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Top-tier Design Requirements of a SFR Demonstration Plant Developing in KAERI

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1. Introduction

The long-term advanced SFR R&D plan aims at the construction of an advanced SFR demonstration plant as follows: conceptual design phase (2007~2011), standard design phase (2012~2017), and construction phase (2018~2028). The plant has a function of transuranics (TRU) burning and a verification of technical issues.

The top-tier design requirements of a SFR demonstration plant are categorized by three; general design requirements, safety and investment protection, plant performance and economy. These requirements reflect the design policies especially emphasizing proliferation resistance, safety assurance and metal fuel performance, and form the basis developing the detailed system design requirements for key NSSS concepts.

2. General design requirements

The general design requirements apply broadly to the key design items such as reactor type, plant size, plant design lifetime, safety design philosophy, seismic design, fuel type, spent fuel, conversion ratio, feed fuel, and environmental impact. The details are as follows.

The pool type reactor has a large thermal capacity and a long grace time, which provides favorable safety characteristics during an accident.

The plant capacity of 600 MWe is temporally determined from the developed technology level, investment risk and no deterioration of transuranics (TRU) transmutation performance. The power has a flexibility of 10% to rise up the core outlet temperature as the fuel cladding performance is improved in future. The plant capacity size will be revised in 2012.

The plant shall be designed to operate at least 60 years. The NSSS main components excluding reactor vessel and internals shall be designed to be replaceable.

Implementing an inherent safety mechanism, which does not rely on off-site support and active mechanism, shall be considered for achieving a high plant safety.

A seismic design load shall be strengthened to SSE 0.3g covering the seismic uncertainties worldwide. A utilization of a seismic isolation system for a reactor building simplifies seismic design and enhances structural safety, and also reduces a construction cost.

Metal fuel is adopted. It is suitable for pyroprocess and has excellent performance characteristics as well as inherent safety characteristics. U-Zr fuel shall be loaded for an initial core, and U-TRU-Zr fuel after some reloading cores.

When fully developed, a TRU burner core shall transmute a fair amount of TRU and contribute to minimizing the high level wastes that originate from other types of reactors like PWRs. In the early stage of burner core deployment, the target conversion ratio is conceived to be about 0.9. As technology is developed, the conversion ratio will move toward 0.45.

An external feed of U shall be kept as small as possible to enhance TRU burning. This specification for feed fuel requirement applies to the amount of external feed uranium alone other than the self-recycled uranium from a TRU burner.

To minimize and prevent the leak of radioactive materials, the concept of a nuclear park in which a reactor and related fuel fabrication and pyroprocessing facilities are co-located is considered.

3. Safety and investment protection

There are three items to the safety and investment protection; accident resistance, core damage prevention, and accident mitigation.

- Accident resistance

Simplicity shall be emphasized in all aspects of the design, construction, operation, and maintenance because a complexity of the plant design has been one of the main sources of a high capital cost and a threat to the safety of nuclear power plants.

A large thermal capacity of the primary system in a pool type reactor moderates thermal hydraulic response transients and also enables the passive decay heat removal system to maintain the reactor in a safe.

Maintaining a negative core power reactivity coefficient during all modes of plant operation is crucial for all aspects of the plant safety.

- Core damage prevention

A mean annual core damage frequency (CDF) for the design shall be less than 1×10^{-6}/reactor.yr. It shall be evaluated by probabilistic safety assessment (PSA).

To assure no fuel-cladding liquid phase propagation during design basis events, a sufficient thermal margin shall be imposed in the fuel and core design for investment protection as well as for reducing the core damage probability.

One of the key factors in securing plant safety is to make the core shutdown reliable. Two diversified and independent core shutdown mechanisms shall be used to achieve a high confidence level of core shutdown.

Safety grade decay heat removal system shall be applied, and non-safety grade one introduce optionally.

The design shall have passive means of negative reactivity insertion and decay heat removal sufficient to place the reactor system in a safe and stable state for specified anticipated transient without scram events without sodium boiling and significant damage to fuel, cladding or system structure integrity.

- Accident mitigation

A reliable containment design shall confirm that the whole body dose at the site boundary is less than 25 rem for a large radioactivity releases from severe accidents, the cumulative frequency of which exceeds 1×10^{-7} per reactor.yr.

Core protection limits should not be exceeded for at least 3 days without any operator‘s action for design basis events. A long grace time during an accident provides an improved reliability of the plant safety function and a more flexibility in coping with an accident.

4. Plant performance and economy

There are several items to the plant performance and economy; plant thermal efficiency, plant availability, refueling interval, spent fuel storage capacity in the reactor vessel, load rejection capability, operation, maintenance and serviceability, reliance on a safety grade diesel generator, and construction cost.

The net plant thermal efficiency is above 38%. The inlet and outlet temperatures of a reactor core usually govern the net efficiency, and the types of pump, SG and passive decay heat removal circuit (PDRC) also give a minor effect if the turbine is same.

The plant shall be designed for an annual average availability of greater than 70 percent over the life of the plant, which is considering the 6 months refueling interval, a planned outage for refueling of being less than 30 days per fuel cycle. It imposes minor outages of being less than 5 days per year, and major outages of being less than 45 days every 3 years.

The plant should be capable of operation with a refueling cycle length of at least 6 months for a U-Zr initial core. A cycle length of U-TRU-Zr reloading core shall be maximized by 11 months as long as a burnup reactivity swing can be safely controlled by control rods, and an individual control rod worth be kept below 1$.

A storage capacity for the spent fuels shall be provided in the reactor vessel. The in-vessel storage shall have room for accommodating one cycle discharge, failed fuel assemblies, and fuel assemblies subject to reloading again in the core after a temporary discharge. A minimum cooling time over 1 year is recommended for easily handling the spent fuel outside reactor vessel.

The capability of 100 % load rejection capability shall be required to mitigate consequences of rapid transients and to relax thermal impact to plant systems.

The number of plant operators shall be minimized by simplifying the plant operation through advanced human-system interfaces, automatic controls and testings, which eventually leads to the reduction of an operational cost and a possibility of human errors.

Major equipments which affect the plant lifetime shall be replaceable for investment protection.

Optimal level of automation shall be introduced to improve the plant availability by preventing the intervention of operators. Automatic inspection and diagnosis shall be implemented to minimize a maintenance cost and human errors. An occupational radiation exposure shall be less than 100 man. rem /yr.

Safety grade diesel generator shall be provided for emergency power supply for coast down devices, decay heat removal circuits, safety values, etc.

A construction cost shall be minimized by a standard design to be competitive with that of PWRs in future.

5. Conclusions

Top-tier design requirements for SFR demonstration plant developing in 2011 by KAERI are described. These requirements are derived from the performance objectives and criteria established by the SFR design team in the KAERI as listed in Table 1. More detailed design requirements will be defined in design specification and system description documents of the demonstration plant.

ACKNOWLEDGEMENT

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REFERENCES

[1] Lee, Jae-Han, “Top-tier design requirements for Advanced SFR demonstration plant,” IOC, SFR-TI111-DR-01-2010Rev.0," 2010.7.

Table 1 Summary of Top-tier Design Requirements

General Design	- Reactor type : pool type
	- Plant size : 600 MWe ± 10%
	- Plant design lifetime : 60 years
	- Design basis earthquakes (SSE: 0.3g)
	- Initial core : U-Zr metal fuel - Reloading core : U-TRU-Zr metal fuel
Safety and Investment Protection	- Design simplification - Negative power reactivity coefficient
	- CDF < 10^{-6}/reactor.yr - No fuel-cladding liquid phase propagation during DBEs - Diversified core shutdown mechanism - Reliable and diversified decay heat removal - Accommodating unprotected ATWS events without any operator's action.
	- Large radioactivity release <10^{-7}/ reactor.yr - 3 days grace time w/o any operator’s action for design basis events.
Performance and Economy	- Plant thermal efficiency : Net > 38%
	- Plant availability ≥ 70 %
	- Refueling interval . U-Zr initial core : ≥ 6 months . TRU burner core : ≥ 11 months
	- Spent fuel storage capacity in RV ≥ 1.5 cycle discharge
	- 100 % off-site load rejection w/o a plant trip
	- Safety grade diesel generator