ENCLOSURE 2

MFN 04-059

Update of ESBWR TRACG Qualification for NEDC-32725P and NEDC-33080P Using the 9-Apr-2004 Program Library Version of TRACG04

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1.0 INTRODUCTION

Two TRACG qualification documents were submitted to the NRC in August of 2002 in support of the safety evaluation for the ESBWR:

NEDC-32725P, "TRACG Qualification for SBWR", Rev. 1, August 2002; and

NEDC-33080P, "TRACG Qualification for ESBWR", Rev. 0, August 2002.

The first of these reports was an update of a 1997 report that was originally prepared in support of the earlier SBWR design. It encompasses TRACG simulations of a large number of separate effects, component and integral systems tests that fulfilled the need to extend the qualification of TRACG to cover design and performance features of the SBWR. The report includes a comprehensive assessment of the relevant TRACG models and quantifies the model biases and uncertainties derived from comparisons between test data and code predictions. Although originally prepared for the SBWR, the qualification studies documented in NEDC-32725P are also applicable to the ESBWR. NEDC-33080P covers two confirmatory studies of TRACG qualification for: (1) a set of ESBWR-specific tests performed in the PANDA test facility in Switzerland (the P-series tests); and (2) a set of high pressure (2.0 and 7.2 MPa) flow stability tests performed in the CRIEPI/SIRIUS test facility in Japan.

The TRACG calculations presented in NEDC-32725P were made in the mid 1990s and those in NEDC-33080P were made in 2002. Most of the NEDC-32725P qualification studies and both of the studies in NEDC-33080P were performed with versions of TRACG04 that incorporated features of importance for application to the SBWR (e.g., condensation heat transfer in the presence of a noncondensible gas). A small number of the NEDC-32725P studies, for which these features were not essential, were performed with TRACG02. The purpose of this document is to present an updated subset of the qualification studies from NEDC-32725P and NEDC-33080P using the current GENE Program Library version of TRACG04. This will provide interim assurance that the conclusions drawn from the results presented in these two reports are still valid. Following the issue of the ESBWR Safety Evaluation Report (SER) for LOCA applications, the two qualification reports will be reissued on the basis of calculations using the final Program Library version of TRACG04.

The presentations in the succeeding sections of this document are arranged in the same sequence as in NEDC-32725P, i.e., separate effects tests, component performance tests, integral systems tests and natural circulation and flow oscillation tests. Every qualification study from NEDC-32725P and NEDC-33080P is represented by an updated calculation for at least one of the tests included in the original study. Each section includes a brief description of the test facility and test matrix and the TRACG model of the facility. The test(s) selected for the current update are identified and results are presented in the form of compound figures that show both the original and updated comparisons between the TRACG calculations and the test results. To facilitate reference to the two qualification reports, the figure numbers used for the original TRACG vs. data comparisons in those reports have been retained.

There is one other major element of the overall TRACG qualification package that is not addressed herein. That is the set of "generic" qualification studies presented in:

NEDC-32177P, "Licensing Topical Report - TRACG Qualification", Rev. 2, December 1999.

NEDC-32177P includes qualification studies based on separate effects, component and integral system tests and operating plant data that are generally applicable to TRACG performance evaluation of operating and conceptual BWR designs. The calculations documented in NEDC-32177P will be updated to the final Program Library version of TRACG04 when the report is reissued following the issue of the SER.

2.0 SEPARATE EFFECTS TESTS

2.1 Toshiba Low Pressure Void Fraction Tests

The Toshiba low-pressure void fraction tests were conducted in a 16-rod bundle at pressures of 0.50 and 1.00 MPa. An X-ray CT scanner was used to measure the void fraction at an elevation of 45 mm above the top of the heated length. Data were obtained at the two pressures for equilibrium qualities at the end of the heated section in the range of 0 to 12%. The test series analyzed for the original TRACG qualification [6-1, Section 3.1] consisted of: (1) Test Series 300 at a pressure of 1.00 MPa and a mass flux of 1390 kg/m^2-s; (2) Test Series 400 at a pressure of 1.00 MPa and a mass flux of 833 kg/m^2-s; and (3) Test Series 110 at a pressure of 0.50 MPa and a mass flux of 1390 kg/m^2-s. Each test series consisted of five tests covering a range of bundle powers and corresponding exit qualities.

All 15 of the original comparisons between TRACG calculations and the test data were repeated with the current Program Library version of TRACG04. The TRACG model simulates the test section with a CHAN component consisting of an unheated bottom cell, 24 equal-length cells covering the heated length and an unheated top cell. The updated comparisons between the TRACG calculations and the measured void fractions are shown together with the original comparisons in Figures 3.1-5 through 3.1-7. The figures show the calculated and measured void fractions plotted vs. the equilibrium exit quality. [[

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2.2 Ontario Hydro Void Fraction Tests

Void data at high pressure and high temperature were obtained in a 12.4-m long, 52-cm I.D. vertical pipe using the pump test facility of Ontario Hydro Technologies (OHT) in Canada. The temperature and flow through the test section were controlled. Two-phase flow was created by draining water from the test loop into a storage tank. The two-phase mass flux in the test section was varied from 600 to 2200 kg/m^2-s during the tests. A multi-detector gamma densitometer was used to measure local void fraction. The cross-sectional average of the void fraction measurements was used for comparison with the TRACG calculations.

For both the original [6-1, Section 3.2] and updated void fraction comparisons, a test at a nominal temperature of 280° C (6.4 MPa) was analyzed with TRACG. The major feature of the TRACG model is a 13-cell TEE component with Cells 4 through 13 representing the vertical test section. Cell 9 corresponds to the location where the void fraction was measured. Figures 3.2-6 through 3.2-8 show the updated and original comparisons between the TRACG calculation and the void measurements. Figures 3.2-6 and 3.2-7 show comparisons between the calculated void fraction and three of the void fraction measurements over 20-s time periods with average void fractions of approximately 0.5 and 0.75, respectively. [[

]] Figure 3.2-8 shows the original and updated TRACG vs. data comparisons over the duration of the test. In this figure, the void data were averaged over successive 36-second segments. [[

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3.0 COMPONENT PERFORMANCE TESTS

3.1 PANTHERS PCC Performance

The PANTHERS PCC (Passive Containment Condenser) test facility consisted of a prototype PCC unit, secondary-side pool, steam supply, air supply and vent and condensate tanks. Steady-state performance testing was conducted by supplying a specified steam/air mixture to the PCC with the secondary-side pool saturated at atmospheric conditions. The measurements included PCC inlet and outlet (vent and drain) flows and the pressures in the vent and condensate tanks. (The pressure in the condensate tank was maintained in equilibrium with the condenser inlet line.) For air/steam tests, the inlet pressure was controlled and the measured vent flow was used to determine the condensation efficiency of the unit. For pure-steam tests, the inlet pressure was allowed to stabilize at whatever level was required to achieve complete condensation. Transient noncondensible accumulation tests were performed by closing the vent and allowing the noncondensible gas (air or helium) to accumulate within the PCC. Transient pure-steam tests were performed by varying the secondary-side pool water level. For both types of transient tests, the inlet pressure was the primary response variable of the system.

The original set of comparisons between PANTHERS PCC test measurements and corresponding TRACG calculations [6-1, Section 4.1] consisted of three steady-state pure-steam tests, nine steady-state steam/air tests and four transient tests. The present update repeats the TRACG calculations for all three steady-state pure-steam tests (T41_1, T43_2 and T49_1), two steady-state steam/air tests (T15 and T23) and one transient test (T54 – variable pool water level). The main feature of the TRACG model is a single PIPE component with eight cells representing the 496 condenser tubes in the PANTHERS PCC unit. Additional components represent the inlet and outlet headers, the inlet, drain and vent piping and the secondary-side pool.

Figure 4.1-14 shows the original and updated comparisons between the measured and calculated inlet pressures for the three steady-state pure-steam tests. Figures 4.1-16a and b and 4.1-18a and b show the original and updated comparisons between the measured and calculated condenser efficiency (inlet flow minus vent flow divided by inlet steam flow) and pressure drop (condensate tank to vent tank) for Tests T15 and T23. The efficiency and pressure drop are plotted vs. the condenser inlet pressure. Finally, Figure 4.1-28 shows the original and updated comparisons between the measured and calculated inlet pressure plotted vs. the secondary-side pool collapsed level for Test T54. [[

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3.2 PANTHERS IC Performance

The PANTHERS IC (Isolation Condenser) test facility consisted of a prototype IC module, a steam supply vessel, a vent tank and associated piping. The IC unit represented one module of the two-module prototype heat exchanger. The IC module was installed in a secondary-side water pool under atmospheric conditions. Steady-state and transient tests were performed. For the steady-state tests, the inlet steam flow was specified and the condenser pressure was allowed to stabilize at the level required to achieve complete condensation. Transient tests included noncondensible buildup and variable secondary-side pool water level with the condenser inlet pressure as the primary response variable. For the noncondensible buildup tests, the condenser pressure was allowed to stabilize at the specified inlet steam flow before noncondensible injection was initiated.

The original set of comparisons between PANTHERS IC test measurements and corresponding TRACG calculations [6-1, Section 4.2] consisted of three steady-state tests and three transient tests. The main feature of the TRACG model is a single PIPE component with eight cells representing the 120 condenser tubes in the one-module PANTHERS IC unit. Additional components represent the inlet and outlet headers, inlet, drain and vent piping, the steam supply vessel and the secondary-side pool. The present update repeats the TRACG calculations for the three steady-state tests (T02, T06 and T11) and the initial steady states that preceded the two noncondensible buildup tests (T12 and T13). The full transient simulation of Test T12 (noncondensible buildup) was also repeated.

Figure 4.2-4 shows the original and updated comparison between the measured and calculated steady-state inlet pressures for Tests T02, T06, T11, T12 and T13. Figures 4.2-7 and 4.2-8 show the original and updated comparisons between the measured and calculated inlet pressure and IC heat removal vs. time for the transient noncondensable buildup test T12. [[

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3.3 PANDA PCC Performance

The original TRACG qualification for the SBWR included steady-state PCC performance tests conducted at the PANDA test facility in Switzerland. The PANDA test facility represents all of the features necessary for an integrated system simulation of the long-term post-LOCA transient including a detailed representation of the Passive Containment Cooling System (PCCS). Each of the three PCC units in the PANDA facility has twenty full-scale condenser tubes and an isolatable secondary-side water pool. The unit designated as PCC3 was used for the steady-state performance tests. The drywell vessels were isolated and a pipe was installed to deliver steam directly from the simulated reactor pressure vessel to the inlet of PCC3. For steam/air tests, air was injected into the inlet line at a point downstream of the steam measurement location and the pressure was controlled by adjusting the venting rate to the outside environment from the wetwell airspace at the discharge end of the PCC3 vent. For pure-steam tests, the vent line to the wetwell was closed and the pressure self-adjusted to the level required for complete condensation. The test matrix consisted of four pure-steam tests and six steam/air tests.

For the original qualification, TRACG calculations were made for all ten tests [6-1, Section 4.3]. The main feature of the TRACG model is a PIPE component representing the 20 condenser tubes. Additional components represent the upper and lower headers and the inlet, drain and vent piping. The present update repeats the TRACG calculations for all ten tests. Figure 4.3-4 shows the updated and original comparisons between the measured and calculated condenser efficiency (fraction of inlet steam flow condensed) for the six steam/air tests. Figure 4.3-5 shows the updated and original comparisons between the measured and calculated condenser pressure for the four pure-steam tests.
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3.4 Suppression Pool Stratification Tests

Two series of blowdown tests to investigate suppression pool stratification were conducted in the Mark III Pressure Suppression Test Facility (PSTF). One series was performed with full-scale vents (the 5707 series) and a second series was performed with one-third area scaled vents (the 5807 series). The test facility included a pressure vessel with electric heaters to simulate the reactor pressure vessel (RPV), a drywell (DW) vessel, an RPV-to-DW blowdown line, a wetwell (WW) vessel and the DW-to-WW vents. Test parameters included the break size and the initial WW pool temperature. Tests were conducted by pressurizing the RPV, opening the blowdown line and recording the DW and WW pressure and temperature response. The test instrumentation included a radial/axial array of thermocouples in the WW pool that provide data for assessing pool stratification.

The original TRACG qualification [6-1, Section 4.4] was performed for one test from the full-scale vent series (5707-01) and one test from the one-third area scaled vent series (5807-29). The principal elements of the TRACG model are a VSSL component that includes representations of the DW and WW volumes and a set of three TEE components to model the vent system. A FILL component is used to supply the measured break flow to the DW. An additional feature of the model is the use of the TRACG control system to regulate mixing within the WW pool on the basis of the vapor flows through the top, middle and bottom horizontal vents. A similar procedure is used in the TRACG model of the ESBWR plant to ensure that suppression pool stratification effects are bounded.

For the qualification update, the calculation was repeated for Test 5807-29. Updated comparisons between calculated and measured WW pool temperatures are shown along with the original comparisons in Figures 4.4-8 through 4.4-13. The initial WW pool temperature was 24° C. Temperature vs. time comparisons are made for six regions (volumes) in the WW pool as defined in the following table:

Volume	Radial Position	Axial Span (m)
1/2	Inner/Outer	0.00 – 0.10
3/4	Inner/Outer	0.10 – 0.74
5/6	Inner/Outer	0.74 – 2.94

The pool is divided at mid-radius to form the inner and outer volumes. The axial positions of the volume boundaries are relative to the position of the free surface. For reference, the axial positions of the three horizontal vent centerlines are 2.2m, 3.6m and 5m. Thus, Volumes 1 through 4 are above the top vent while Volumes 5 and 6 subtend the level of the top vent. [[

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4.0 INTEGRAL SYSTEMS TESTS

4.1 GIST

The GDCS Integrated Systems Test (GIST) facility simulated the ESBWR plant components and features that could affect the performance of the Gravity Drain Coolant System. These include the reactor pressure vessel (RPV), upper and lower drywell (UDW and LDW) and the wetwell (WW). The GIST RPV included a lower plenum, guide tube, heated channel, bypass, upper plenum, standpipe (chimney), downcomer and steam dome. The RPV was equipped with an Automatic Depressurization System (ADS) and the facility was capable of simulating a main steamline break (MSLB), a GDCS line break (GDLB) and a bottom drain line break (BDLB). Principal measurements included RPV dome pressure, GDCS flow rate and pressure taps that could be used to infer liquid inventories in the heated channel, bypass and downcomer. [[

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Five GIST tests representing different breaks were included in the original TRACG qualification study [6-1, Section 5.1]. The TRACG model represents the GIST RPV with a VSSL component and the tall cylindrical DW and WW tanks with PIPE components. The VSSL component includes all of the GIST RPV features described above. A CHAN component is used for the heated channel. A pair of PIPE components connecting the downcomer with the lower plenum represents the annulus region.

The GDCS line break (Test C01A) was selected for the present update. Updated comparisons of the TRACG04 calculations with the measurements for Test C01A are shown along with the original comparisons in Figures 5.1-19, 5.1-23, 5.1-27 and 5.1-31. Figure 5.1-19 compares the measured and calculated RPV steam dome pressures. [[

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4.2 GIRAFFE Helium Tests

The GIRAFFE helium test series provides a qualification basis for the startup and operation of the ESBWR passive containment cooling system (PCCS) in the presence of noncondensibles that are both heavier (nitrogen) and lighter (helium) than steam. In addition to the PCCS, the GIRAFFE facility included representations of the reactor pressure vessel (RPV), drywell (DW), wetwell (WW), gravity drain cooling system (GDCS) and isolation condenser system (ICS). The GIRAFFE PCCS consisted of a heat exchanger, upper steam box, lower water box and three connecting heat exchanger tubes. A steam supply line from the DW to the steam box, a drain line from the water box to the GDCS pool, a vent line from the water box to the WW pool and a secondary-side pool with a steam vent to the atmosphere completed the system. Test measurements included PCCS temperatures and flows, and pressures, temperatures and gas samples in the upper and lower DW and the WW. The test series simulated the PCCS startup phase, beginning at one hour from the initiation of the LOCA, of a main steamline break with the noncondensible gas environment as the principal test parameter. The ICS was not in service for these tests.

The tests included in the original TRACG qualification [6-1, Section 5.2] study were: H1 (the "base case") with a prototypical mixture of steam and nitrogen in the DW at test start; H2 with helium instead of nitrogen in the DW at test start; H3 with a mixture of steam, nitrogen and helium in the DW at test start; H4 with nitrogen only in the DW at test start but with helium slowly bled in over time; and T2 with an initial DW nitrogen concentration three times greater than H1 and no helium. The TRACG model uses a VSSL component to model the RPV, upper DW, WW and PCCS secondary-side pool. Three individual PIPE components are used to represent the three PCCS condenser tubes. Test H1 was selected for the current qualification update.

Updated comparisons between the TRACG calculations and the GIRAFFE measurements are shown together with the original comparisons in Figures 5.2-9 (DW and WW pressures), 5.2-12 (nitrogen partial pressure in the upper and lower portions of the condenser tubes), 5.2-13 (nitrogen partial pressure in the upper and lower DW) and 5.2-14 (nitrogen partial pressure in the WW). The "measured" PCC nitrogen partial pressures are inferred from total pressure and temperature measurements by assuming saturated steam conditions. The nitrogen partial pressures in the DW and WW are obtained from the gas sampling measurements.

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4.3 GIRAFFE Systems Interactions Tests

The GIRAFFE systems interaction test series provides a qualification basis for the performance of the ESBWR emergency core cooling system (ECCS) during the transition from the late blowdown phase of a LOCA to the startup of the gravity drain cooling system (GDCS) and the subsequent reflood of the reactor vessel. The major features of the GIRAFFE test facility were described in Section 4.2. The principal differences in the facility as configured for the systems interaction tests were the inclusion of the isolation condenser system (ICS) and the initiation of the tests from a reactor pressure of 1.03 MPa. The GIRAFFE ICS was similar to the PCCS but for these tests flow was only permitted through one of the three ICS tubes. Key measurements included RPV, DW and WW pressures, break and GDCS flows, and chimney, bypass and downcomer water levels.

The systems interaction test series included: Test GS1 (the base case) simulating a GDCS line break with a single DPV failure and no PCCS or ICS operation; Test GS2 simulating a GDCS line break with a single DPV failure and parallel PCCS and ICS operation; Test GS3 simulating a bottom drain line break with a single DPV failure and PCCS and ICS operation; and Test GS4 simulating a GDCS line break with a GDCS valve failure in one of the remaining GDCS lines and PCCS and ICS operation. All four of the systems interaction tests were included in the original TRACG qualification study [6-1, Section 5.3]. The principal feature of the TRACG model is a VSSL component with various regions of the r-z geometry representing the test facility components that simulated the reactor pressure vessel (RPV), upper drywell (UDW), wetwell (WW), the GDCS pool and the PCC and IC secondary-side pools. One-dimensional components are used to model the GDCS lines, the middle and lower drywells and the PCC and IC primary systems. Test GS1 was selected for the present update of the TRACG qualification.

Updated comparisons of the TRACG04 calculations with the measurements for Test GS1 are shown along with the original comparisons in Figures 5.3-12 (RPV dome pressure), 5.3-13 (DW pressure), 5.3-14 (WW pressure), 5.3-19 (chimney collapsed level), 5.3-20 (channel delta-P), 5.3-21 (bypass collapsed level), 5.3-22 (downcomer collapsed level) and 5.3-23 (GDCS flow). [[

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4.4 One-Sixth Scale Boron Mixing Tests

A series of tests was conducted in a 1/6-scale mockup of a BWR/5 to examine the mixing behavior of a boron solution injected into the reactor coolant via the Standby Liquid Control System (SLCS). The test facility simulated the flow resistances of the core and bypass regions and could be run under either forced or natural circulation. The tests were conducted at atmospheric pressure and air was injected into the channels to simulate steam voids. Sodium thiosulfate was used to simulate the sodium pentaborate used in BWRs. The concentration of the sodium thiosulfate was adjusted to simulate the prototypical density difference between the much hotter reactor coolant and the injected salt solution in a BWR. In the test, the injected solution was actually 54K hotter than the simulated circulating coolant so that temperature measurements could be used to supplement direct specific gravity measurements as a means of determining the local concentration of the salt solution. Test 342 in the test series, which was performed under natural circulation with the salt solution injected in the upper plenum, was chosen for the original qualification study [6-1, Section 5.4] and is most representative of the conditions in an ESBWR

The objective of the qualification study was to show that TRACG could be used to model the transport of the boron solution through the bypass, core and lower plenum regions. The principal element of the TRACG model is a VSSL component with ten axial levels and four radial rings representing the facility reactor pressure vessel (RPV). From bottom-to-top, the level structure in the VSSL component models the lower plenum, core and bypass, upper plenum and steam dome. The three inner rings represent the region inside the shroud and the outer ring the downcomer. The core model represents 560 channels, apportioned within the three inner rings. The channels and other RPV components (e.g., control rod guide tubes) are modeled with PIPE and TEE components. Two TRACG models were used in the original qualification study. [[

]] The TRACG models were run at prototypical reactor conditions (7.24 MPa and 561 K) to simulate the density difference that was artificially introduced in the test by adjusting the concentration of the salt in the injected solution.

Updated comparisons between the Model 1 TRACG calculations and the test results are shown along with the original comparisons in Figures 5.4-3 through 5.4-10. The comparisons are in terms of mixing coefficients at various locations in the regions representing the flow channels, bypass and plenums. The mixing coefficient is defined as the local concentration of the sodium thiosulfate divided by the global average concentration. [[

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4.5 PSTF Mark III Containment Response

Tests were conducted in the General Electric Pressure Suppression Test Facility (PSTF) in support of the original Mark III pressure suppression containment design, which uses a horizontal vent system similar to that employed in the ESBWR. Emphasis in the tests was placed on vent clearing phenomena that influence the magnitude of the short-term peak in the drywell (DW) pressure following a large-break LOCA. The test facility included an electrically heated pressure vessel (RPV) connected to a DW via a blowdown line. The blowdown line had a rupture disk to simulate the rupture of a main steam line and a critical flow venturi to set the break size. The DW vessel was connected via a discharge duct to a set of horizontal vents that discharged to a wetwell (WW) vessel that was open to the atmosphere. The key test measurement is the DW pressure. The complete test matrix included tests with one, two and three horizontal vents.

Test Series 5703, which was run with three horizontal vents and, accordingly, is most representative of the ESBWR design was selected for the original TRACG qualification [6-1, Section 5.5]. Test Series 5703 included three tests with two different break sizes and differing top vent submergences. The TRACG model uses a VSSL component to represent the PSTF DW and WW and a TEE component to represent the RPV. The horizontal vent system is modeled by a set of three interconnected TEE components. Test 5703-01, which had a break size of 63.5 mm (venturi diameter) and a top vent submergence of 2.06m, was selected for the updated qualification.

Updated and original comparisons of the calculated and measured DW pressure for Test 5703-01 are shown in Figure 5.5-5. [[

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4.6 4T/Mark II Containment Response

A series of blowdown tests, designated Test Series 5101, was conducted in the Pressure Suppression Test Facility (PSTF) to provide supporting data for the Mark II vertical-vent containment design. Test Series 5101 used the same steam generator and drywell vessels as the PSTF Mark III tests described in Section 4.5. The major difference in the test facility as configured for the Mark II tests was the use of a vessel designated as the Temporary Tall Test Tank (4T) to simulate the Mark II wetwell and vertical vent system. The 5101 test series included seven tests representing two break sizes, three vent submergences and a range of initial WW pool temperatures. Tests were conducted with both closed and open wetwells. The key measurements are the DW and WW pressures.

The original TRACG qualification study [6-1, Section 5.6] included all seven tests performed with a closed WW. The principal element of the TRACG model is a VSSL component that includes both the DW and WW of the test facility. One-dimensional components are used to model the steam generator, blowdown line and DW-to-WW vent line. Test 5101-34, which had a break size (venturi diameter) of 76.2 mm, vent submergence of 4.112 m and initial WW pool temperature of 20.6° C was selected for the updated calculation.

Updated comparisons of the measured and calculated DW pressure, WW pressure and DW-to-WW pressure difference as functions of time are shown together with the original comparisons in Figures 5.6-5 through 5.6-7. [[

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4.7 PANDA Transient Tests (M-Series)

The original TRACG qualification for the SBWR included nine transient tests (the M-series) performed at the PANDA test facility in Switzerland. The PANDA facility has all of the features necessary for an integrated system simulation of the ESBWR long-term post-LOCA transient, including a detailed representation of the Passive Containment Cooling System (PCCS). Additional PANDA components represent the reactor pressure vessel (RPV), drywell (DW), wetwell (WW), Isolation Condenser System (ICS) and Gravity-Driven Cooling System (GDCS). The M-series test matrix consisted of Tests M3, M3A, M3B, M2, M10A, M10B, M6/8, M7 and M9. Test M3 (the "base case") was a simulation of the long-term cooling phase following a LOCA caused by a guillotine rupture of one of the main steam lines. Tests M3A and M3B repeated the Test M3 transient scenario while examining possible alternatives for configuring and refilling the PCC and IC secondary-side pools. Tests M2, M10A and M10B examined the influence of asymmetric distributions of the DW steam-air mixture on the startup and long-term performance of the PCCS. Test M6/8 considered system interaction effects associated with parallel operation of the ICS and the PCCS and the effect of a direct bypass of steam from the DW to the WW gas space. Test M7 addressed the issue of PCCS startup from a condition representing the upper limit of initial DW noncondensible inventory. Test M9 examined PCCS performance during the transition from the GDCS-injection phase to the long-term cooling phase of the post-LOCA transient. Measurements included pressures, temperatures, flows and noncondensible gas (air) concentrations.

For the original qualification study [6-1, Section 5.7], TRACG calculations were performed for all nine of the M-series tests. The M-series PANDA TRACG input model represents the DW, WW and GDCS vessels within a VSSL component. The RPV, PCCS, ICS and the piping that interconnects the PANDA vessels are represented by one-dimensional PIPE, TEE, VLVE, CHAN, BREK and FILL components. The procedures used to initiate and control the tests in the PANDA facility were directly simulated in the TRACG model. Tests M3 (the base case) and M10B (all steam directed to DW1 and PCC1 out of service) were selected for the current update.

Updated comparisons between TRACG calculations and PANDA M-series measurements for Tests M3 and M10B are shown in Figures M3-1 and M10B-1 (DW and WW pressures) and M3-2 and M10B-2 (PCC inlet flows). (In the updated comparisons, the test measurements have been decimated 10:1 to facilitate plotting with EXCEL.) [[

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4.8 PANDA Transient Tests (P-Series)

A confirmatory PANDA test program designated as the P-series was performed after the facility was modified to incorporate specific features of the ESBWR design. As in the case of the prior M-series tests, the emphasis was on the long-term cooling phase of a LOCA caused by a main steamline break (MSLB). To more closely represent the ESBWR containment configuration, the PANDA facility was modified to connect the GDCS gas space to the WW gas space instead of to the DW as for the M-series. The P-series test matrix consisted of Tests P1, P2, P3, P4, P5, P6, P7 and P8. Test P1 was a base-case simulation of the long-term cooling phase following a MSLB LOCA. Test P2 was configured to cover the transition from the GDCS injection phase to the long-term cooling phase. Test P3 demonstrated PCCS startup from a condition representing the maximum initial inventory of noncondensible gas in the DW. Tests P4 and P5 addressed long-term cooling performance with the delayed release of noncondensible gas in the DW. Test P6 addressed parallel operation of the ICS and PCCS and the direct bypass of DW steam to the WW gas space. Test P7 addressed PCCS performance in the presence of a noncondensible gas (helium) that is lighter than steam. Test P8, performed as an extension of Test P1, addressed PCCS behavior with the secondary-side pool water level below the bottom of the condenser upper headers.

For the August 2002 ESBWR qualification study [6-2, Section 2], TRACG calculations were performed for all of the P-series tests. The TRACG input model for the P-series tests differed from that used for the M-series primarily by the inclusion of the RPV and the PCC and IC secondary-side pools in the VSSL component along with the DW, WW and GDCS pool. The model was, of course, modified to represent the connection of the GDCS gas space to the WW gas space. As for the M-series, the method used to initiate and control the TRACG transient simulations closely followed the procedure used in the PANDA facility. Test P4 (delayed injection of DW noncondensible) and P6 (parallel operation of the ICS and PCCS and DW-to-WW steam bypass) were selected for the current qualification update.

Updated comparisons between TRACG calculations and PANDA P-series measurements for Tests P4 and P6 are shown in Figures P4-1 and P6-1 (DW and WW pressures) and P4-3 (PCC inlet flows) and P6-3 (IC and PCC inlet flows). [[

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5.0 NATURAL CIRCULATION AND FLOW OSCILLATION TESTS

5.1 Analysis of February 1992 Startup of Dodewaard Natural Circulation BWR

The original TRACG SBWR qualification study included a simulation of the 1992 startup of the Dodewaard natural circulation reactor in the Netherlands following a refueling outage [6-1, Section 6.2]. The startup measurements showed early establishment of circulation flow and no evidence of reactor instability. The Dodewaard reactor (subsequently shut down permanently) was a natural circulation BWR with internal free surface steam separation and a maximum thermal power output of 183 MWt. In January 1992, the reactor was shut down for annual maintenance and refueling. On February 15 and 16, 1992 the reactor startup was performed in accordance with the normal startup procedure. Measurements included: thermal power; pressure; main steamline flow; collapsed water level; downcomer subcooling, pressure difference and velocity; and bypass temperature and velocity.

The TRACG simulation of the Dodewaard startup was repeated using the current Program Library version of TRACG04. The TRACG input model uses a VSSL component to model the Dodewaard reactor vessel. The VSSL cells are arranged in 16 axial levels and four radial rings. The three inner rings contain the core and the chimney and the outer ring contains the downcomer. Four CHAN components are used to represent the fuel. One-dimensional PIPE components are used to model the control rod guide tubes.

Updated comparisons between TRACG calculations and the Dodewaard startup measurements are shown along with the original comparisons in Figures 6.2-4 through 6.2-14. In Figure 6.2-4, the TRACG thermal power, derived from the measured neutron flux power by averaging, is compared with the thermal power calculated from a heat balance using the Dodewaard measurements. The TRACG thermal power is an input to the startup calculation. Figures 6.2-5 and 6.2-6 compare the TRACG and Dodewaard pressure and steam flow. In the first phase of the simulation (0-25,000s) the steam flow is prescribed (via a FILL component) and the pressure is calculated. In the second phase of the transient (25,000 to 70,000s), the pressure is prescribed (via a BREK component) and the steam flow is calculated. Figure 6.2-7 compares TRACG and measured water level; Figures 6.2-8 and 6.2-9 compare TRACG and measured downcomer subcooling and velocity; Figures 6.2-10 and 6.2-11 compare TRACG and measured differential pressures in the downcomer; Figures 6.2-12 and 6.2-13 compare TRACG and measured bypass temperature and velocity; and Figure 6.2-14 compares TRACG and measured feedwater sparger flow. [[

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5.2 CRIEPI Low Pressure Oscillation Tests

The original TRACG qualification included comparisons between TRACG calculations and data from low-pressure thermal-hydraulic oscillation tests performed in the CRIEPI test facility in Japan [6-1, Section 6.3]. The CRIEPI test loop consisted of two electrically heated channels, a chimney, a separator/upper plenum, downcomer, preheater and subcooler. Tests were conducted at pressures of 0.2, 0.35 and 0.5 MPa. Principal measurements included the inlet temperature and the flow rate.

The original TRACG qualification study included comparisons of calculated and measured downcomer inlet velocities as functions of inlet subcooling at pressures of 0.2 and 0.5 MPa with a power of 2.5 kW per channel. The TRACG model uses CHAN components to model each of the heated channels and a VSSL component for the upper plenum/separator tank. A BREK component connected to the VSSL is used to impose the pressure boundary condition and PIPE components are used for the chimney and downcomer. For the current update, the 0.5 MPa results were recalculated. Figure 6.3-10 shows the updated and original comparisons of downcomer inlet velocity vs. inlet subcooling. [[

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5.3 PANDA Exploratory Tests

The PANDA test facility was used to conduct a series of exploratory tests (designated the E-Series) to investigate and clarify the nature of pressure and steam flow oscillations that were observed during some of the facility shakedown tests. The configuration of the PANDA facility for the E-Series was essentially the same as for the steady state S-series tests described in Section 3.3. In this configuration, the RPV steam flow is directed to passive containment condenser unit PCC3 and condensate is returned to the RPV via the GDCS line. The sensitivity of the steam flow oscillations to RPV power, RPV water level and air fraction in the PCCS inlet flow was investigated. The full test matrix consisted of Tests E1A and E1B with the initial RPV water level below the top of the chimney and Tests E1C, E2 and E3 with the initial RPV water level above the top of the chimney.

The original qualification study [6-1, Section 6.4] consisted of TRACG simulations of Tests E1C and E2. These two tests were similar except that in Test E2 the power level was decreased by 50% during the test. Both of these tests were characterized by well-defined oscillations. In Test E2, the oscillations stopped after the power was reduced. The TRACG model for the PANDA E-Series tests models the RPV with a CHAN component for the electrically heated rod bundle, PIPE and TEE components, respectively, for the chimney and downcomer and a VSSL component for the upper plenum. Additional PIPE components represent the steam line from the RPV to PCC3 and the GDCS return line. BREK and FILL components, respectively, are used to specify the steam line pressure and the PCC3 condensate return via the GDCS line. The basis for this simplification was the conclusion that the PCC3 unit was not a causative factor for the steam flow oscillations. The Test E2 simulation was selected for the current update.

Figure 6.4-18 shows the updated and original comparisons between the calculated and measured RPV steam flow for Test E2. [[

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5.4 SIRIUS Two-Phase Flow Instability Tests

The ESBWR TRACG qualification included simulation of two-phase flow instability tests performed in the SIRIUS loop of the CRIEPI test facility in Japan. The SIRIUS loop was designed to investigate thermal-hydraulic instabilities in natural-circulation BWRs. As described in Section 5.2, the test loop consisted of two electrically heated channels, a chimney, upper plenum/separator, downcomer, preheater and subcooler. Test measurements included the channel inlet flow and temperature. Data were collected at a fixed system pressure by maintaining constant channel power while using the preheater to vary the channel inlet subcooling. (The recorded inlet subcooling values were based on the upper plenum pressure.) Pressure drop, flow and temperature data were recorded at each subcooling. With these data, it was possible to estimate the subcooling that marked the transition from stable to oscillatory flow at each power level.

The original qualification study [6-2, Section 3] included TRACG simulation of testing sequences performed at system pressures of 2.0 and 7.2 MPa. For the current update, the TRACG04 simulation of the 2.0 MPa test sequence at a power corresponding to a channel heat flux of 190 kW/m^2 was repeated. Figure 3-3 shows the updated and original comparisons between calculated and measured stable inlet velocities as functions of inlet subcooling. [[

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6.0 REFERENCES

6-1. NEDC-32725P, "TRACG Qualification for SBWR", Rev. 1, August 2002

6-2. NEDC-33080P, "TRACG Qualification for ESBWR", Rev. 0, August 2002.