Agency for Natural Resources and Energy, Ministry of Economy, Trade, and Industry of Japan, and Japan Atomic Energy Agency: Japan's Current Efforts for Nuclear Innovation

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The ANRE is one of the external bureaus of the Ministry of Economy, Trade and Industry. The ANRE is responsible for Japan's Energy policies including nuclear, renewable, and natural resources.

JAEA is Japan's sole comprehensive research and development institute in the field of nuclear energy. In the area of advanced reactor development, JAEA is implementing research and development on fast reactors, high-temperature gas-cooled reactors (HTGRs), and related fuel cycle technologies, in order to attain further enhancement of future energy sustainability, safety, economic competitiveness, and flexibility.

1.1 Necessity of Nuclear Innovation and the Launch of the Nuclear Energy x Innovation Promotion Initiative

Nuclear power is an essential, economically efficient, carbon-free, and base load power source, as described in the Fifth Strategic Energy Plan issued by the Japanese government in 2018. Toward 2050 in the Plan, nuclear power is described as one of the viable energy source options for decarbonization, contributing to mitigating the risks of climate change specified in the Paris Agreement on Climate Change (UNFCCC 2015). Meanwhile, recent trends, such as the rapid expansion of renewable energy and new energy demands for the production of hydrogen and the utilization of process heat, are increasing the necessity of innovative nuclear technologies. In other words, ensuring flexibility to meet various societal needs in an integrated energy system is a long-term challenge and opportunity for nuclear technology development.

Under such circumstances, the Japanese government launched the Nuclear Energy x Innovation Promotion initiative in Fiscal Year 2019, aiming for innovation in nuclear technology. This initiative has a feature whereby it induces technological innovation led by the private sector and that it makes maximum use of the facilities and knowledge resources of the national nuclear research laboratory, the JAEA. In the Nuclear Energy x Innovation Promotion initiative, various nuclear power systems and safety improvement technologies are currently evolving, including SMRs and other nuclear power systems aimed at nonelectric production and use (e.g., hydrogen production) and harmonized combination with renewable energy. The JAEA has several test reactors and related post-irradiation test facilities, important numerical simulation tools, a knowledge database on nuclear system designs, and operational experiences in advanced reactors (https://www.jaea.go.jp/04/o-arai/en/index.html). JAEA will play an essential role in promoting nuclear innovation.

This document encompasses one section of a larger report, titled Flexible Nuclear Energy for Clean Energy Systems. The full report can be found at https://www.nrel.gov/docs/fy20osti/77088.pdf. The author(s) of each section is/are solely responsible for its content; the publication of these perspectives shall not constitute or be deemed to constitute any representation of the views or policies of any Governments, research institutions, or organizations within or outside the NICE Future initiative.

1.2 Innovation for Flexible Use of Nuclear Power in JAEA

The flexibility of nuclear technology is one of the significant capabilities for advanced reactors when we consider their commercialization. The expanded flexibility concept was shown by the Electric Power Research Institute (EPRI) (Sowder 2019), with the definition of flexibility sub-criteria and attributes for evaluating advanced reactors as follows: (1) Operational flexibility (Maneuverability, Compatibility with Hybrid Systems, Island Mode Operation); (2) Deployment flexibility (Scalability, Siting, Constructability); and (3) Product flexibility (Electricity, Process Heat, Radioisotopes).

JAEA has several research and development activities aiming at innovation that will provide further flexibility, including a sodium-cooled fast reactor (SFR) and an HTGR. These activities are as follows:

1. Development of an innovative design evaluation code system for SFR and other advanced reactors
2. Codes and standards for maintenance of innovative reactors
3. Fast neutron irradiation using the experimental fast reactor, Joyo
4. Demonstration of higher safety performance of HTGR and the capability of its application to hydrogen production.

The details of these activities and how they contribute to improving the flexibility (i.e., operational flexibility, deployment flexibility, and product flexibility) of advanced reactors, such as SFR and HTGR, are explained below.

1.2.1 Development of an Innovative Design Evaluation Code System for SFR and Other Advanced Reactors

JAEA is developing a numerical simulation and design estimation system, named ARKADIA, which covers the whole plant life cycle for advanced reactors.

The ARKADIA system supports innovative plant design with higher safety and reliability through multilevel and Multiphysics simulations and a knowledge base that incorporate reactor design, operational experience, basic experiments, and numerical simulations. Part of the system was recently developed to simulate core behavior of SFRs, incorporating thermal hydraulics, neutronics, and deformation interactions of core structures. The ARKADIA contributes to the evaluations and design improvements for the safety of advanced reactors, which are the essential factors for their deployment flexibility. A safety evaluation code, named SPECTRA, was recently developed as a part of ARKADIA. Figure 1 shows physical models of the SPECTRA.

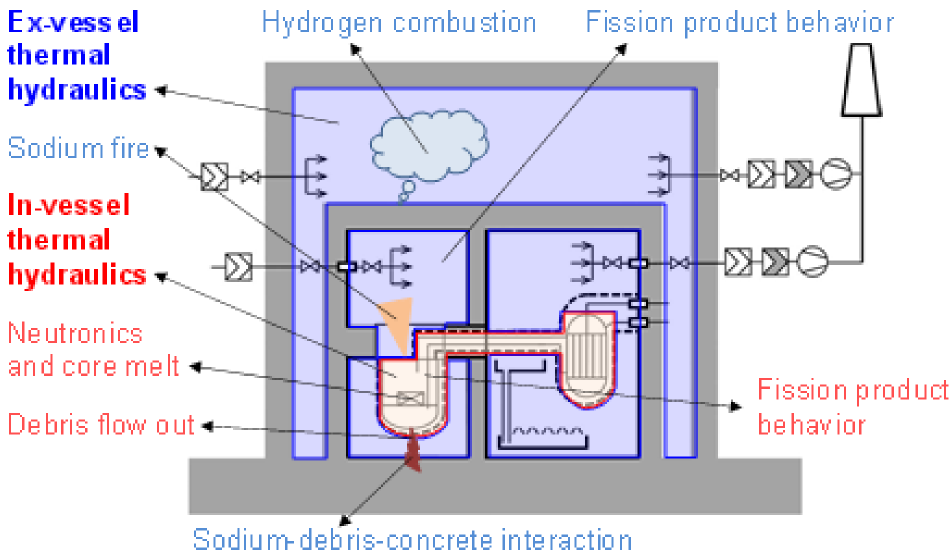

Figure 1. Physical models to be integrated into SPECTRA

Source: JAEA used with permissions.

Maintenance is also a significant issue for the safety and economics of an innovative power plant. Development of ARKADIA will consider the mechanisms of plant damage, including thermal shock, thermal fatigue, and so on, using the Multiphysics simulation system, which provides feedback on the plant design before construction to develop an optimum balance between design and maintenance. Such thermal shock and thermal fatigue are key issues of the operational flexibility of advanced reactors which are operated at higher temperatures than LWRs.

1.2.2 Codes and Standards for Maintenance of Innovative Reactors

Codes and standards are important for establishing maintenance procedures in securing a high level of safety in innovative reactors through appropriate inspections. Good maintenance through adequate inspections can contribute to not only flexible operation of the reactors, but can also lead to simple designs with higher deployment flexibility. For example, excess inspection requirement may need large space around the weld lines and result in large or complex geometry of the components. Reliability of design and inspection requirement can be optimized in the component design based on the codes and standards of maintenance procedures. A resultant simple design enables factory manufacturing, and construction at a site.

JAEA contributes to the development of codes and standards through the Japan Society of Mechanical Engineers. Recently, a new code based on the “leak-before-break” concept entered the final stage for approval. It will contribute to standardizing necessary and sufficient inspection strategies for the proper maintenance of an SFR plant. It will further contribute to simple reactor designs and easy operation aiming for higher flexibility.

1.2.3 Fast Neutron Irradiation With the Experimental Fast Reactor, Joyo

Irradiation experiments are key to the development of advanced reactors, especially for the development of core materials used for those reactors. The reactor core must have an adequate safety margin for the operational flexibility and development flexibility. The irradiation experiment for the core material is significant to confirm the influence of neutron irradiation on the fuel integrity so as to cover wide range of plant operation conditions. JAEA operates the experimental fast reactor, Joyo. Many irradiation experiments have been conducted in Joyo using higher fast neutron flux. Various measurement techniques were also developed (e.g., online monitoring during irradiation and also high-resolution x-ray computed tomography for irradiated fuel subassemblies as a nondestructive post-irradiation examination).

JAEA is preparing for the restart of Joyo. JAEA submitted the amendment of permission for a change in reactor installation license to the Nuclear Regulation Authority of Japan in October 2018, and it is currently under review.

1.2.4 Demonstration of Higher Safety Performance of HTGR and the Potential for Application to Hydrogen Production

JAEA has been developing an SMR HTGR because of its inherent safety characteristics, compelling economics, and superior operational, deployment, and product flexibility. As for the product flexibility, HTGRs, due to their high temperatures, can be used in multiple heat applications, including power generation, hydrogen production, supplying process heat, sea water desalination, and so on. The overall utilization of reactor thermal power can exceed 80%. Regarding operational flexibility, the HTGR gas turbine and hydrogen cogeneration system has an excellent ability to adjust to the conditions and support power quality of an electric grid with a large input of VRE. As for deployment flexibility, HTGRs can be built close to industrial facilities and residential sites due to their excellent safety features. Inland installation is possible by adopting a dry cooling tower.

Toward the commercialization of HTGRs, JAEA is planning to:

- Demonstrate the safety of HTGRs and develop technologies for connecting hydrogen production and helium gas turbine systems to HTGRs by using the High-Temperature Engineering Test Reactor in Oarai, JAEA.
- Develop a steam generation system and technology for connecting to HTGRs and enhance reactor core performance through international cooperation.

With the successful development of HTGR by JAEA, it is expected that private companies will do the following things:

- Demonstrate the economic viability and reliability of HTGRs and validate business models using a demonstration reactor to be developed through international cooperation
- Commercialize the hydrogen production and helium gas turbine systems coupled to HTGRs in Japan.

The key facility of HTGR development is the High-Temperature Engineering Test Reactor, the only nuclear reactor in the world that can supply 950^{o} C of reactor outlet coolant temperature. The High-Temperature Engineering Test Reactor has been stopped since Great East Japan Earthquake in 2011. In June of 2020, JAEA obtained the permission of changes to reactor installation of the High-Temperature Engineering Test Reactor toward restart by Japan's Nuclear Regulatory

Authority in conformity with the New Regulatory Requirements. The restart of the High-Temperature Engineering Test Reactor will occur in early 2021, and the High-Temperature Engineering Test Reactor safety demonstration tests (loss of forced cooling test and loss of forced cooling test without vessel cooling) under the Organization for Economic Co-operation and Development/Nuclear Energy Agency framework will be carried out immediately after the restart.

1.3 References

Sowder, Andrew. 2019. "EPRI Perspectives on Product Flexibility and Alternative Revenues for Increased Competitiveness of Existing and New Nuclear," 19.

UNFCCC. 2015. "Paris Agreement." In *Record Thumbnail Image Report of the Conference of the Parties on Its 21st Session*. Paris, France. https://digitallibrary.un.org/record/831052.