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Validation of PT-CT Contact Model of CAISER Code with Separate Effect Test

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1. Introduction

In order to develop and validate computer codes aimed at designing and analyzing the safety of nuclear power plants, the International Atomic Energy Agency (IAEA) has organized International Collaborative Standard Problems (ICSPs). These ICSPs typically encompass both experimental investigations into relevant phenomena and the simulation of these experiments using computer codes.

As a specific example of an ICSP, the IAEA-TECDOC-1890 [1] addresses the utilization of heavy water moderator as a backup heat sink during accidents. The primary objective of this ICSP was to furnish thermomechanical experimental data regarding the collective behavior of the pressure tube (PT) and the encompassing calandria tube (CT) when the overheated PT comes into contact with the moderator-cooled CT. To tackle this ICSP, an experiment was executed at the Canadian Nuclear Laboratories (CNL), and the resulting data were subsequently employed as a benchmark.

In this particular study, the ICSP experiment serves as a benchmark for validating the PT-CT contact model within the CAISER [2, 3] (CANDU Advanced Integrated SEveRe accident code) framework, which was developed by the Korea Atomic Energy Research Institute (KAERI).

2. ICSP Experiment in CNL

2.1 Test Facility

CNL's Chalk River Laboratories possess an experimental facility dedicated to the examination of CANDU fuel channels under hypothetical accident scenarios. The experimental setup comprises a test section composed of a 1750 mm long Zr/2.5Nb PT and a 1700 mm long Zircaloy-2 CT.

This test section is encompassed by heated distilled light water, contained within an open tank measuring 750 mm in height, 1425 mm in length, and 600 mm in width.

For the purpose of emulating a fuel rod, a uniformly sized graphite rod heater with a diameter of 38 mm was employed. The arrangement of the test facility and the locations of its thermocouples are illustrated in Fig. 1 and 2.

Table I: Diameters of PT, CT and heater rod

Component	I. D. [mm]	O. D. [mm]	Thickness [mm]
PT	103.8	112.4	4.40
CT	129.4	132.2	1.42
Heater rod		38	

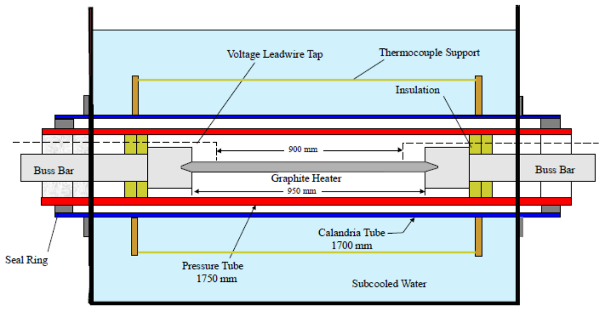

Fig. 1. Test facility for ICSP test

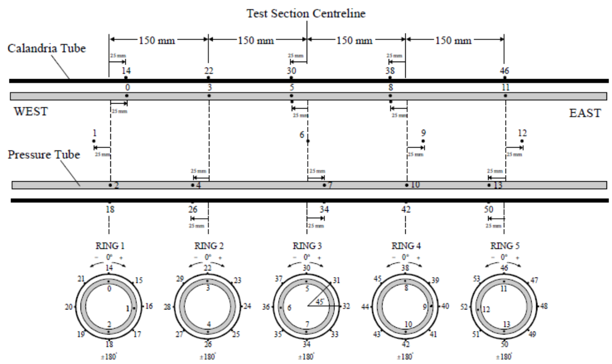

Fig. 2. Thermocouple location of test facility

2.2 Experimental Procedure

The targeted test conditions are presented in Table II. The average internal pressure within the test section was 3.5 MPa throughout the duration of the test, with automated pressure control. Following the pressurization of the interior of the PT, an average electric power of 164 kW/m was applied to the graphite heater. The temperatures of both the PT and CT were measured at five distinct axial positions, as illustrated in Fig. 2. The test concluded after 160 seconds.

Table II: Target Test Conditions

Test pressure	Heater power	PT heat-up rate	Subcooling
3.5 MPa(g)	140 kW	20 ℃/s	30 ℃

3. Computational Methods and Results

3.1 Implementation of Test Condition to CAISER

CAISER is comprised of two distinct modules: a fuel channel module and a calandria tank module. Within the fuel channel module, a fuel rod is discretized into two dimensions denoted as [m][n]. In alignment with the nodalization of the fuel rod, the PT and CT are divided with the notation of [h]. In addition to these cross-sectional nodalization schemes, CAISER longitudinally divides the two modules using the notation [k].

The fuel rod was divided into a 2x3 grid to correspond with the positions of experimental thermocouples. Accordingly, the PT and CT has 5 nodes (0 to 4) as shown in Fig. 3. The input file for CAISER, encompassing both initial and boundary conditions, was created by referencing [1].

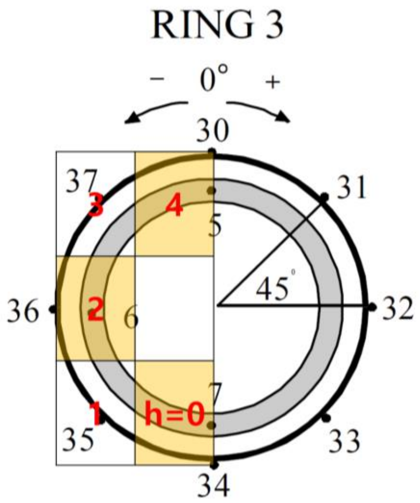

Fig. 3. Thermocouple positions of experiment (numbers on dots) and fuel channel node structure of CAISER (h)

3.2 Comparison of Simulation Results with Experiment

The temperature profiles of the PT and CT from both the experiment and simulation results are displayed in Fig. 4. It is evident that CAISER accurately predicts the experimental temperature trends up to the 73-second mark. However, subsequent to this point, a significant temperature disparity between the PT and CT is observed in the experiment, while the simulation demonstrates only minor deviations. This discrepancy is attributed to the omission of contact conductance [4, 5] in the present analysis.

PT-CT contact was established between the 71 to 75-second interval in the experiment, and in the simulation, it occurred at the 73-second mark. To model the PT-CT contact, Shewfelt's correlation [3, 6] was integrated into CAISER as a deformation model for the PT. This correlation encapsulates the relationship between creep rate and the applied stress on the PT.

The temperatures of the water within the tank surrounding the PT and CT, as observed in both the experiment and simulation results, are depicted in Fig. 5. CAISER appropriately replicates the measured temperature profiles.

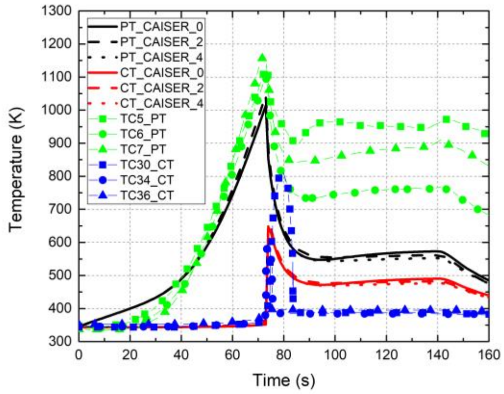

Fig. 4. Temperature of PT and CT

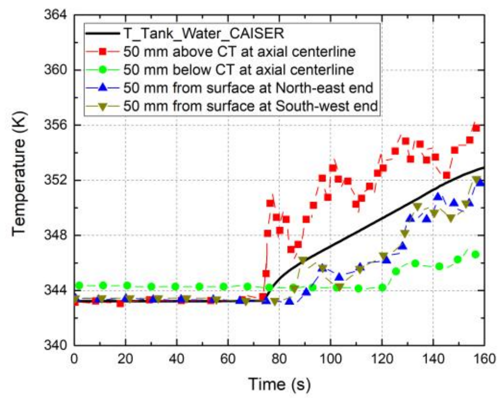

Fig. 5. Temperature of water in the tank surrounding PT and CT

4. Conclusions

In order to validate the PT-CT contact model that has been integrated into CAISER, a benchmark simulation utilizing the IAEA ICSP test was carried out. The simulated temperature profiles of the fuel channel and the encompassing water closely aligned with the experimental results. To enhance the performance of the CAISER code, the incorporation of an additional contact conductance model is under consideration.

ACKNOWLEDGEMENT

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