CONCEPTUAL DESIGN FOR THE POOL-TYPE SODIUM-COOLED FAST REACTOR

(1) General plan and core design

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Regarding the development of a demonstration fast reactor in Japan, a pool-type sodium-cooled fast reactor (SFR) proposed by MFBR was selected as the conceptual design target in the fast reactor technology selection conducted in 2023, and MHI was selected as the core company responsible for its manufacture and construction in the future. In response, the conceptual design of the reactor, the study of fuel cycle facilities related to the reactor, and research and development (R&D) work for these have been launched and now in progress.

This paper presents the design concept of the demonstration SFR, and the overall plan for the conceptual design and research and development work to be implemented from 2024 to 2028.

1. DESIGN CONCEPT AND DEVELOPMENT PLAN FOR THE CONCEPTUAL DESIGN PHASE

The selected design concept is a medium-sized pool-type SFR shown in FIG. 1, which can be expanded to a large-scale reactor with high economic efficiency due to the scale effect, and can also be developed into a small-scale reactor. This design is based on the accumulated experience of previous domestic reactors (design, construction and operation) and existing projects, as well as knowledge gained through international cooperation (Japan-France and Japan-U.S.). In addition, in order to improve safety, new safety features such as passive reactor shutdown and cooling are incorporated.

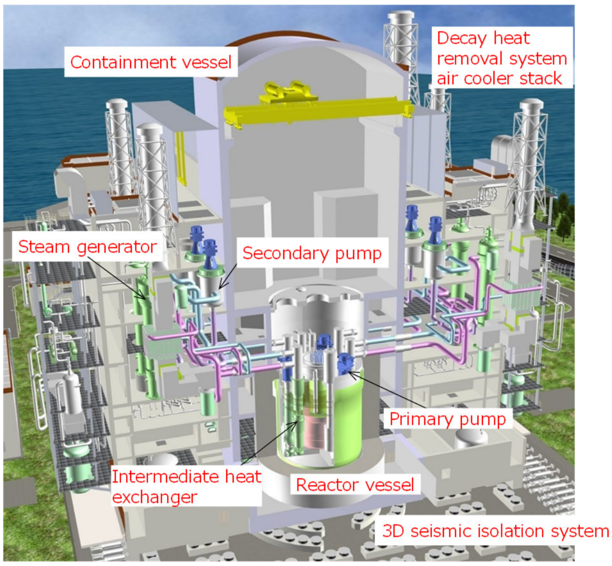

FIG. 1. Bird's eye view of the demonstration SFR

The development plan for the conceptual design phase is shown in FIG. 2. Prior to the start of the conceptual design phase, preliminary studies have been already conducted on the structure and safety design concept of the pool-type SFR [1]. At the start of the conceptual design phase, the main plant specifications and design conditions were established based on the results of these studies. Conceptual design is performed for each item of structures, systems and components (SSCs), such as the reactor core and fuel, reactor structure, coolant systems, reactor containment and building, and balance-of-plant (BOP), in accordance with the specified specifications and conditions. The plant performance evaluation is also conducted to clarify if the development goals of safety and reliability, economics, reduction of radioactive waste volume and toxicity, efficient use of resources, proliferation resistance and flexibility and marketability are achievable.

We will promote R&Ds for the newly introduced design and evaluation technologies and improve the maturity of the conceptual design by reflecting the progress of R&Ds [2]. In addition, we will formulate a development plan for the basic design phase during the conceptual design period. Extrapolation to commercial reactors will also be studied. Based on these results, a decision will be made at the end of the conceptual design phase, scheduled in 2028, on whether to proceed to the basic design phase. With regard to fuel technology, a comparative study of oxide and metal fuels will be conducted from a comprehensive perspective, including the fuel cycle system, and a selection will be made in 2026.

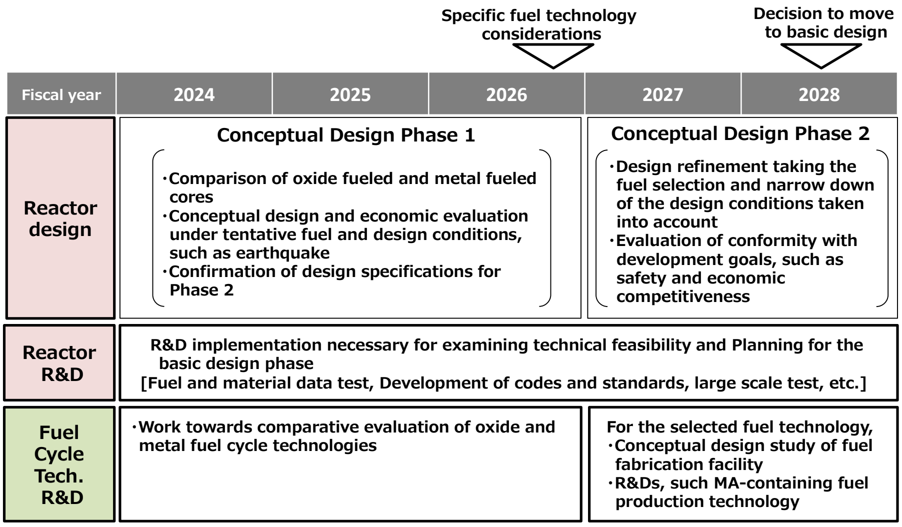

FIG. 2. General plan for the conceptual design phase

1.1 Conceptual design phase 1

At the start of conceptual design, key plant specifications and design conditions including site conditions are preliminary specified. Conceptual design is performed to finalize the design of each SSCs in accordance with the specified specifications and conditions, and to construct an overall plant design that is consistent and technologically feasible.

Core Fuel: compare oxide fuel cores and metal fuel cores and select one.

Safety: establish safety design principles and incorporate them into the design. Select design basis accidents and severe accident sequences and perform analysis and evaluation.

Reactor coolant system: establish plant heat and mass balance and perform plant dynamic characteristic analysis.

Reactor structure: establish the structural concept and evaluate the life-time integrity in terms of seismic and thermal resistance, and evaluate accident tolerance. Perform studies on the optimization of the coolant flow in the reactor vessel and on the maintainability and reparability. Specify the structure and functions of the control rod drive mechanism, rotating plug, fuel handling machine, roof deck and internal structures [3].

Coolant systems and components: Establish structural concepts, evaluate life-cycle structural integrity for seismic and thermal resistance, and evaluate accident tolerance. Perform maintainability and repairability studies. Evaluate performance of decay heat removal systems, including during accidents.

Reactor building and Layout: Design the layout and structure of the reactor building, including the containment, with three-dimensional seismic isolation. Evaluate seismic response and investigate measures against external events other than earthquakes and their effectiveness.

Electrical power, instrumentation and control: Specify electrical power, and instrumentation and control systems, including safety protection systems, and equipment specifications.

Present preliminary evaluation results for plant performance in terms of the development goals of safety and reliability, economics, reduction of radioactive waste volume and toxicity, efficient use of resources, proliferation resistance and flexibility and marketability.

1.2 Conceptual design phase 2

Based on the results of fuel selection and plant performance feasibility study, and the related R&Ds conducted in Phase 1, the design specifications and conditions will be revised in accordance with more specified site conditions, and the design work will be updated in integrated manner.

The evaluation results of achievement of the design objectives will be presented.

A R&D plan to be implemented at the basic design phase will be presented.

A draft application for an installation license will be presented.

2. OVERVIEW OF THE CORE DESIGN

For oxide fuel cores, we have investigated homogeneous cores using fuel assemblies with internal ducts for molten fuel discharge (FAIDUS: Fuel Assembly with Inner DUct Structure). In this design concept, the fuel pin diameter is increased and the fuel assembly size is increased to increase the fuel volume fraction of the core. In addition, the use of ODS steel for the fuel cladding tubes and PNC-FMS steel for the wrapper tubes enables high burn-up, long operating cycles and the use of MA-bearing fuel. However, since the development of FAIDUS, including confirmation irradiation tolerance, requires a long period of time, it was decided to adopt a design based on matured technologies in the initial phase of the demonstration reactor. FIG. 3 shows the design of the core.

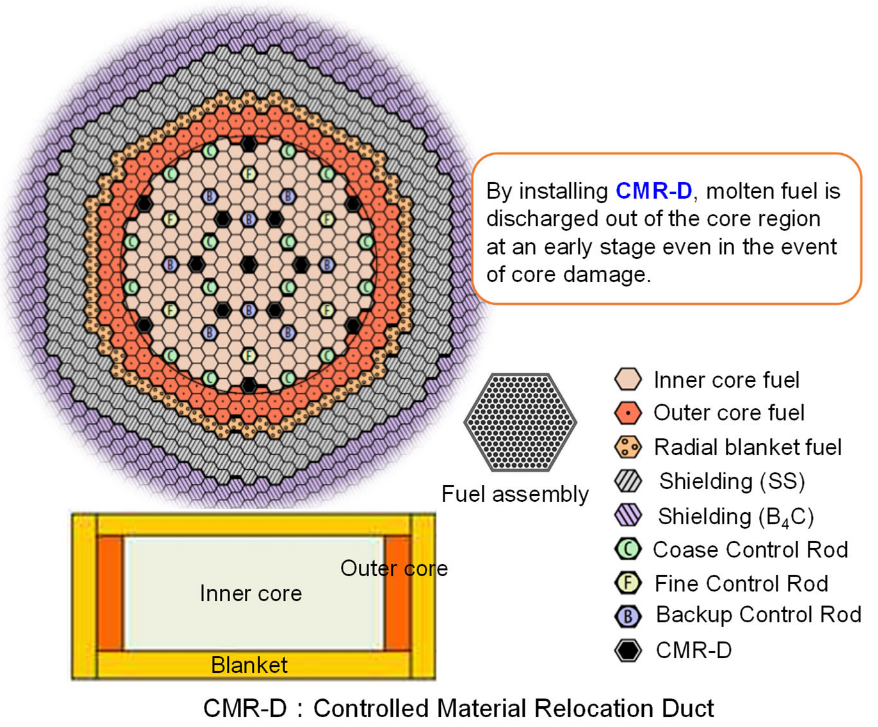

FIG. 3. General plan for the conceptual design phase

Proven PNC316 steel is used for the cladding tubes of the fuel pins, and the pin diameter is 8.5 mm. The number of fuel pins per fuel assembly is 217, and PNC316 steel is used for the wrapper tubes. Therefore, although the core performance such as burnup will be limited in the initial stage of the demonstration reactor, we will improve the core during the operation period of the demonstration reactor to achieve the development goals. In terms of safety, the introduction of FAIDUS has been postponed, and as an alternative technology, molten fuel discharge tubes called CMR-D (CMR(Controlled Material Relocation)-Duct) have been placed at appropriate locations in the core. The purpose of CMR-D is to reduce reactivity by discharging molten fuel outside the core during severe accidents involving fuel melt, thereby avoiding severe recriticality that could lead to a large release of mechanical energy [4]. An analysis using the SIMMER code was performed to evaluate its feasibility, and the results showed fuel discharge behavior similar to that of FAIDUS [5]. We plan to proceed with the design of oxide fuel cores based on this new core concept.

For the metal-fueled core, we will continue the design study of a core concept that can be installed in the plant concept shown in FIG. 1. We expect that the technology accumulated in the United States will be useful for the irradiation performance and safety evaluation of the fuel. We are studying a metal-fueled core concept that can meet the Japanese design requirements through Japan-U.S. collaboration.

3. CONCLUSION

We formulated a design concept of a demonstration pool-type SFR and an overall plan for the conceptual design and related R&Ds in line with the specific consideration of fuel technology to be conducted in 2026 and the decision to move to basic design phase in 2028, as indicated in the strategic roadmap for fast reactor development in Japan. We then started design and R&Ds in accordance with this plan.

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