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Attention: Richard W. Borchardt, Director
Standardization Project Directorate

**Subject: Draft report, *Scientific Design of Purdue University Multi-dimensional Integral Test Assembly (PUMA) for GE SBWR*, NUREG/CR, PU-NE 94/1, revised July 1994.**

References:

1. Letter, M. Malloy (NRC) to P. W. Marriott (GE), *TRANSMITTAL OF DRAFT REPORT ON PURDUE UNIVERSITY'S MULTI-DIMENSIONAL INTEGRAL TEST ASSEMBLY (PUMA) FOR THE GE NUCLEAR ENERGY (GE) SIMPLIFIED BOILING WATER REACTOR (SBWR)*, dated August 9, 1994.

2. Letter, M. Malloy (NRC) to P. W. Marriott (GE), *TRANSMITTAL OF CHANGE PAGES FOR DRAFT REPORT ON PURDUE UNIVERSITY's MULTI-DIMENSIONAL INTEGRAL TEST ASSEMBLY (PUMA) FOR THE GE NUCLEAR ENERGY (GE) SIMPLIFIED BOILING WATER REACTOR (SBWR)*, dated August 12, 1994.

3. Purdue/NRC/EPRI/DOE/GE meeting at Purdue University, *"MEETING ON GE TESTING PROGRAM AND NRC CONFIRMATORY TESTING PROGRAM FOR THE SIMPLIFIED BOILING WATER REACTOR (SBWR)"*, October 1, 1993.

4. Letter, J. F. Quirk (GE) to J. N. Wilson (NRC), *"SBWR TEST PROGRAM"*, MFN No. 168-93, dated October 19, 1993.

5. Letter, P. W. Marriott (GE) to J. N. Wilson (NRC), *"SBWR TEST PROGRAM"*, MFN No. 170-93, dated October 20, 1993.

6. Letter, J. E. Leatherman (GE) to R. W. Borchardt (NRC), *"NRC REQUESTS FOR ADDITIONAL INFORMATION (RAIs) ON THE SIMPLIFIED BOILING WATER REACTOR (SBWR)DESIGN"*, dated February 3, 1994.



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7. Letter, P. W. Marriott (GE) to R. W. Borchardt (NRC), *"NRC SIMPLIFIED BOILING WATER REACTOR (SBWR)DESIGN"*, dated May 31, 1994.

The Attachment to this letter provides comments on the DRAFT report "Scientific Design of Purdue University Multi-dimensional Integral Test Assembly (PUMA) for GE SBWR", revised July, 1994, as requested by the References 1 and 2 letters.

GE is pleased to continue to provide comments on the PUMA Facility and Test Plans as documented in References 3 through 7 and the many informal telephone discussions held directly with Purdue.

If you have questions on these comments, please contact Terry McIntyre on (408) 925-1441.

Sincerely,

P. W. Marriott, Manager
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Attachment: "GE Review of Purdue University Report PU-NE 94/1, July 1, 1994"

cc: P. A. Boehnert (ACRS) (w/1 copy of Attachment)
F. W. Hasselberg (NRC) (w/1 copy of Attachment)
M. Malloy (w/2 copies of Attachment)
M. Ishii (Purdue) (w/1 copy of Attachment)

*Attachment to MFN No. 104-94*

**GE Review of Purdue University Report PU-NE 94/1, July, 1994**

**"Scientific Design of Purdue University Multi-Dimensional Integral Test Assembly (PUMA) for the GE SBWR"**

## 1.0 Overview

GE Nuclear Energy is pleased to have had the opportunity to review the design of the Purdue University Multi-Dimensional Assembly test. We view the success of this program as critical in the overall certification effort for the SBWR, and consequently submit these comments in the spirit of constructive criticism.

As a preface, it is common knowledge that if GE were performing this test, we would approach scaling and facility design from a different direction. The scaling approach used by GE, and others, utilizes full height and reduced area scale, with resulting unity time and pressure scales. The approach used at PUMA reduces the height scale, resulting in a better representation of the system aspect ratio, at the expense of adoption of different time scales for height, time, pressure differences, volumes and power. Several GE technical experts have reviewed the PUMA scaling approach, and while we have found no fatal errors in the approach, it is our opinion that this approach unnecessarily complicates facility design, and makes understanding of the scaled system behavior more difficult.

Likewise, during our review, we have concluded that the authors of this report seem to misunderstand the fundamental driving forces in action during operation of the SBWR Passive Containment Cooling System. The SBWR, like all previous pressure suppression containment systems, utilizes the thermodynamic pressure differences between the drywell and wetwell to move mass and energy between these volumes. Pressure suppression systems are forced convection systems, not natural convection systems. We believe that this misconception has no effect on the validity of the scaling approach chosen for PUMA, but it may effect certain elements of the facility design. It is also important that this fact be understood by those who are evaluating and interpreting data which will eventually come from PUMA.

In our review, we have endeavored to identify those elements where the facility design might have potential shortcomings, or where resources may be used in a more cost-effective manner. These comments are enumerated in Section 2. Additionally, we have identified several specific areas where the scaling approach may be strengthened. These comments are listed in Section 3. Finally, we have noted several minor items and typographical errors, and differences between the current SBWR design and that as cited in the PUMA report. These items are listed in Section 4.

## 2.0 Facility Design

### 2.1 Reduced height Scaling

As noted above, it is our opinion that adoption of different time scales for height, time, pressure differences, power, and volume complicates the scaling and makes interpretation of the data more difficult. The only advantage of this scaling approach is in a better representation of the system aspect ratio. Even with the improved aspect ratio relative to area scaled tests, the PUMA system configuration is far removed from geometrical similitude with the SBWR. For example, the drywell is still basically a tall, relatively narrow, empty, right circular cylinder, with an orifice plate separating the upper and lower drywell volumes. In the SBWR, the upper drywell is an annular space, with the reactor pressure vessel and biological shield in the center, and the cylindrical lower drywell volume below the RPV. More importantly, operating plant drywells are not "clean" geometrically, but are filled with equipment, cable trays, piping, seismic supports, etc. In our opinion, it is difficult, if not impossible, to determine how prototypical the 3-D mixing processes which will occur in PUMA will be, relative to the SBWR. We would not suggest that Purdue change the PUMA scaling approach, but we believe that the authors should be prudent in their representation of mixing in the facility.

Interestingly, GE does not view the extent of mixing between steam and non-condensables in the drywell as nearly as critical a phenomenon in overall containment response as is indicated by the PUMA report. This is probably due to our differing views on the role of condensation and natural convection in driving flow from the drywell to the wetwell as described in the next item.

### 2.2 Drywell to Wetwell Venting

The authors of the report seem to misunderstand the fundamental driving forces in action during operation of the SBWR PCCS. This is illustrated by the statements made in Section 4.2.1 where it is stated, "The driving force for the steam and gas mixtures through the PCCS is provided mainly by the condensation induced pressure gradient. There is a pressure gradient between the drywell and suppression pool due to the water level difference". Both of these statements are technically incorrect, and confuse dependent and independent variables. Although natural circulation drives the flows inside the RPV, and flows through the isolation condenser (IC) system, flows between the drywell and wetwell, and specifically flows through the PCCS heat exchanger, are not natural circulation flows.

In all pressure suppression containment systems, mass and energy are added to the drywell from the break in the primary system, and the drywell pressure increases. The pressure will continue to increase, lowering the water level in the vent system, until a flow path is established between the drywell and the wetwell. The wetwell pressure is set by the thermodynamic conditions in the wetwell, including partial pressure of the original wetwell air (or nitrogen in the case of the SBWR), the partial pressure of the air purged over from the

drywell to the wetwell air apace, and the vapor pressure of steam corresponding to the suppression pool surface temperature. Once the vents have cleared, the drywell pressure is equal to the wetwell pressure, plus the submergence head of the vents, plus any flow head losses in the vent system. There would be flow from the drywell to the wetwell even if there are only non-condensable gasses in the drywell. (In fact, some of the containment testing performed in the 1970's and '80's was performed with only non-condensables.) Once sufficient mass and energy are added to the drywell so that the vent submergence head is overcome, flow will occur. This holds true whither the flow is through the main vents, or through the PCCS heat exchangers.

A critical element of SBWR design is the PCCS heat exchanger vent configuration. The PCCS vent exits into the suppression pool at a shallower submergence than the top main vent. Early in the LOCA scenario, mass and energy addition rates into the drywell from the primary system are substantially larger than the heat removal capacity of the PCCS. Consequently, the drywell pressure is such that both the PCCS vent and the main vents are cleared, and flow goes to the suppression pool via both paths. As decay heat decreases, the drywell pressure will decrease, eventually allowing the top main vent to recover, but flow will still occur, through the PCC heat exchanger and PCC vent. It is the difference in submergence between the main vent and PCCS vent that preferentially directs flow through the heat exchanger, and shifts the primary LOCA heat sink from the suppression pool to the PCCS pool.

From the information provided in the PUMA report, it is unclear whether the submergence relationship between the main and PCCS vents is maintained in the PUMA facility, nor is it clear how this is to be scaled using the reduced height scaling scheme. It is critical that this be addressed, or containment performance may be substantially perturbed from SBWR expectations.

## 2.3 Condenser Tube Length

Upon review of the scaling relationships and facility design, we see no reason why it is necessary to foreshorten the PCC tube length in the PUMA design. The PCC heat exchanger design is independent from the reactor and containment designs, and we believe the heat exchanger performance would be much closer to prototypic in a full-length configuration.

With the PUMA scaling, the condenser heat exchange area scales with power (1:200), but the height of the condenser tubes is scaled with system height (1:4). This produces 4 times more 1/4 length tubes. The analysis of Section 5.4.13 used Eqs. (5.186) and (5.187) which imply uniform heat transfer coefficients. This assumption is acceptable on the outside of the tubes, but is not appropriate for the inside (condensing side) of the tubes. Most condensation takes place in the upper part of the tubes. Thus, a large number of tubes will likely enhance the condensation rate.

2.4 Containment Wall Heat Sinks

Additional consideration on the effects of heat losses from the facility should be considered. SBWR accident scenarios result in long transients, where heat losses from the facility can be on the same order-of-magnitude as the simulated decay heat rate. All vessels must be heavily insulated to avoid heat transfer to the environment dominating overall containment system response. Section 7.8 gives estimated heat losses for various insulation thicknesses but does not define the thickness to be used. Losses should be evaluated at the end of the transient, not at the beginning.

2.5. Reactor Internals Simulation

Purdue has gone to substantial effort to provide simulation of internals in the reactor pressure vessel. While such an effort is commendable, we believe that the detail of the simulation is more than is necessary, and probably not cost effective. For example, it may be shown that for the flow rates involved after blowdown, the pressure drop through the steam separators and dryers are vanishingly small. For this reason, GE has chosen not to model these components in out test facilities. Likewise, the overall core simulation seems to be more detailed than necessary. Based on review of the report text, we assume that this level of detail was included to assure that post-dryout and reflood characteristics of the SBWR core can be simulated.

Section 5.4 of the PUMA report discusses the phenomena involved in core uncovery, critical heat flux, and vessel reflood in some detail. None of the issues addressed are SBWR -unique, all have previously been investigated in detail, and resolved with the NRC staff in licensing of operating BWRs. It was because of these types of issues that GE imposed ECCS success criteria on the SBWR that are substantially more conservative than have been applied to previous generations of reactors. The SBWR is designed so that no fuel uncovery occurs during any LOCA scenario. This ECCS success criteria, coupled with the natural circulation initial conditions in the SBWR core, result in no core heatup in any LOCA scenario. Typically, SBWR LOCA scenarios result in a minimum water level on the order of 2-3 meters above the top of the fuel. Consequently we believe that critical heat flux and reflood issues are highly unlikely to exist with the SBWR.

In light of the above, we believe that a simple core model including the core, bypass region, and chimney are sufficient for adequate simulation. Additional detail does not hurt the simulation, but is not necessary. It should be noted that the PUMA facility will have the same scaling distortion that all other subscale facilities suffer; heat transfer from the vessel walls to the lower plenum will be substantially less than scaled. This will have a major effect on lower plenum flashing and RPV water level early in the blowdown phase of the LOCA scenario.

## 3.0 Specific Comments on Scaling

### 3.1 Consistency of Approach

The PUMA report follows three level scaling approach that is very similar to the "top-down", "bottom-up" approach that we at GE have used in developing our own test programs. However, a consistent treatment of all elements in the experiment seems to be missing. For example, in Section 5.3 the reference length, velocity, and temperature difference are identified for the core and recirculation loop, and the important dimensionless parameters are evaluated using these reference parameters. The same detail has not been extended to other components such as the PCCS, IC, drywell, and suppression pool/wetwell air space.

### 3.2 Quantification of Distortions

The report does not quantify scaling distortions that result from the facility design. A set of non-dimensional parameters has been developed, and those which can and cannot be scaled are identified. Following our own interactions with the NRC and ACRS, we have determined that it is important to identify and quantify appropriate non-dimensional parameters in order to better assess the significance of scaling distortions. We have seen that it is not sufficient to say that a particular parameter is unimportant, it is necessary to demonstrate numerically what is and is-not important, and to quantify any distortions. We recommend that the numerical values of the various scaling parameters and their ratios should be calculated and presented as part of the scaling analysis.

### 3.3 Pressure Scaling

More justification for the approach taken to "pressure scaling" in Section 5.3.3 should be provided. In the GE scaling report (NEDC-32288), pressure scaling was rigorously considered, and it was determined that the "enthalpy-pressure number,"

$$\Pi_{hp} = \frac{\Delta h^\circ}{\Delta P^\circ / P^\circ}$$

must be preserved. An analogous grouping is not defined for PUMA and there is no analysis showing that it is not necessary to preserve it. In particular, we are concerned that the difference (by a factor of 4) in the hydrostatic pressure difference between the prototype and model does not effect the system pressure level, and all phenomena that depend upon it.

The analysis of Section 5.3.2 starts with mass and energy conservation equations, but does not make the rate-of-pressure-change term dp/dt appear explicitly. Thus, it leads to only trivial results, and the relationship between the "thermodynamic" and "hydrodynamic" pressure differences in the system is ignored. We do not understand how the pressure history and pressure distribution within the system can be properly scaled without these pressure differences matched.

### 3.4 Pressure Differences

According to the PUMA scaling, certain pressure differences (RPV-to-drywell during the initial blowdown phase; pressure drops in lines dominated by frictional losses) have a scale of 1:1 (Eq. 5.63), while other pressure differences (vent submergence hydrostatic heads, pressure drops in lines dominated by gravity) have the height scale (1:4, in equation 5.64). Both types of pressure drops can occur, however, at the same time in the same location. For example, flow though the vent system has both frictional and hydrostatic (vent submergence) components. How the two types of pressure scaling will be matched needs more explanation.

### 3.5 Inventory-Pressure Relationships

Having similar vessel inventory histories (Eq. 5.51) does not necessarily satisfy the similarity of the rates of pressure change (Eq. 5.50). The role of energy transfer in pressurization of containment volumes is important and cannot be ignored.

### 3.6 Mass Flow Scaling

Mass flow scaling is based on a time scale obtained by considering transit times (Eq. 5.54) i.e., on the ratio of system segment lengths (based on segments controlling natural circulation) to the velocity in those segments. For a forced flow system such as the SBWR, we believe a more appropriate basis is fill time, i.e. the ratio of the containment volumes to the volumetric flow rates in the connections feeding them. Transit times in containment connections are much shorter than the volume fill times. According to the Hierarchical Two-Tiered Scaling Methodology, longer time scales are the controlling ones.

We are unclear as how this effects the overall scaling results. For the particular values chosen for PUMA the results seem to be unimportant, since flow areas and volume cross sectional areas have the same scaling ratio. However, the confusion in basic mechanisms involved casts doubt on the overall approach.

### 3.7 Heat Flux Scaling

Section 5.4.5 states that critical heat flux is likely to be controlled by void fraction, and thus will be correctly reproduced if the void fraction remains prototypical. However, we calculate the heat fluxes from the fuel rod simulators to be 11 times higher than the SBWR heat fluxes (total rod area is 2232 times smaller in PUMA with a power scaling of 1:200). How this will effect CHF should be investigated.

3.8 Flashing in the Core and Chimney

Comparison of the Flashing number (Eq. 5.112) with the definition of the Phase Change number (Eq. 5.29) indicates that the liquid fraction ($1 - \alpha$) should not be included.

3.9 Condensation in the Suppression Pool

The discussion in Section 5.4.7 regarding scaling of the interfacial area is based on bubbles in fully developed situations. With a 1:4 scaling of vent submergence, plumes at submergences as low as 0.2 m are possible. The maximum cap bubble size given by Eq. 5.148 is 72 mm at 3 bar. This is about 1/3 of the submergence. This effect needs further investigation, as bypass of steam to the wetwell air space cannot be ruled out in this situation.

Likewise Section 5.4.9 discusses mixing in stratified volumes and is based on the assumption of a fully developed plume. This is not likely to be the case with the shallow vent submergence used in PUMA.

3.10 PCCS Condenser Performance

The statement made at the bottom of page 5-53 regarding the independence of the condensation heat transfer coefficient from the mixture Reynolds number is not correct: there is clearly enhancement of condensation by thinning of the water film due to the shear produced by the gas flow.

**4.0 Minor Comments, Typographical Errors, and SBWR Design Information**

4.1 Page 4.8: The report incorrectly states that each lower header of the IC has two drain pipes. Each IC unit in the SBWR has two lower headers. There is one drain pipe from each lower header. The two drain lines from the two headers are routed to a common drain line.

4.2 Page 4-12: In the paragraph titled "GDCS Equalization Line Flow to the Vessel" GE does not concur with the statement that "an effective long-term operation of the GDCS is not possible because only condensed steam from PCCS can replenish GDCS inventory." Our studies and tests have shown that for all Design Basis Events the closed loop of PCCS condensation and GDCS drainage to the RPV results in long-term coverage of the core. GDCS equalization flow may be necessary for beyond design basis events where multiple failures are assumed.

4.3 Equation (5.94): The factor should be 1/2 rather than 1/4.

4.4 Equation (5.109): The density in the denominator should be defined.

4.5 Equation (5.182): Define q.

4.6 Just before Eq. (5.198): should say "From Eq. (5.188)" rather than (5.189).

4.7 Figs. 5.1 and 5.3: the axes are not labeled.

4.8 The meaning of the "iteration scheme" of Eq. (7.43) is not clear. Knowing the correct inside wall boundary conditions from TRACG calculations, there is no need to make any approximations in solving the conduction equation (7.40). The finding of a uniform temperature profile (see text after Eq. (7.43)) could have been made simply by considering the wall time constant for conduction.

4.9 The heat released from the SBWR RPV wall during the 600 seconds to 5 hour time period is estimated to be 0.6948 MJ (top of page 7-42). This seems orders of magnitude too small (it results in an average release rate of 46 W).

4.10 Page 4-3, 2nd par.: The role of the vacuum breakers is misstated. While it does prevent backflow through the vents, its role is to prevent sub-atmospheric pressure in the drywell.

4.11 Page 4-10, 4th par. (also p. 7-16, 1st par.): The force driving the flow through the PCCS condenser is not only a "condensation induced pressure gradient". See the discussion in Section 2.2.

4.12 Table 4.1: RPV Inside height should be 24.505 m.

4.13 Paragraph 4.1.2: Sliding block type supports are used instead of Vessel support skirt.

4.14 Table 4.3: Suppression pool gas volume, water vol me and surface area have all increased by about 1% due to the decrease in the suppression pool ID (or inner ring) from 15.6 m to 15.3 m.

4.15 Figure 4.1: Vent wall thickness has decreased from 1750 mm to 1600 mm.

4.16 Table 4.4: Levels with respect to Top-of-Active-Fuel (TAF) Control Functions: The levels specified in this Table are Nominal trip set points. Level 8 should be 12220 mm. Analytical limits that are used in the safety analysis are given in Table 15.0-1 of Rev. 9.1 in the report. The level 2 analytical limit in Ref. 9.1 is out of date, it should be 7.60 m with respect to the TAF.

4.17 Table 4.7: The IC inlet size has increased from a 10 inch nominal pipe size to 12" NPS. The ID is 288.9 mm, and the OD is 323.9 mm.

4.18 Table 4.8: FWL break area limiting break area is 585 square cm.

4.19 Table 9.1: SRV line OD is 273.1 mm and the ID is 242.9 mm. IC Supply line OD is 323.9 mm, and the ID is 288.9 mm. The IC supply line lengths are given in Figure A1.

4.20 Table 9.1: Pipe IDs are listed as equal to the nominal pipe size which is incorrect. Unless otherwise specified, all piping should be considered schedule 80 and pipe tables should be used to determine the actual ID.