Development of BWR Regional Stability Experimental Facility SIRIUS-F, which Simulates Thermalhydraulics-Neutronics Coupling in Reactor Core, and Stability Evaluation of ABWR

Background

In BWRs, the reactor power is suppressed when the amount of steam bubbles (voids) increases in the core (void-reactivity feedback). The feedback may cause self-sustained oscillations depending on the core design and operating conditions. There are core-wide instability (in-phase oscillation) and regional instability (out-of-phase or first azimuthal mode oscillation). Current BWRs are designed and operated to prevent those instabilities from occurring.

Stability estimation methods were reassessed according to the experiences such as core-wide instability observed at La-Salle 2 plant in the United States and regional instability, which occurred at Caorso plant in Italy. Currently, BWRs are designed and operated on the basis of stability analyses by the developed stability estimation methods. These analyses are validated with instability events observed at power plants and experimental data from out-of-pile thermal-hydraulic loops, which ignore void-reactivity feedback. It is of importance to build an out-of-pile experimental facility which simulates void-reactivity feedback to yield wide range of experimental database to validate analysis code.

Objectives

This study is intended to develop an experimental facility to simulate channel, core-wide and regional stabilities, and to evaluate stabilities of the ABWR for validation of design stability analysis code, ODYSY for a wide range including conditions for the licensing.

Principal Results

(1) Development of Stability Estimation Method

The SIRIUS-F facility was designed and constructed for highly accurate simulation of channel, core-wide and regional instabilities of an ABWR. A real-time simulation is performed for modal-point kinetics of reactor neutronics and fuel-rod conduction on the basis of measured void fractions in a reactor core section of the thermal-hydraulic facility (Fig-1). Two tie plates and seven spacers were installed in the facility at the same location of a commercially employed 9×9A fuel. The pressure profile of thermal-hydraulic facility along the flow direction agrees with that of the 9×9A fuel (Fig-2).

A noise analysis method was performed to calculate stability indexes (decay ratios and resonance frequencies) from dominant poles of transfer function on the basis of the AR method by applying time series of a core inlet flow rate. The online analysis allows us to obtain stability indexes directly in any operating conditions without assuming hypothetical conditions.

(2) Thermal-hydraulic stability including the licensing conditions

Channel stability experiments were conducted for a wide range of operating conditions including maximum power points along the minimum pump speed line and the natural circulation line. The decay ratio and the resonance frequency of the experiments are in good agreement with analytical results by ODYSY (Fig-3). The SIRIUS-F facility is the first out-of-pile facility to estimate the decay ratio as an index of the stability for code validation, while stability boundary is only obtained as an index obtained in the other facility.

(3) Thermalhydraulic-neutronic coupling stability including the licensing conditions

Core-wide and regional stability experiments were conducted with artificial void reactivity feedback including maximum power points along the minimum pump speed line and the natural circulation line (Fig-4). The regional stability was observed, which is the least stable mode. There is a distinct peak of the cross correlation function with a negative value observed at delay time of 0s. Therefore, regional mode was exited rather than core-wide mode.

The decay ratio and the resonance frequency of the experiments are in good agreement with analytical results by ODYSY (Fig-4).

In conclusions, although available stability data from the operating reactors are limited, the SIRIUS-F facility is the first out-of-pile facility which enables us to evaluate stability of BWR for wide range of operating conditions accurately and systematically to validate design stability codes.

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Reference

M. Furuya and F. Inada, "BWR Regional Stability Estimation using SIRIUS Facility with Noise Analysis Technology," Proc. Tenth International Meeting on Nuclear Reactor Thermal-Hydraulics, A503 (CD-ROM Publication), Seoul, Korea, October 5-9,2003.

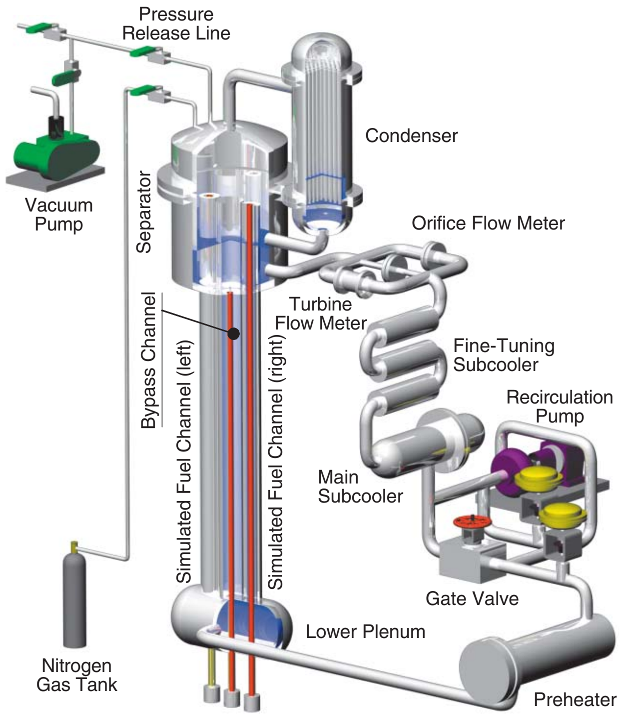

Fig.1 Thermal-hydraulic Loop of SIRIUS-F Facility
13m-high SIRIUS-F facility is designed to simulate boiling two-phase flow accurately in reactor core of ABWR.

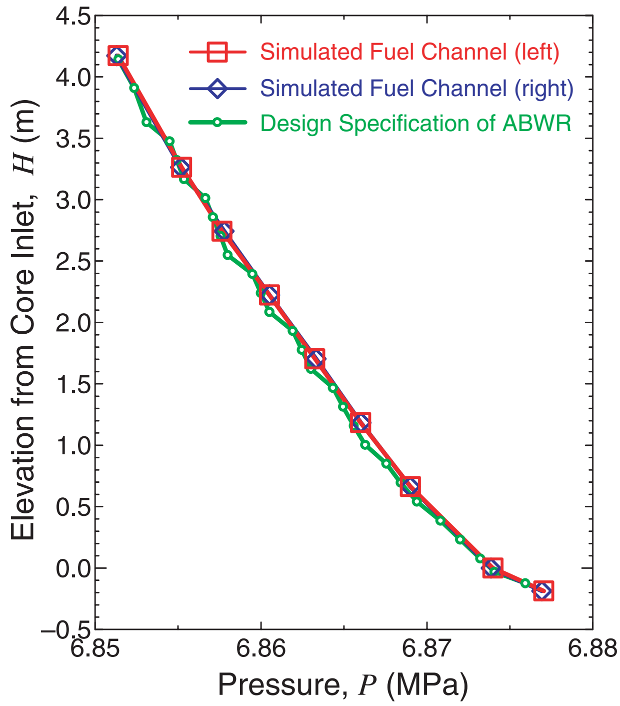

Fig.2 Comparison of Pressure Profile
Pressure profile is sensitive for stability estimation. Pressure profile of the SIRIUS-F facility is in good agreement with that of ABWR.

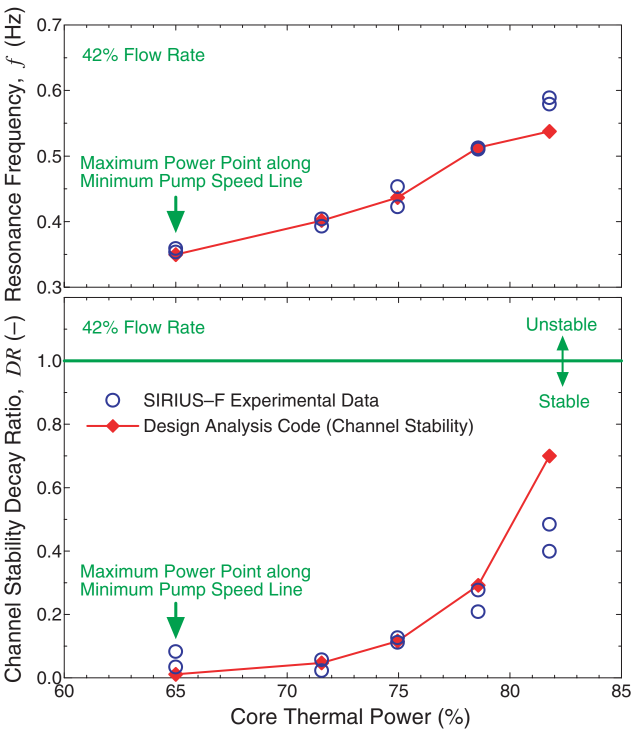

Fig.3 Channel Stability Results
Experiments were conducted with fix power level. The results of design analysis code agree with those of experimental results.

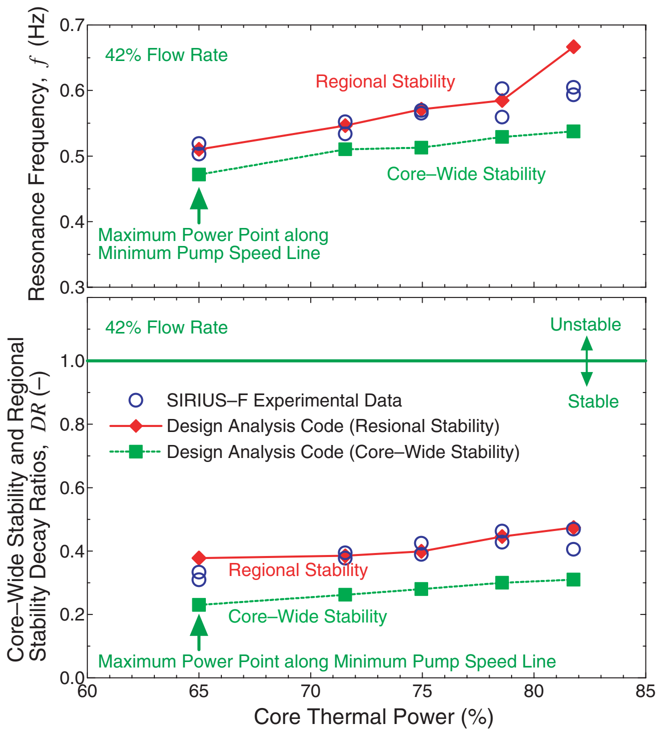

Fig.4 Core-Wide and Regional Stability Results
Experiments were conducted with artificial neutronic feedback. The results of regional stability by the code agree with those of experimental results.