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Safety performance of the 4S reactor on the ATWS events − statistical estimation of uncertainty

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Abstract

4S reactor is a sodium-cooled fast reactor developed as a small-decentralized power supply. The name of "4S" in this reactor stands for Super-Safe, Small and Simple, and they show representative features of the reactor.

The purpose of the present work is to evaluate quantitatively the super-safety of 4S reactor, and the safety performance is analyzed with ARGO-3, which is a plant dynamics code of a sodium-cooled fast reactor.

In this evaluation, some events, such as Unprotected Loss of Flow (ULOF) and Unprotected Transient Overpower (UTOP), are selected as typical cases from various transients and accidents. After metrics concerned with safety design is defined for each event, it is evaluated with statistical methods whether each metric satisfies acceptance criteria in a given criteria level.

Result about ULOF is as follows. The coolant temperature in the nominal hottest assembly outlet, "T_c" is selected as metric, and the upper side value of 95% confidential section in T_c is below 900 °C that is acceptance criteria. Also in UTOP, it is shown that the fuel maximum temperature in the nominal hottest assembly, "T_f" satisfies acceptance criteria. This result shows that 4S reactor has margin for safety acceptance criteria.

Keywords: 4S; ARGO-3; Uncertainty analysis; Sensitivity analysis; ULOF; UTOP

1. Introduction

4S reactor (Ueda et al., 2003; Yokoyama et al., 2003) is a sodium-cooled fast reactor developed as small-decentralized power supply, and the conceptual design has been done so far. The name of "4S" in this reactor stands for Super-Safe, Small and Simple, and they show representative features of the reactor. The detailed main features are described in Section 2.

The purpose of present work is to evaluate quantitatively the super-safety of 4S reactor, and the safety performance is analyzed with ARGO-3, which is a plant dynamics code of a sodium-cooled fast reactor and has been developed by Toshiba. In this paper, two transient events are selected as typical cases of analysis from various Design Based Events (DBEs) and Beyond DBEs (BDBEs). Those are Unprotected Loss of Flow (ULOF) and Unprotected Transient Overpower (UTOP) classified as Anticipated Transient without Scram (ATWS). Authors have carried out the analyses under an unrealistic severe condition of ULOF, in which case it was shown that 4S reactor had margin for safety acceptance criteria (Horie et al., 2006). In the present paper, results under more realistic conditions are shown.

The purpose of estimation is to show that even if the uncertainty of input parameters, that is uncertainty width, is taken into consideration, the upper or lower side value of metric at a given confidence level is within acceptance criteria.

2. 4S reactor system

4S reactor is a small and simple reactor with various functions based on a safety concept for system design. Fig. 1 is a bird's-eye view of the reactor. The life of fuel is designed to be 30 years by the use of long metallic fuel pins, which have high thermal conductivity and low enthalpy, and a dense core configuration. The slim cylindrical shaped core, which is

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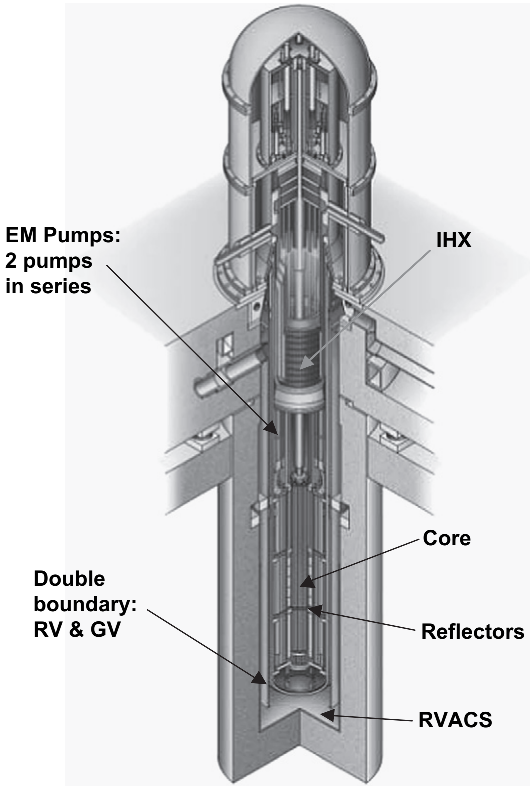

Fig. 1. Core and equipments around core.

2.5 m in length and 0.94 m in effective diameter, serves the negative coolant reactivity feedback.

4S reactor uses a reflector to control criticality. The reflector surrounds the core and moves upward at approximately 1 mm/week in order to compensate for reactivity loss through the 30 years' burn-up. In the reactor accident, the reflector descends to render the core sub-critical.

Electromagnetic pumps (EMP) and intermediate heat exchanger (IHX) are arranged in the upper part of the reactor vessel. Both are annular in shape, therefore the primary coolant flows in the annular region in the IHX and EMP. The guard vessel (GV) is put on the circumference of the reactor vessel (RV). Hence, the double vessels protect the primary coolant from leakage.

There is the reactor cavity surrounding the guard vessel, so called Reactor Vessel Auxiliary Cooling System (RVACS). RVACS is a flow path to remove heat from the primary system. RVACS has no active components and utilizes only natural circulation. This is one of passive safety functions.

3. Analysis models of ARGO-3 code

ARGO-3 code is used to estimate the safety performance of the fuel pins, the primary coolant boundary under the main DBEs and their state under BDBEs such as ATWS. The main DBEs include a change of heat removal by Balance of Power (BOP), a change of flow in the primary or secondary coolant systems, anticipated reactivity insertion at full power operation or start-up, and loss of power. In order to calculate the fuel cladding and primary coolant boundary temperatures, the plant transient status must be modeled with sufficient precision.

ARGO-3, which uses the flow network model, describes the equation of motion in one dimension with the balance of pump head, the natural convection head, and pressure loss. This model includes both the flow distribution in the reactor core and the flow in the heat exchanger. The main flow network model is shown in Fig. 2.

The core is described as multi-channels. Each channel has one pin, which represents the many fuel pins enclosed in each wrapper duct. Each flow in the channel receives heat from fuels and wrapper duct and joins at the channel exit. At this time, a heat flow in the core is dealt not only in the axial direction but also in the radial direction. That is, the heat flow in the radial direction is considered with thermal conduction between channels. The fuel, cladding and coolant in the core are divided in axial direction, while the fuel pellet is further divided into the radial direction meshes.

This code describes the fuel pin under a specific thermal condition such as the hottest pin in the core. The hottest pin

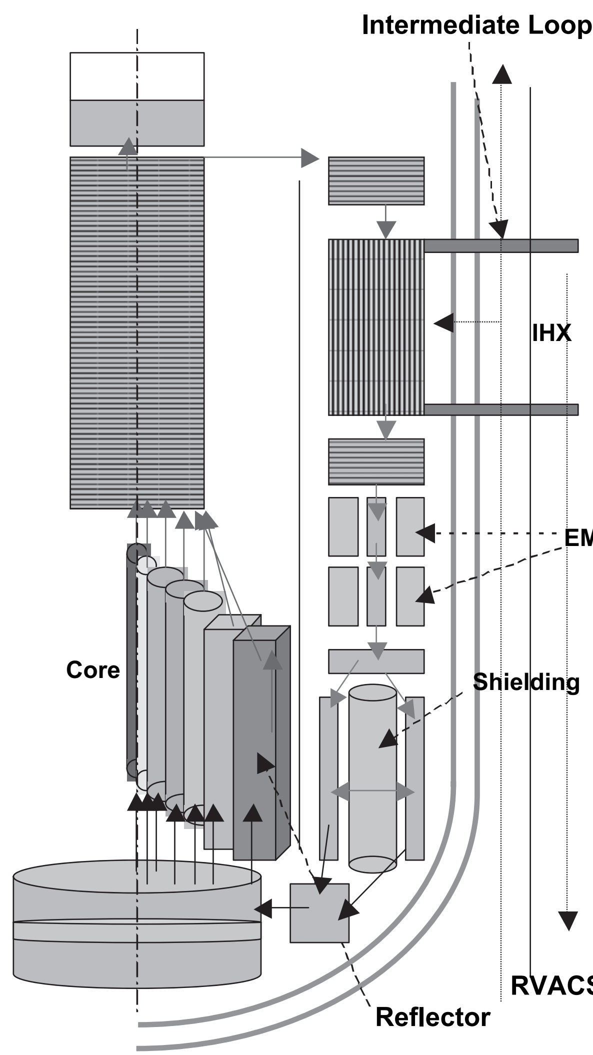

Fig. 2. Network model of ARGO-3 code.