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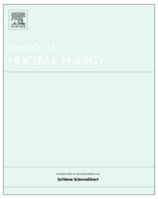

Core design for super fast reactor with all upward flow core cooling

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ABSTRACT

A 1000 MWe level supercritical-pressure light water-cooled fast reactor (Super FR) is proposed in this paper. The newly improved features include two flow paths which both applies upward flow pattern. Compact lattice of MOX fuel pins are arranged in hexagonal seed assembly while blanket assembly comprised of depleted UO_2 fuel pins wrapped with solid moderator ZrH layer for negative void reactivity. This core design includes 162 seed assemblies and 73 blanket assemblies with 1.7 cm of solid moderation layer of ZrH, the core active height is 3.6 m. The axial coolant density distribution of the core is far from uniform due to the all upward flow pattern, however, by applying axial Pu enrichment zoning and new loading and refueling scheme, flattened power distribution is obtained and all the design criteria as well as limitations have been fulfilled with significant delivery of high power density up to 237 kw/L, 500 °C average core outlet temperature, both whole core and local negative void reactivity.

1. Introduction

The supercritical-pressure light water-cooled reactor (SCWR) has been developed as promisingly innovative candidate in the G-IV reactor concept for its high thermal efficiency and simplification of the plant with respect to the capital cost. R&D activities are carried out for the past decades Numbers of conceptual design have been proposed both for thermal spectrum design (Cheng et al., 2003, 2008; Dobashi et al., 1998; Kamei et al., 2006; Liu and Cheng, 2009; Oka et al., 1992; Okano et al.,1994,1996; Yamaji et al., 2005a, 2005b; Yang et al., 2011), and fast spectrum concept (Jevremovic et al., 1993a, 1994; Mukohara et al., 1999; Yoo et al., 2006).

Supercritical-pressure light water-cooled fast reactor (Super FR) is functioning with relatively higher neutron energy spectrum which requires less amount of moderation so that the core design is compact in size with distinguishing higher power density for economic competitiveness. Meanwhile, MOX fuel loading with flexible design of LWR spent fuel is available with a potential for closed fuel cycle and breeding.

In the recent Super FR core design, tight lattice of the MOX fuel assembly in hexagonal geometry has been proposed with some blanket loaded in the core (Cao et al., 2008; Yoo et al., 2006). The blanket assembly is comprised of depleted UO_2 fuel and ZrH layer as solid moderator. One notable characteristic and design challenge for Super FR is the possible positive void reactivity coefficient during the loss of coolant. Blanket assembly is therefore capable of functioning not only to compensate the reactivity loss with burnup but also to perform neutron absorption and moderation while the coolant is lost. The in vessel flow path is also initiated for two paths for axially uniform coolant density and safety behavior during transient and accident.

Different flow schemes have been proposed with downward flow blanket assembly as 1st path while all the seed assemblies are in the 2nd path with up flow pattern. This design will help to establish more uniform coolant density axial distribution due to high density coolant in the blanket assembly (Yoo et al., 2006). In the improved design (Cao et al., 2008), some seed assemblies are moved to the 1st path from the 2nd path to improve the core behavior during transients and accidents. This design is proven by safety analysis (Ikejiri et al., 2010) to be effective to decrease the maximum cladding surface temperature (MCST) in the 2nd path during total loss of flow accident; it helps to maintain the flow by the coolant expansion from 1st path seed assembly. However, there are some issues remained from the aspect for flow stability and manufacture complexity, especially during loss of coolant accident and re-flooding process. The flow direction is against buoyancy which will hamper the heat transfer and flow during accidents. Meanwhile the downward flow path is very complicated for control rod element and in-vessel upper core structure. A new flow pattern with all upward flow has been suggested by the preliminary safety analysis (Ishiwatari and Wu, 2011); this flow scheme can significantly simplify the upper core structure from mechanical aspect and make it more realizable for the deployment of control rod mechanism. The intention of this flow pattern pursues better performance in the total loss of flow accident (no the leakage and loss of coolant from the loop, but loss of the driving force in the coolant flow, for example, main pump stuck). During

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this accident, core will automatically shut down to very low power level of decay heat, the flow driving force will simply depend on the coolant heating and natural circulation, therefore the flow rate is very low. The main function of the first path assembly during this accident is to maintain the flow better for the 2nd path where MCST occurs. The buoyancy of the first path coolant will be against the flow direction if it is downward cooled. Upward cooling in the first path can overcome this drawback and perform better flow stability. It is also suggested that decrease of the maximum linear heat rate of the fuel rod is necessary to satisfy the MCST criterion during this accident.

In this study, Neutronics coupled with thermal–hydraulics calculation is carried out for two flow path, all upward flow core design, maintaining high power density and negative void reactivity; it is observed that both the design target and limitations are satisfied.

2. Design goals and criteria

As previous SCWR and Super FR design characteristics, similar goals and criteria (Oka et al., 2010; Yoo et al., 2006) are employed as follow; goals:

1. The core should be around 1000 MWe class commercial scale.
2. Core average outlet temperature should be over 500 °C, which ensures approximately 44% thermal efficiency of the plant.
3. Core average power density should be above 100 W/cc and the core has to be non-flat shape.
4. Average fuel assembly discharge burn-up around 60 MWd/kgHM.

The discharge burn-up is slightly lower with the previous work due to the concern of void reactivity because the most severe case occurs at EOC when blanket fuel has been bred up and contributed more reactivity than BOC. Decease of the discharge burn-up can significantly benefit the core performance in terms of void reactivity at EOC.

Criteria for nominal condition core design is further updated based on the feedback information from preliminary safety analysis (Ishiwatari and Wu, 2011; Okumura et al., 2007), same fuel rod design is applied with no remarkable modification so that all the criteria for fuel rod design still apply.

1. Fuel centerline temperature should be below 1900 °C.
2. Maximum linear heat rate should be further lower than 39 kW/m.
3. Maximum cladding surface temperature should be below 650 °C at normal condition.
4. Negative void reactivity while overall and local void occurs.

3. Design methodology

The code system used for the design is based on the SRAC, ASMBURN, and COREBN code system developed by JAEA (Okumura, 2002). Script files on C shell and awk language as well as perl language was developed for the assembly branch-off calculation, core geometry generation, whole core pin-power reconstruction, equilibrium cycle search etc. as well as the thermal–hydraulic coupling with single channel code SPROD (Han, 2010).

The macro cross-section of seed and blanket assembly are prepared in various coolant densities and fuel temperature as tabulation for the core calculation meanwhile Heterogeneous Form

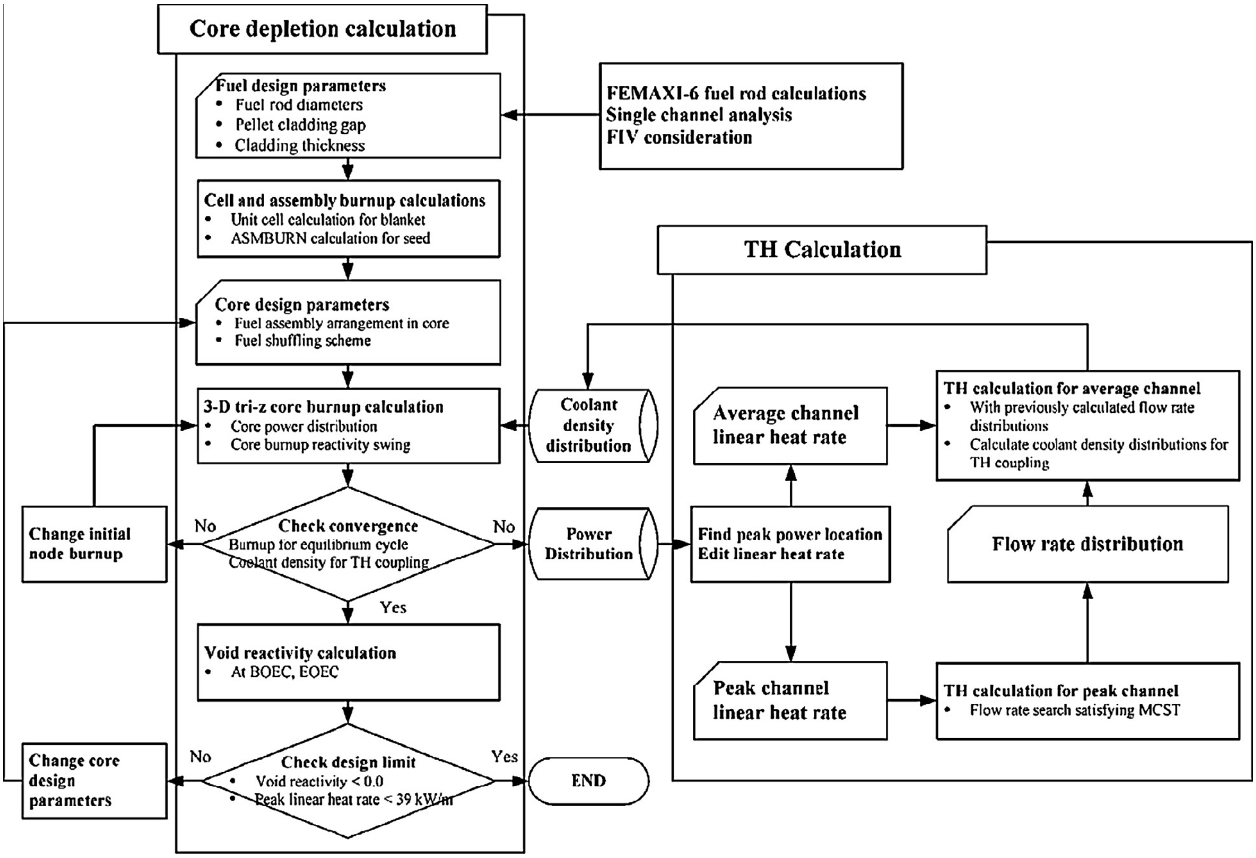

Fig. 1. Code system for the core design (based on single channel T–H coupling).