ENCLOSURE 2

MFN 03-142

Response to NRC RAI number (25) – Additional Supplementary Information

Non-proprietary

Errata for NEDC-33080P			
No.	Location	Original	Revised
1	Section 1, p. 1-1, 1st paragraph, 1st sentence	This report describes qualification studies of the TRACG computer code performed for the European Simplified Boiling Water Reactor (ESBWR).	This report describes confirmatory qualification studies of the TRACG computer code performed for the ESBWR.
2	Section 1, p. 1-1, 3rd paragraph, 1st sentence	The present report documents two additional validation studies performed specifically in support of the ESBWR.	The present report documents two confirmatory validation studies performed for the ESBWR.
3	Section 1, p. 1-1, 3rd paragraph, last sentence	The CRIEPI/SIRIUS tests extended the previous CRIEPI investigation of hydrodynamic instability at low pressure to cover the pressure range from ESBWR startup to full-power operation.	The CRIEPI/SIRIUS tests augmented the previous CRIEPI investigation of hydrodynamic instability at low pressure to confirm the application of TRACG over the pressure range from ESBWR startup to full-power operation.
4	Section 1, p. 1-1, 4th paragraph	(Add sentence to end of paragraph.)	The thermal-hydraulic phenomena of importance to the performance of the ESBWR were identified in the PIRT Tables provided in the ESBWR TAPD [1-3]. No additional phenomena of importance were identified for the ESBWR relative to the earlier SBWR study. Thus the existing data base that was available for the SBWR program is sufficient for the validation of TRACG for the ESBWR as well.

Errata for NEDC-33080P			
5	Section 2.1, p. 2-1, 2nd paragraph, 1st sentence	To support the extension of the TRACG qualification activity to the ESBWR, an ESBWR-specific PANDA test program was performed.	To confirm the application of the TRACG SBWR qualification activity to the ESBWR, an ESBWR-specific PANDA test program was performed.
6	Section 2.2, p. 2-3, 3rd paragraph, 3rd sentence	Subsequent tests incorporated variations of key parameters and addressed specific thermal-hydraulic phenomena which are considered to be of potential importance for calculation of long-term post-LOCA behavior in the ESBWR.	Subsequent tests incorporated variations of key parameters and addressed specific thermal-hydraulic phenomena that are relevant to the confirmation of TRACG qualification for the calculation of long-term post-LOCA behavior in the ESBWR.
7	Section 2.3.3, p. 2-11, 1st paragraph, 1st sentence		
8	Section 2.6.1, p. 2-30, 3rd paragraph, 1st sentence		
9.	Section 2.6.2, p.2-31, 1st paragraph, 4th and 5th sentences		

Errata for NEDC-33080P			
10	Section 3.1, p. 3-1, 1st paragraph, last sentence	The study described here was undertaken to provide a qualification basis for the use of TRACG to predict two-phase flow instability at higher pressures.	The study described here was undertaken to provide a confirmatory qualification basis for the use of TRACG to predict two-phase flow instability over the ESBWR pressure range.
11	Section 3.1, p. 3-1, 2nd paragraph, 6th sentence	The objective was to extend the TRACG qualification base for prediction of thermal-hydraulic oscillatory conditions in a natural circulation reactor from startup to normal operation.	The objective was to confirm the application of TRACG for prediction of thermal-hydraulic oscillatory conditions in a natural circulation reactor from startup to normal operation.
12	Section 3.7, p. 3-6, 2nd paragraph, last sentence	The results of these comparisons show that TRACG is capable of predicting the dependence of the oscillation characteristics (amplitude and period) on the relevant system parameters.	The results of these comparisons confirm that TRACG is capable of predicting the dependence of the oscillation characteristics (amplitude and period) on the relevant system parameters.
13	Section 3.7, p. 3-6, 4th paragraph, 1st sentence	The results of these simulations, together with those presented in References 3-8 and 3-9, show that TRACG is capable of predicting thermal-hydraulic instabilities, including geysering, flashing-induced instability at low system pressure and density wave oscillation at relative high system pressure.	The results of these simulations, together with those presented in References 3-8 and 3-9, confirm that TRACG is capable of predicting thermal-hydraulic instabilities, including geysering, flashing-induced instability at low system pressure and density wave oscillation at relatively high system pressure.

1. INTRODUCTION

This report describes confirmatory qualification studies of the TRACG computer code performed for the ESBWR.~~This report describes qualification studies of the TRACG computer code performed for the European Simplified Boiling Water Reactor (ESBWR).~~ It supplements the material in the generic TRACG qualification report [1-1] and the TRACG qualification report for the SBWR [1-2]. Computer code qualification, as defined at GE Nuclear Energy, incorporates the process of validation of the code against data or alternate engineering calculations. Validation is part of the process of "qualifying" the computer code for design application. 1

The generic TRACG qualification report [1-1] includes a comprehensive collection of TRACG qualification studies applicable to BWR-related separate effects, component, integral system and reactor tests These tests cover a wide range of phenomena and configurations representative of BWR conditions for loss-of-coolant accidents (LOCAs), operational transients and density wave oscillation. Most of these test data are also applicable to the ESBWR, as discussed in the ESBWR Test and Analysis Program Description (TAPD) [1-3]. Reference 1-2 supplemented the TRACG generic qualification by documenting an extensive set of validation studies performed as part of the earlier SBWR program. All of the Reference 1-2 studies are considered to be directly applicable to the ESBWR [1-3].

The present report documents two confirmatory validation studies performed for the ESBWR.~~The present report documents two additional validation studies performed specifically in support of the ESBWR.~~ The test data used for these studies are from the P-series containment tests performed at the PANDA test facility in Switzerland and from the elevated-pressure hydrodynamic instability tests performed at the CRIEPI/SIRIUS test facility in Japan. The PANDA P-series tests extended the previous PANDA investigation of SBWR post-LOCA long-term containment cooling to confirm the post-LOCA performance of the higher-power ESBWR with its modified containment configuration. The CRIEPI/SIRIUS tests augmented the previous CRIEPI investigation of hydrodynamic instability at low pressure to confirm the application of TRACG over the pressure range from ESBWR startup to full-power operation.~~The CRIEPI/SIRIUS tests extended the previous CRIEPI investigation of hydrodynamic instability at low pressure to cover the pressure range from ESBWR startup to full-power operation.~~ 2 3

This report is one of several documents that provide the information necessary for the validation of the TRACG computer code and its application for ESBWR design analysis. The relationship of this report to the generic TRACG qualification report [1-1] and the SBWR qualification report [1-2] was addressed above. The other relevant reports are the ESBWR Test and Analysis Program Description [1-3], the ESBWR Test Report [1-4], the ESBWR Scaling Report [1-5], the TRACG Model Description [1-6], and the TRACG Application for ESBWR [1-7]. A unifying element of the ESBWR documentation is reference to a set of "PIRT" phenomena that have been judged to be of significance for the calculation of ESBWR safety parameters. The PIRT acronym derives from the Phenomena Identification and Ranking Tables that are used to identify and prioritize the phenomena in relation to the safety parameters. The thermal-hydraulic phenomena of importance to the performance of the ESBWR were identified in the PIRT Tables provided in the ESBWR TAPD [1-3]. No additional phenomena of importance were identified for the 4

ESBWR relative to the earlier SBWR study. Thus the existing data base that was available for the SBWR program is sufficient for the validation of TRACG for the ESBWR as well.

TRACG is being qualified for ESBWR licensing analyses of operational transients, LOCA-ECCS and LOCA-containment. A detailed description of the application methodology is provided in Reference 1-7. There are differences in the application approach for the three types of events. Operational transients are being addressed within the framework of the Code Scaling, Applicability and Uncertainty (CSAU) methodology [1-8]. For LOCA-ECCS, the CSAU process will be followed to identify the uncertainties in the TRACG models, correlations and parameters

2. PANDA TRANSIENT TESTS P1-P8

2.1 Introduction

Reference 2-1 describes a comprehensive qualification of the TRACG computer code [2-2 and 2-3] for analysis of the SBWR. A major element of the TRACG SBWR qualification program was a series of integral systems tests performed in the PANDA test facility at the Paul Scherrer Institute (PSI) in Switzerland. The PANDA facility was designed to model the long-term cooling phase of the SBWR LOCA. It includes the Passive Containment Cooling System (PCCS), the Isolation Condenser System (ICS) and the Gravity Drain Cooling System (GDCS). The SBWR test matrix (known as the M-series) included, in addition to a design-basis LOCA simulation, a series of tests designed to challenge both the performance of the passive safety systems and the ability of TRACG to predict that performance. The most significant conclusion from the SBWR PANDA qualification activity [2-1] was that TRACG accurately calculates post-LOCA containment pressurization and is well-suited to the calculation of post-LOCA containment transients involving interactions between the passive safety systems.

To confirm the application of the TRACG SBWR qualification activity to the ESBWR, an ESBWR-specific PANDA test program was performed.~~To support the extension of the TRACG qualification activity to the ESBWR, an ESBWR-specific PANDA test program was performed.~~ The PANDA facility was modified to represent the ESBWR and a test matrix, designated as the "P-series", was defined. The P-series consisted of eight transient tests representing design-basis and beyond design-basis post-LOCA conditions [2-4]. The purpose of this section is to present the results of TRACG post-test calculations for the P-series tests as an extension to the qualification reported in Reference 2-1. The post-test analyses of the transient tests were performed by an ESBWR PANDA analysis team, with participation from PSI in Switzerland, where the tests were conducted, and the General Electric Company (GE) in the United States. The calculations were performed with the TRACG04 version of the code. 5

The remainder of this section is organized as follows. Section 2.2 presents a brief description of the PANDA test facility and the P-series test matrix. Section 2.3 discusses the applicability of the PANDA transient data to the ESBWR and includes a rationale for each of the P-series tests. Section 2.4 provides a description of the PANDA TRACG input model used for the post-test analyses. For each test, there is a summary table of the measured thermodynamic conditions at the start of the test which were used for the initialization of the various components in the TRACG model. Section 2.5 presents the results of the post-test calculations on a test-by-test basis and includes a quantitative evaluation of the accuracy of the TRACG predictions. Section 2.6 discusses the results of the study with reference to key ESBWR phenomena and presents a final set of conclusions.

2.2 Test Facility and Test Matrix

The PANDA test facility was originally designed to model the long-term cooling phase of the loss-of-coolant accident (LOCA) for the SBWR. In its original configuration, it was a 1/25 volume-scaled, full-height simulation of the SBWR primary system and containment and included the major components necessary to simulate the SBWR system response during the long-term phase of the LOCA. These components include the containment drywell (DW), the cooling phase and represents the starting point for most of the PANDA simulations of ESBWR post-LOCA behavior.

The long-term cooling phase of the LOCA is defined as starting at one hour from the occurrence of the break. Conditions at this time in the LOCA transient were derived from ESBWR TRACG calculations. The calculations show that the one-hour thermodynamic conditions throughout the system are relatively stable. The effect of subcooling of RPV water by GDCS injection is just on the verge of being overcome by the decay power. The pressure difference between the RPV and DW is just sufficient to maintain flow of the boiloff steam through the break and the open depressurization valves. To remove the energy added to the DW, the PCCS must first purge residual noncondensable gases from the DW to the WW and, accordingly, the pressure difference between the DW and WW is just sufficient to clear the PCC vents.

One of the compromises made in the original design of the PANDA test facility was to not scale the volume of water available to replace boiloff in the SBWR and, by extension, the ESBWR PCCS. In the ESBWR, this volume, which extends outside the individual PCC pools, is sufficient to maintain coverage of no less than 50% of the condenser tube length for 72 hours. In PANDA, only the water in the four individual pools (three PCC pools and one IC pool) is available to replace boiloff. Capability was originally provided to either interconnect or isolate the individual pools and to provide replacement water through fittings in the pool bottoms. It was subsequently decided that the ability to directly assess individual PCC and IC heat transfer through the boildown of the individual pools outweighed the advantage of allowing refill from the pools for condenser units (typically, the IC) that were not in service for a given test. With the exception of Test P1/8, the duration of the P-series tests was short enough to preclude uncovery of the condenser tubes by pool boildown.

The P-series test matrix is described in detail in Reference 2-4. Test Pl was a base-case simulation of the ESBWR LOCA long-term cooling phase following a MSLB. Subsequent tests incorporated variations of key parameters and addressed specific thermal-hydraulic phenomena that are relevant to the confirmation of TRACG qualification for the calculation of long-term post-LOCA behavior in the ESBWR.~~Subsequent tests incorporated variations of key parameters and addressed specific thermal-hydraulic phenomena which are considered to be of potential importance for calculation of long-term post-LOCA behavior in the ESBWR.~~ Test P2 was configured to start at an earlier time in the transient and provided data during the transition from the GDCS injection phase to the long-term cooling phase. Test P3 demonstrated PCCS start-up capability with initially non-condensable-filled DW vessels and PCC units, representing the upper limit of initial DW noncondensable inventory. In addition, Test P3 examined the influence of asymmetric distributions of steam and air in the DW on the startup and long-term performance of the PCCS by releasing all of the RPV steam to DW2. To further challenge the system, the PCC unit on DW1 was valved out of service. Test P4 included the delayed release of non-condensable gas into the DW to simulate the effect of noncondensable hideout in regions of the ESBWR DW that are not directly exposed to mixing by the steam jets emanating from the RPV. Test P5 was similar to Test P4 but further challenged the system by valving one of the PCC units out of service. Test P6 considered system interaction effects associated with parallel operation of the PCCS and ICS and the effect of a postulated direct bypass of steam from the 6

DW to the WW air space. Test P6 was started with the Isolation Condenser (IC) in operation in parallel with the PCCs. Later in the test, a DW-to-WW leakage path was opened to simulate a possible steam bypass. At a still later time, the IC was valved out,

3. SIRIUS TWO-PHASE FLOW INSTABILITY TESTS

3.1 Introduction

A potential concern during the design of the ESBWR [3-1, 3-2] was the startup process. The design uses a chimney installed on the top of the core to enhance the natural circulation core flow. Experiments have shown that hydraulic oscillations can occur under low pressure and low power conditions during the startup process of a natural-circulation reactor. These hydraulic oscillations include geysering [3-3], flashing-induced instability at low system pressure (0.1 – 0.5 MPa) [3-4], and density wave oscillation at relatively high system pressure (1.0 – 7.2 MPa) [3-5]. In previous studies, TRACG has been successfully qualified against test facility and plant stability data [3-6 and 3-7]. TRACG has also been qualified against geysering data and flashing induced instability data at low system pressure [3-8, 3-9, 3-10]. The study described here was undertaken to provide a confirmatory qualification basis for the use of TRACG to predict two-phase flow instability over the ESBWR pressure range.~~The study described here was undertaken to provide a qualification basis for the use of TRACG to predict two-phase flow instability at higher pressures.~~ 10

TRACG analyses were performed to simulate the two-phase flow instability data at relatively high pressure from the SIRIUS loop at the Central Research Institute of the Electric Power Industry (CRIEPI) in Japan. The SIRIUS loop was designed to investigate thermal-hydraulic instabilities in natural-circulation BWRs. In previous qualification studies, TRACG has been qualified against stability data from operating plants and test facilities, including flashing-induced instability data at low pressure from the SIRIUS test facility [3-10]. The TRACG comparisons described here include the dependence of the amplitude and period of the oscillations on heat flux, inlet subcooling and system pressure. Comparisons are also made in terms of stability maps in the plane of inlet subcooling versus heat flux. The objective was to confirm the application of TRACG for prediction of thermal-hydraulic oscillatory conditions in a natural circulation reactor from startup to normal operation.~~The objective was to extend the TRACG qualification base for prediction of thermal-hydraulic oscillatory conditions in a natural circulation reactor from startup to normal operation.~~ 11 The evaluation includes a comparison between the nominal operating condition of the ESBWR and the measured stability map at a system pressure of 7.2 MPa to demonstrate the margin to instability in terms of inlet subcooling.

3.2 Test Facility and Test Matrix

The SIRIUS test facility was constructed at CRIEPI in Japan to investigate thermal-hydraulic instabilities in BWRs. The test facility was based on non-dimensional scaling of the original SBWR design [3-1] with 70% of the chimney height of the prototype. A schematic of the SIRIUS test facility is shown in Figure 3-1. The test loop consists of two electrically heated channels (1.7-m high), chimney (5.4-m high), separator (upper plenum), downcomer, preheater and subcooler. The total length of the downcomer section is about 30 m. Water temperature at the channel inlet was measured by thermocouples and the flow rate was measured by an orifice flow meter [3-4].

Detailed measurements of the pressure drop across different sections of the test loop under forced liquid flow conditions were previously performed at the SIRIUS test facility in order to obtain local loss coefficients. The test facility is divided into eight regions (see Figure 3-1) and agreement between the TRACG results and the data. The key results and conclusion from these comparisons are summarized below.

For cases with sinusoidal oscillations, the shape and amplitude of the oscillations in inlet velocity and void fraction depend on inlet subcooling, heat flux and system pressure. Detailed comparisons between test observations and TRACG calculations were made for cases covering a wide range of inlet subcoolings at low, medium and high heat fluxes and medium and high pressures. The results of these comparisons confirm that TRACG is capable of predicting the dependence of the oscillation characteristics (amplitude and period) on the relevant system parameters.~~The results of these comparisons show that TRACG is capable of predicting the dependence of the oscillation characteristics (amplitude and period) on the relevant system parameters.~~ 12

The results of these simulations, together with those presented in References 3-8 and 3-9, confirm that TRACG is capable of predicting thermal-hydraulic instabilities, including geysering, flashing-induced instability at low system pressure and density wave oscillation at relatively high system pressure.~~The results of these simulations, together with those presented in References 3-8 and 3-9, show that TRACG is capable of predicting thermal-hydraulic instabilities, including geysering, flashing-induced instability at low system pressure and density wave oscillation at relative high system pressure.~~ These qualification studies demonstrate that TRACG can be used to analyze the thermal-hydraulic oscillatory conditions in a natural circulation reactor from start-up to normal operation. Based on comparison of the measured stability map to the ESBWR startup trajectory [3-15] and nominal operating condition (Figure 3-15), the SIRIUS test results support the conclusion that the ESBWR design has significant core inlet subcooling margin to the hydraulic instability region. 13