Advanced Nuclear R&D in Korea

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ABSTRACT

Advanced nuclear R&D efforts and programs in the Republic of Korea have generally focused on sodium-cooled fast reactors (SFRs), although there has also been some work on very-high-temperature reactors (VHTRs). Although a wide range of advanced reactor and Generation-IV designs were originally considered, the SFR was selected for its technological maturity, actinide burning capabilities, and enhanced safety characteristics. While the SFR was initially planned as a support reactor for the conventional LWR fleet, policy changes have led to a greater emphasis on the SFR's spent fuel management mission and transuranic (TRU) burning role. Key decisions on the SFR program in Korea will be made once the national policy on spent nuclear fuel (SNF) management has been determined. Further work is currently being conducted on further enhancing the SFR's passive safety profile and transmutation capabilities, and studies are being done on the Pyroprocessing-SFR fuel cycle's economics and proliferation resistance. The ultimate goal of these R&D efforts as a whole is the elimination of the need of emergency offsite response and limiting the consequences of any incidents to within site boundaries—extremely important considering issues related to social acceptance. In the future, R&D will focus on non-electricity applications, including hydrogen production, and other Generation-IV types.

SUMMARY

In Korea, efforts are focused on two main advanced reactor designs: the SFR and the VHTR. KAERI is focused on developing the SFR with hopes of constructing a prototype SFR (PGSFR) as a technology demonstration. Because of the current energy transition in Korea, no more PWRs can be constructed after Shin-Kori units 5&6, existing PWRs cannot have lifetime extensions, and the operation of PWRs will be finished around 2082. Based on Korea's changing nuclear energy policies, the role of the SFR will be modified. Previously, the SFR was intended to be a support reactor for the PWR fleet, which would be continuously constructed and operated. Now, the SFR will be a dedicated TRU burner to consume 28,000 or 40,000 tons of spent nuclear fuel (SNF).

- The national policy on SNF has not yet been determined but two options have been considered: direct disposal and final disposal after recycling using Pyroprocessing-SFR. Technical feasibility, including the safety and cost of SFR, should be provided to the government and public in deciding upon a technical option to manage SNF by the end of 2020.
    - The final disposition of spent nuclear fuel should commence in the early 2050s and the final policy should be decided before the 2040s, until an official decision is made, construction of the Prototype Generation-IV Sodium-cooled Fast Reactor (PGSFR) will be suspended.
- A 3-year plan for SFR R&D was established recently. This plan includes: achievement of key technology certifications related to SFR safety, enhancement of TRU transmutation

capabilities, re-evaluation of economics, and safety enhancement to address social issues.

  - In addition to TRU burning, transmutation of long-lived iodine and technetium is another capability that will be sought after.

KAERI has achieved a number of key milestones with its SFR development activities.

- KAERI completed the preliminary engineering design of the 150 MWe Prototype SFR just before the construction of the PGSFR. All the design information is consolidated into the SDSAR (Specific Design Safety Analysis Report) with supporting technical documents.
- KAERI has accomplished technology validation of safety performance. The first phase of the large sodium test facility (STELLA program) has been completed, and the second phase is ongoing. The reactor mock-up physics test for the SFR core (utilizing the IPPE BFS facility) has been constructed, and the fuel/cladding in-pile and fuel assembly hydraulic/mechanical tests have been completed.
- KAERI has manufactured the fuel and fuel subassembly—including the fuel slug, cladding (HT9), fuel assembly parts (duct, wire, etc.) in full scale—and they have established the fuel fabrication infrastructure with a domestic partner.

According to the SFR R&D 3-year development plan that was established recently, the key milestones are: key technology certifications related to SFR safety, enhancement of the transmutation capability of TRU, safety enhancement for social issues, and re-evaluation of economics for the Pyroprocessing-SFR recycle system.

- KAERI has suspended engineering design of the PGSFR. No further engineering design development of PGSFR will be conducted until 2020, and the continuation of the design will be determined in 2020 after all 10 topical reports have been submitted.
- KAERI hopes to have key technologies on SFR safety certified. This will be determined by the submission of the 10 topical reports along with an independent safety review of the PGSFR from a French institute.
- KAERI hopes to enhance the transmutation capability of TRU to minimize deployment of SFR for transformation of TRU from spent nuclear fuel, and increase the power unit capacity of the SFR to be deployed around 2040. Furthermore, high TRU-content fuel development will be required.
  - By increasing the size of the SFR and the content of TRU in the fuel, less units will be needed for the technology platform to adequately perform its spent fuel management mission.
- KAERI is focusing on safety enhancements for social issues, including the validation of metal fuel safety during a severe accident, along with prevention of sodium risk and enhanced seismic response of structures and/or improved seismic behavior.
  - In terms of preventing sodium risk, KAERI is considering a number of solutions, including double piping, reduced welding points, an improved steam generator, etc.

- KAERI hopes to evaluate the economics for a Pyro-SFR Recycle System. Construction costs of the SFR must be a key consideration when conducting an economic evaluation of the entire fuel cycle—this includes construction costs and operational costs, which would account for over 70% of the costs of the whole fuel cycle system/concept.

KAERI has recognized global trends in and perspectives on advanced reactor development.

- Advanced reactors offer improved inherent safety characteristics by altering the fuel type from MOX to metal, particle, carbide, or nitride fuel. These altered fuel types result in inherent safety features from the fuel, such as high heat conductivity, high melting point, thermal expansion, and fragmentation behaviors. A significant portion of improved safety margins is from the fuel itself.
- Advanced reactors offer improvements to passive safety features through decay heat removal systems such as DRACS, RVACS, and RCCS using natural circulation. Furthermore, these reactor designs offer passive reactor shutdown systems, passive core constraint systems, and atmospheric heat sinks for long-term decay heat removal.
- Advanced reactors focus on severe accident prevention and mitigation. There is an increased need for verification of molten fuel behavior under severe accidents, and there is increased emphasis on prevention, but mitigation is required.
- Safety goals of Generation IV reactors eliminate the need for an emergency offsite response. Technologies such as SMRs offer a small emergency-planning zone that is confined to the site of the reactor, allowing a significant reduction in accident risk.
    - The ultimate goal of reactor development is to limit all consequences of severe accident scenarios within the confines of the reactor's site boundary.
    - However, in addition to achieving technical progress towards this ultimate goal, work must be done to inform and educate stakeholders, experts, officials, and the public on these technical developments—there must be social agreement between the technology developer and the public.
- Advanced reactor developers are also seeking alternate applications for their technologies, including heat production and chemical/hydrogen production.
    - Smaller reactors are being developed in order to provide heat and electricity solutions to remote and off-grid communities.
    - In the future, carbon constraints and constraints on fossil fuel use may encourage the deployment of reactors on commercial shipping, icebreakers, and other marine vessels.
- The direction of advanced reactor development will go towards greater inclusion of various reactor types and designs, including other Generation IV reactors (MSR, LFR, SCWR, and so forth).

QUESTION & ANSWER

Q: *You mentioned the previous role of the SFR was to support the PWR reactor fleet. Does that change the number of units deployed that you had envisioned? What would have been the ratio*

of SFR to LWR for the previous role, and how many do you need to fill the TRU burning mission that is currently the objective?
A: The ratio should be changed according to energy policy changes. The target for the support ratio was originally 2:1. If we have to construct 3 LWRs in Korea, if we replace one LWR with a SFR, we can manage the spent fuel discharged from those two operation LWRs.

Q: *How many SFRs do you need for the second role?*
A: The total number of reactors is not important in the large scheme of strategic planning. The ratio is important. For the TRU burning mission, the number can depend according to the size of each unit and the TRU content of the fuel, but 4-5 large units may suffice in addressing current stockpiles and accumulating SNF.

Q: *Regarding the issue of interest and focus on reactor design, development, and construction, I was interested in how you're working with industry that can manufacture such units. What does this mean for the overall product and cost? Given the problems of public acceptance, how much are you and the industry looking at the export market to drive commercialization and development?*
A: We have very good industrial partners for LWR construction and operation: KEPCO, KHNP, Doosan, and many smaller companies. We can equally use that infrastructure for advanced reactor development. For PGSFR development, KAERI is in charge of validation and design of the PGSFR. Doosan participates in a project for determining manufacturing feasibility. They have their own components for the LWR, but the SFR components are different—so they started the manufacturing feasibility project to determine what is possible and what is not possible. For the LWR, I don't know exactly the current situation in Korea. For advanced reactors, I think it's the same market, but we have to construct the reactor regardless of each size in Korea for ourselves.

Q: *Where do you envision these SFRs to be sited and constructed in Korea?*
A: Korean LWRs are distributed in the southwest or the east. Maybe we'll put one in the southwest, and four on the east coast. Maybe to reduce the burden of SNF transportation, perhaps we can construct an SFR on LWR sites. For the PGSFR, we haven't decided on the site specification of the design. We originally envisioned that the SFR would replace the LWR on the same site.

Q: *If your shift is to use the fuel as part of reprocessing, is it just that you're focused on this one concept? There are other fast concepts that have the same physics, but different materials such as the molten salt reactor (MSR) design.*
A: We explored many advanced reactor designs. When we participated in the Gen-IV forum, the candidates covered the whole scope of designs. The Korean government chose to focus on a few types because the R&D capability in Korea is limited. We chose the SFR because it had the most technical maturity. If we see another application or potential advanced reactor designs for

micro or modular reactors, we will consider all of the Generation-IV designs again from scratch. For example, we can choose the MSR or LFR for micro reactors or SMRs. Some design experience and computation code systems can be used for the MSR and LFR.

Q: *You mentioned sodium and water heat transfer in one concept. For the reliability, is there a key concept that allows that reliability number?*
A: There are three barriers from sodium to steam called a copper-burned steam generator. We separated the sodium and steam tube. We have to utilize the isostatic-pressing process to produce the material for this type of technology, but that heat process is already matured, even in Korea and other countries.

Q: *Climate tracker is a website that is keeping track of the commitments to the Paris accord, to which Korea is still a party. Korea, Japan, and the U.S. are currently rated as insufficient: we are not going to meet the Paris goals. Those of us familiar with mathematics do not believe that Korea, Japan, and the U.S. can even meet the goals stated without nuclear power. So then, what is the budget outlook for your SFR project for KAERI and the domestic budget situation for nuclear in Korea, given that you are not going to meet the currently pledged carbon emissions target?*
A: The situation is not good because our past project, the PGSFR project, was an engineering design project and our SFR project is our flagship project. Now, if we suspend the engineering design of the PGSFR, if we only focus on R&D activity for the SFR and microreactors, the whole budget will be reduced. Nevertheless, the budget and development will continue.

Q: *You were talking about technological maturity being one of the considerations for selecting the SFR as a design. What were the other considerations?*
A: The biggest consideration was for the transmutation of TRU elements, and among fast reactors, SFR was the best at that time. You need a fast neutron spectrum for TRU transmutation—thermal neutron designs cannot fulfill a TRU-burning role.

Q: *Is KAERI interested in working with U.S. advanced reactor companies?*
A: We have collaboration programs with the U.S. on PGSFR. We have two contracts with ANL for joint development of the PGSFR and safety demonstration and other activities for severe accidents through CRADAs. Many U.S. researchers have participated in the design and selection of the SFR. There have been many collaborative studies between the Korean and American sides on the SFR and nuclear R&D in general.

Q: *Is there a joint MOU between KAERI and Terrapower?*
A: No. We keep in touch with the Terrapower guys. We were contacted to work with Terrapower for the traveling wave reactor, but it was not in our institute's research focus.

Q: *If the PRISM reactor is built at INL as the Versatile Advanced Reactor, is that similar enough to the PGSFR that you can use that to advance your program without having to build the PGSFR?*
A: There are significant differences. There are some similarities such as the RVACS being applied in both, but they're completely different designs.

Q: *Where are you looking to do your fuel testing?*
A: If we construct the PGSFR, we will test the fuel in Korea.

Q: *Can you give us the status of the PRIDE facility in terms of demonstrating large-scale pyroprocessing?*
A: I'm not involved in pyroprocessing technology development. I know that the construction of the large-scale pyroprocessing facility is suspended in Korea, in a similar manner as the PGSFR.
A: That decision on the PRIDE facility will be made after 2020.

Q: *In talking about advanced reactors generally, including SFR designs, how far ahead is China?*
A: In my personal opinion, they have achieved great progress in the engineering design phase. The capability of their engineering design is at a certain level, but for R&D on SFR, they are still low compared to Korea or the U.S. They are still leaning on Russia or others for developing new concepts.
A: They are developing HTGRs too.
A: For the early phase of their HTR development, China imported key technologies, computational codes, and fuel fabrication technologies from Germany. Again, they have good progress at the engineering design level, but they're at the same position in terms of R&D design innovation.