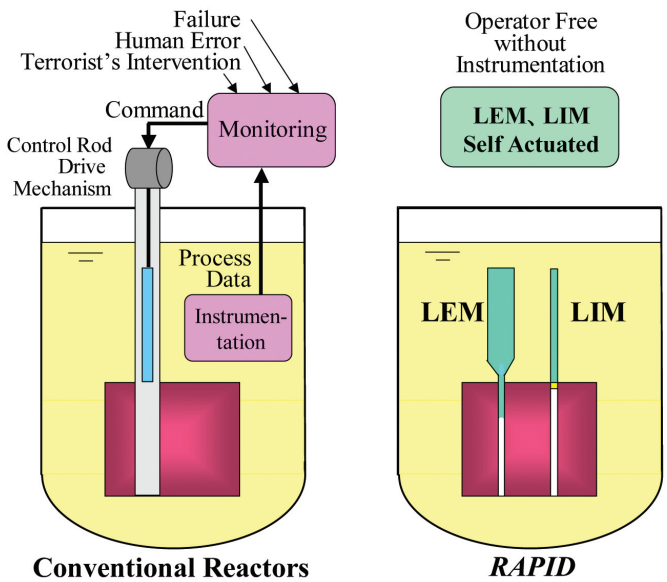

Fig. 4 Advantages of RAPID

16. Who are current Central Research Institute of Electric Power Industry's global partners?

As for the RAPID project, Mitsubishi group including Mitsubishi Research Institute is the major partner, while KE Technologie GmbH plays an important role in the development of reactor control devices LEM, LIM and LRM.

17. You may share any domestic or international utilities who have expressed interest in RAPID?

When the president Bush of the USA announced manned lunar missions in 2004, NASA expressed strong interest on the RAPID-L (one of the variants of RAPID) lithium cooled fast reactor for the lunar base. NASA has sent the delegates to CRIEPI, JAEA and KE Technologie to discuss about its development and future collaboration with us; however, this attempt was not realized due to changing NASA's situation.

18. *What is the electrical megawatt range of the final power plants utilizing the discussed technology?*

Nuclear Power System Performance Parameters:

Reactor thermal power (MWth) 10
Gross electrical output (MWe) 1.2
Net electrical output (MWe) 1.0
Plant design lifetime (years) 40

Thermoelectric system inlet/outlet temperature (degree C)
530/380
Conversion efficiency (%) 12
Waste heat to reject (MWth) 8.8

19. *When do you expect the prototype to be operational and which company is going to implement, construct, and make the prototype operational?*

At the moment, we have no plan of construction.

In case customer is available, it would be easier to manufacture large components such as reactor vessel in the Japanese factories which manufactured the reactor vessel of the experimental fast reactor JOYO and the prototype fast breeder reactor MONJU.

Thermoelectric modules could be provided by Hitachi Chemical Co., Ltd.

20. *Please describe any other details of your revolutionary reactor.*

Electromagnetic pumps drive the primary coolant circulation. The reactor is coupled to four thermo-electric power conversion segments placed around the reactor, Fig.A1. Each segment has a pumped sodium heat rejection loop.

Hot sodium on leaving the reactor flows into the sodium manifolds to which cesium heat pipes are connected. Cooling water of 30°C flows into the water manifolds to which water heat pipes are connected. One of the most striking features of the design lies in the absence of sodium-water heat exchangers (steam generators) used in the conventional fast reactors. Another attractive feature is the low pressure water cooling circuits as well as unpressurized sodium circuits. In addition both sodium and water manifolds have safety vessels and are separated by barriers. These features will contribute to eliminate a risk of sodium-water reaction.

Water outlet temperature of 45°C is the optimized design point between the gross power generated by TE cells and the power consumed by the water circulating pumps. No moving parts are involved in the system except for the water circulating pumps.

A TE unit of 1 inch square consists of segmented TE cells sandwiched between Cu/Al2O3 /Cu FGM compliant pads on which rectangular ducts of cesium heat pipe and water heat pipe are attached. The bond-free compliant pad is also adopted. In this case, bismuth (Bi, melting temperature: 271°C) is infiltrated in porous copper (Cu). Each TE unit is expected to generate approximately 10 W when exposed to the temperature gradient caused by the heat source (i.e., hot side average: 455°C and cold side average: 38°C).

21. *What is the type of your reactor: light water reactor or fast breeder reactor or any other type?*

RAPID reactor is a sodium cooled fast spectrum reactor. However, breeding is not intended because of moderate peak linear power (43 W/cm: as moderate as BWR) and burnup (6600 MWd/t). Even though the rector could be operated 10 years without refueling.

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