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WESTINGHOUSE CLASS 3

Documentation of the Westinghouse Core Uncovery Tests and the Small Break Evaluation Model Core Mixture Level Model

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DOCUMENTATION OF THE WESTINGHOUSE CORE UNCOVERY TESTS

AND THE

SMALL BREAK EVALUATION MODEL CORE MIXTURE LEVEL MODEL

I. INTRODUCTION

The purpose of this report is to provide documentation of the Westinghouse core uncovery tests and justification of the present core level swell model in WFLASH[1,2]. The derivation of the relationships that utilize the experimental data and formulate the analytical model in the WFLASH code is provided. The information contained in this report fulfills the requirement specified by the NRC Staff in NUREG-0611, Section 4.2.1.8. This issue was responded to by Westinghouse previously in Reference 3, Section 2.10. This report represents an expansion of the work done there, and includes all experimental data specific to the core level swell model in WFLASH. The test facility utilized for the experiment is the Westinghouse ECCS Verification Test Facility, incorporating a rod bundle of the 15×15 design configuration. The test facility is discussed in detail in the Appendix.

II. DERIVATION OF THE WFLASH CORE MIXTURE LEVEL MODEL

A. Conceptual Discussion of the WFLASH Void Fraction Model.

The purpose of this section is to provide an understanding of the interface of the steam separation rate to the general solution technique in WFLASH, in terms of the resultant mixture level and core average void fraction calculation performed at every time step.

A control volume in WFLASH[1,2] may be represented as a two region model. The upper region consists of a saturated steam space and the lower region consists of a mixture of liquid and steam existing as trapped bubbles. At any time in the transient, the average lower phase mixture void fraction is known, as well as the elevation of the mixture level. The WFLASH model assumes a uniform distribution of bubbles in the lower phase of any one "heterogeneous" control volume.

Figure 1 illustrates a general heterogeneous control volume shown with inlet and exit flow paths. The height of the two phase mixture is determined by the mass of liquid and the mass of steam bubbles trapped in it. The state of the fluid exiting the control volume depends on the elevation of the pipe connection with respect to the two phase mixture height in the control volume. With respect to the core control volume specifically, the heat transfer characteristics of the clad, and thus the clad temperatures, are also dependent on the two phase level elevation. Heat generated and released below the mixture level is utilized to generate steam bubbles in the mixture. [ ]^{a,c}

[

[ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c}

This is accomplished by [ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c} (1)

a,c

In the WFLASH code, [ ]^{a,c}

[ ]^{a,c} (4)

[ ]^{a,c}.

[ ]^{a,c}

The steam separation rate is the important term to be defined in order to calculate realistic core mixture levels. The variable drift velocity model as explained later is utilized to calculate this term. It is here where the Westinghouse core uncovery test data is utilized.

B. The Drift Velocity Model

As stated in the previous section, the rate of loss of steam from the mixture, or the steam separation rate is an important quantity in the mixture level model. In all WFLASH control volumes, the steam separation rate is calculated using a drift velocity model. Redfield and Murphy[4] have shown that use of a drift velocity model rather than a constant bubble rise model provides a better representation of experimental data, particularly void fraction and mass inventory experiments.

[ ]^{a,c} based on the Westinghouse core uncovery tests. A description of the model is given in Reference 3, and is summarized here.

The drift velocity model used is derived from the basic drift flux relationships:

$$j_f = (1 - C_o\alpha)\, j - \alpha\, V_{gj} \tag{5}$$

$$j_g = \alpha\, (C_o j + V_{gj}) \tag{6}$$

where

$$j = j_f + j_g \tag{7}$$

Assuming that $C_o = 1$ and the liquid volumtric flux, jf, is zero, gives:

$$j_g = \frac{\alpha_{mix}}{1 - \alpha_{mix}}\; V_{gj} \tag{8}$$

The steam separation rate from the mixture in a bubble rise control volume is therefore:

$$W_{sep} = \frac{\alpha_{mix}}{1-\alpha_{mix}} \rho_g V_{gj} A \qquad (9)$$

The calculation of this term provides the required quantity to determine the transient core average void fraction and mixture level. [

]^{a,c} The specific values utilized are given in the next section.

III. ANALYSIS OF THE WESTINGHOUSE CORE UNCOVERY TEST DATA

A. Data Reduction and Analysis Methods

The purpose of the Westinghouse core uncovery tests was to determine an appropriate core level swell model for a PWR core region under thermal hydraulic conditions typical of a small break LOCA. Rather than to describe in detail the test design and procedures in this section, the final test report is attached as an Appendix. This report provides complete details of the test configuration and includes preliminary data reduction. In addition to the test facility design and testing procedures, the resultant experimental data and plots are fully explained in the narrative sections of the test report contained in the Appendix, and are not repeated in the body of this report.

The Appendix is separated into two sections. The first section includes a description of the test facility and procedures, and presentation of the experimental data taken at all test pressures. The second section contains plots of measured temperatures for each run in the test series at all nominal pressures. A description of the plotted information is also included. The original test series was separated into two sections. The first included testing at 100 and 400 psig nominal pressure. The second included testing at 1200, 800, and 14.7 psia nominal pressure. The Appendix included here contains a combination of all test pressures. The data contained in the Appendix pertaining to the 100 and 400 psia test points has previously been submitted to the NRC through Duke Power Company. Additional analysis of the data was required to determine the appropriate values of V_{gj} in WFLASH and will be discussed in the following paragraphs. However, discussions with the NRC Staff indicated that they desired to see a complete grouping of all data in one place, and the attached Appendix fulfills this request.

The output parameters of interest that were determined from the test include[ ]^{a,c}

Other important test parameters utilized in the analysis of the data are the core heat generated below the mixture level, Q_{mix}; the inlet (downcomer) subcooling throughout the test, h_{in}; and the test pressure and associated densities and enthalpies.

The first step to determine a value of V_{gj}[ ]^{a,c}

[ ]^{a,c} (10)

Note that this calculation determines[ ]^{a,c}

a,c

This was verified through independent modelling of the test facility and uncovery test transients with WFLASH. A summary of the results of this exercise is included in Reference 3.

a,c

a,c

(11)

a,c

a,c

(12)

Substituting eq. (12) into eq. (11) and simplifing yields a relationship where a,c as shown below:

a,c

(13)

[ ]^{a,c} information required to calculate the drift velocity V_{gj} utilizing the simplified drift flux relationships provided in Reference (3). The final relationship for V_{gj} is given by eq. 14.

$$V_{gj} = \left(\frac{1 - \alpha_{mix}}{\alpha_{mix}}\right) j_g \qquad (14)$$

This completes the discussion pertaining to the transformation of the experimental data into test values of drift velocity. The experimental data included a number of data points and test conditions as shown in the Appendix. The nominal test pressures were 1200 psia, 800 psia, 400 psia, 100 psia, and 14.7 psia to cover the important range of 1200-600 psia range existing during the major core uncovery and peak clad temperature period for small breaks. The test power levels ranged from 0.5 Mw to 2.0 Mw. This approximately corresponds to decay heat levels from [ ]^{a,c} of full power, when calculated in terms of the heated volume of mixture per unit length of core. This also bounds the range expected during a small break LOCA.

The test data report included contains discussion on the measurement uncertainties. The temperature errors assumed, [ ]^{a,c} on measured temperatures, [ ]^{a,c} on estimated temperatures, and the transient pressure variation assumed, [ ]^{a,c} represent very conservative estimates. Actual expected uncertainties for temperature and pressure measurements would be lower than that assumed. No convolution of these uncertainties was applied.

[

]^{a,c} As shown in the plots in the Appendix, this occurs very distinctly, and is easily identified. The definition of mixture level [

]^{a,c} This is consistent with the change in the mode of heat transfer, and the magnitude of the change in heat transfer coefficient at this location.

In the calculation of drift velocity, [

]^{a,c} Therefore, this term has a second order effect on the V_{gj} calculation, and its measurement uncertainty is not included directly in the uncertainty analysis in the Appendix.

It can also be demonstrated that the test core power level, Q_{mix}, has a [ ]^{a,c} This effect can be observed through investigation of the components of V_{gj} given by Equation 14. [ ]^{a,c}

[ ]^{a,c}

[ ]^{a,c}

Previously it was stated that the test bundle power range corresponds to approximately [ ]^{a,c}

[ ]a,c

[

]a,c Conservatism in the values of V_{gj} utilized in WFLASH as shown on Figure 2 for small break FSAR type calculations [ ]a,c

As stated in the Appendix, the assumption is made in the determination of the "equivalent water level" that the head losses due to steam expansion and flow out of the rod bundle up into the upper plenum are negligible. This assumption results in [

]^{a,c} This is discussed in more detail in the next section.

B. Calculation of Drift Velocity Correlation for WFLASH

The equations presented previously were programmed, and calculation of the drift velocity was performed for all "good" data points. Definition of "good" data points are those in which all rod thermocouples at a given level achieved an equilibrium cooling condition near the water saturation temperature, and later many heated up substantially above saturation. Additionally, consistancy of system pressure and power throughout the test transient was required. Conservative uncertainties were assumed in the test measurement of Z_{liq} and were also utilized to determine an uncertainty band on V_{gj}. A discussion of the uncertainty considerations on the measurements is contained on pp. A-1 through A-8 in the Appendix. Table 1 presents the results of all "good" data points transformed to values of V_{gj}.

[ ]^{a,c}

a,c

[ ]^{a,c}

[ ]^{a,c}

IV. RESULTS AND CONCLUSIONS

Figure 2 shows that the present V_{gj} relationship utilized in WFLASH is a conservative representation of the experimental data as compared to the average of all "good" data points[ ]^{a,c} This statement is based on contents of Reference 3, which presented the results of a sensitivity study performed that demonstrated that[.]^{a,c} For typical Westinghouse PWR worst small break calculations of 3 to 4 inches in diameter, the equilibrium pressure where pumped safety injection becomes greater than break flow is approximately[ ]^{a,c} At this pressure in the transient for these breaks, the accumulators have injected to recover the core and the pumped safety injection maintains a fully covered core condition. Since the pumped SI is greater than the break flow and boiloff when the RCS pressure stabilizes, the system liquid inventory increases. Therefore the core mixture level will continue to rise regardless of the steam separation rate. Peak clad temperatures for these cases typically occur at a system pressure approximately equal to the accumulator setpoint pressure of 600 psia in the analysis, which represents the minimum possible pressure of injection including instrument uncertainty.

Larger break sizes than the worst break size of 3-4 inch diameter are also typically analyzed. While these cases exhibit an equilibrium pressure below[ ]^{a,c} first core recovery and the turnaround from the maximum clad temperature period also occurs near the time of first accumulator injection, which is assumed to occur at a pressure of 600 psia. Also, the clad temperatures of these larger breaks are typically hundreds of degrees less than the worst small break size for most plants. The core drift velocity model [ ]^{a,c} Therefore, the present core mixture level swell model accurately predicts the worst small break size and yields a core mixture level that results in deeper uncovery and conservative PCTs for the entire small break spectrum, as compared to the average drift velocity resultant from all "good" data points of the Westinghouse core uncovery tests.

References

1. Esposito, V. J., Kesavan, K., and Maul, B. A., "WFLASH - A FORTRAN-IV Computer Program for Simulation of Transients in a Multi-Loop PWR", WCAP-8200 Rev 2, July, 1974.

2. Skwarek, R., Johnson W., and Meyer, P., "Westinghouse Emergency Core Cooling System Small Break October, 1975 Model," WCAP-8970-P-A, April, 1977.

3. Report on Small Break Accidents for Westinghouse NSSS System, Westinghouse Electric Corp., Nuclear Safety Department, WCAP-9600, June, 1979.

4. Redfield, J. A., and Murphy, J. H., "Void Fraction and Residual Water Prediction During Loss-of-Coolant," Trans. ANS, Vol 12, 685 (1968).

5. Zuber, N., and Findlay, J. A., "Average Volumetric Concentration in Two Phase Flow Systems," Heat Transfer, November, 1965.

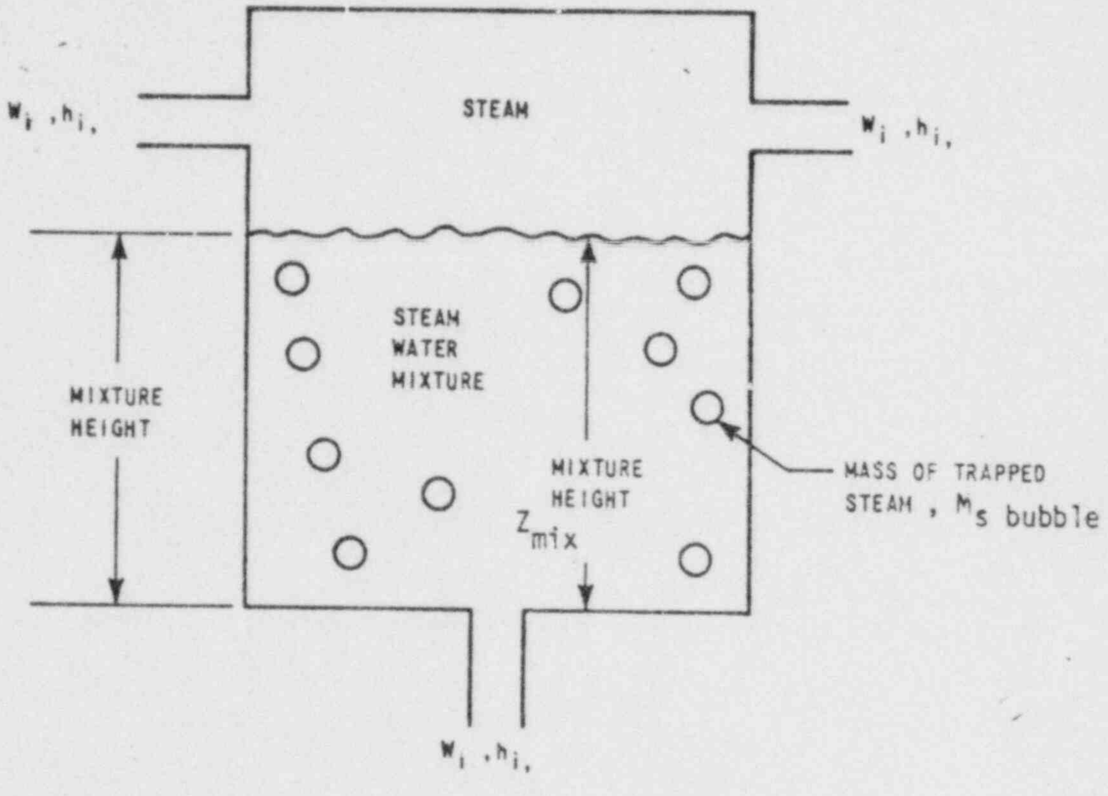

Figure 1 - Heterogeneous Control Volume

a,c

TABLE 1 - Pertinent Test Results and Calculations of V_{gj}

a,c

TABLE 1 (continued) - Pertinent Test Results and Calculations of V_{gj}

Figure 2

a,c

V. APPENDIX

WESTINGHOUSE SMALL BREAK CORE UNCOVERING TESTS

THE FOLLOWING PAGES IN THIS APPENDIX REPRESENT THE CORE UNCOVERY FINAL TEST REPORTS, AND ARE ALL PROPRIETARY:

PAGES 1 THROUGH 18 (TEST INFORMATION)
- A-1 THROUGH A-8 (UNCERTAINTY ANALYSIS)
- B-1 THROUGH B-5 (DATA TABLES)
- 20 THROUGH 33 (DATA TABLES)
- C-1 THROUGH C-473 (CLAD TEMP. PLOTS)

APPENDIX FORMAT

This Appendix includes the test reports and data for the core uncovery tests at 1200, 800, 400, 100, and 14.7 psia nominal pressure. The information in presented in the following format: A description of the test facility, testing procedures, and a summary of pertinent test results is provided first. A discussion on data acquisition and measurement uncertainties follows. Thus far, the test report will refer to 100 and 400 psia data. This information is also applicable for testing at other pressures. A table of conditions and significant data for all tests follows next, with the 100 and 400 psia data given first, followed by the 1200, 800, and 14.7 psia data. The last section includes sets of plots of significant data for each run, preceded by a description of all plotted information, to aid in understanding the general behavior of the system. Similarly, the 100 and 400 psia data is given first, followed by the data at the remaining test pressures.

Since this Appendix represents the combination of two individual test reports written at the completion of the test program, the page numbering system and table and figure numbers are not entirely consistant. However, all pertinent data and discussion applicable to all tests performed is included.