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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATING TO TOPICAL REPORT NUSCO-152, ADDENDUM 4

"PHYSICS METHODOLOGY FOR PWR RELOAD DESIGN"

NORTHEAST UTILITIES SERVICE COMPANY

MILLSTONE NUCLEAR POWER STATION, UNIT NO. 3

DOCKET NO. 50-423

1.0 INTRODUCTION

In a submittal of March 8, 1995 (Ref. 1), the Northeast Utilities Service Company (NUSCO) requested review and approval of the topical report NUSCO-152, "Physics Methodology for PWR Reload Design, Addendum 4, January 3, 1995" (Ref. 2). The report described the use of an approved Westinghouse (W) methodology and computer code package for Millstone Unit 3, beginning with the Cycle 7 reload design. This report documents the capability of NUSCO to perform in-house core reload nuclear design analyses for Millstone Unit 3 using standard W methodologies previously approved by the NRC.

NUSCO intends to use the currently approved W methodology and computer programs for Pressurized Water Reactor (PWR) reload applications, including steady-state reload physics design, calculations for startup predictions, generation of physics and kinetics input for transient and safety analyses and for the plant reactivity computer.

2.0 SUMMARY OF THE TOPICAL REPORT

This addendum to the topical report describes the enhanced W computer programs and physics models used by NUSCO to analyze reload cores and compares the model predicted results with measurements obtained from benchmarking data covering Millstone Unit 3 operating Cycles 3, 4, and 5. The Millstone Unit 3 analyses were performed over a range of conditions from hot zero power (HZP) to hot full power (HFP) operation. The agreement between the measured and calculated values presented in the topical report is used to validate the application of the computer programs for analysis of Millstone Unit 3.

NUSCO intends to use these methods for steady-state PWR core physics reload design applications, including fuel assembly and loading pattern analysis, startup predictions, and safety analysis inputs.

Enclosure

2.1 Overview

Section 1 of the topical report provides introductory background information and an overview of the objectives and scope of the report.

2.2 Physics Codes

Section 2 of the topical report provides a description of each of the individual computer codes. The major W codes used by NUSCO are PHOENIX-P (Ref. 3), ANC (Ref. 4), FIGHT-H (Ref. 5, 6), and APOLLO (Ref. 7).

2.3 Physics Methodology

Section 3 of the topical report describes the approved W PWR methodology used by NUSCO, and outlines the procedures used for the model applications.

2.4 Physics Model Applications

Section 4 of the topical report describes the application of the previously specified Westinghouse physics methodology in four major areas:

- core power distributions at steady-state conditions,
- axial power distribution control limits,
- core reactivity parameters, and
- core physics parameters for transient analysis input.

2.5 Physics Model Verification

Section 5 of the topical report describes three operating cycles of Millstone Unit 3 which provided measured plant data from a range of plant startup and normal operation conditions. Millstone Unit 3 is a four-loop W PWR plant with a 17x17 fuel rod array, 193 fuel assembly core, generating 3411 megawatts-thermal (Mwt) at rated power, which began commercial operation in 1986. There are 61 full-length rod cluster control assemblies (RCCAs). The in-core flux instrumentation consists of moveable fission chambers which can be inserted into multiple core locations. The neutron flux detector signals are processed off-line with the W INCORE program (Ref. 8) to infer the 3D measured power distribution in the core.

The topical report compares the calculated PWR physics parameters with measured or inferred plant data. The measured data cover the range from zero power startup testing to normal full power operations. Three operating cycles were included.

The key PWR physics parameters for which comparisons of predicted to measured or inferred plant data were performed to provide verification of NUSCO's ability to apply the W methodology to plant-specific reload designs are listed. The parameters measured during zero physics tests are:

- critical boron concentration,
- isothermal temperature coefficient, and
- control rod worth.

For each of the parameters compared, the observed differences were compared to a set of startup test review criteria which represent the maximum expected deviation between prediction and measurement (Ref. 9).

The parameters measured or inferred during at power operation include:

- boron letdown curves,
- power peaking factors, F_Q and $F_{\Delta H}$,
- radial power distributions,
- axial power distributions, and
- axial offset.

3.0 TECHNICAL EVALUATION

3.1 Background

NUSCO has been a technology licensee of W since 1985, through which the relevant physics design methodology and associated computer programs have been obtained, beginning in 1986. The licensee states that all methods employed and described in this topical report (including model development, computer programs, measured data processing, etc.) are standard W methods and reflect current practices. NUSCO has used the W methodology to model operating Cycles 3 through 5, and has performed detailed comparisons of the results to measured operating data. An evaluation of these comparisons is presented below for the key PWR physics parameters to be generated by the licensee.

3.2 Critical Boron Concentrations

Critical boron concentrations (CBC) were measured at HZP conditions with all rods out (ARO) and with banks D, C, B and A fully inserted. The ANC 3D model predictions of CBC were compared to zero-power startup test measurements as well as W ANC predictions. All differences between calculated and measured boron ppm data are within the physics test review and acceptance criterion of ± 50 ppm. The results from the HZP comparisons qualify the model for predicting the CBC and core reactivity for beginning-of-cycle (BOC), xenon-free conditions.

3.3 Isothermal Temperature Coefficient

The isothermal temperature coefficient (ITC) is defined as the change in reactivity due to an incremental change in the core average moderator and fuel temperature. Measured ITCs were compared for both rodded and unrodded conditions to NUSCO and W ANC model predictions. All differences between

NUSCO ANC predictions and measured data are within the physics test acceptance criterion of ± 2 pcm/°F from the three cycles of operation. Note that 1 pcm is equivalent to $1x10^{-5}$ percent delta-K/K.

3.4 Control Rod Worths

Control rod worth is the reactivity difference (pcm) between different control rod configurations. The worth of the control rod banks A, B, C, and D was measured by boron dilution, using step-wise bank insertion and summing the differential worths obtained from the reactivity computer. The 3D ANC model was used for the prediction of the individual control rod bank worths and was compared with the BOC zero-power startup measurements for three operating cycles. All differences between NUSCO ANC predictions and measured bank worths are within the test review criteria of ±15% or 100 pcm, whichever is greater.

3.5 Radial Power Distributions

The measured radial power distributions are inferred by the INCORE procedure, after the flux map measurements are performed using the moveable incore neutron flux detector system. The predicted power distributions from the 3D ANC calculations are compared to measured values at several burnup intervals. The predictions show good agreement with the average difference between measured and predicted assembly powers less than 1.67% with a standard deviation less than 1.25%.

3.6 Axial Power Distributions and Axial Offset

A total of 12 axial power distribution measurements from the above flux maps over the three cycles of operation were plotted with the 3D ANC model predicted values at similar depletion points. The measured axial offset (AO), defined as the percent difference between the relative power in the top half of the core and that in the bottom half of the core, is also inferred by INCORE and is compared with the predicted values from ANC at 25 flux map statepoints. In general, the overall agreement between measured and predicted values of axial power distribution and axial offset are good. A larger than expected disagreement was observed during the latter part of Cycle 4 and has been attributed to plate out of soluble boron in certain areas of the core. Since the W predicted axial power shapes are essentially identical to the NUSCO predicted values, this tends to confirm that the Cycle 4 disagreements are due to this unusual physical phenomenon and its effect on the measurements.

3.7 Power Peaking Factors

Measured values of the primary power peaking factors, the heat flux hot channel factor (F_Q) and the nuclear enthalpy rise hot channel factor ($F_{\Delta H}$), were inferred using the W INCORE program. The predicted power peaking factors were obtained from the 3D ANC model depletion results at the closest burnup intervals. For F_Q, the largest absolute difference between the measured and predicted values for 25 measured statepoints over the three cycles was 7.1% and occurred in Cycle 4 due to the axial anomaly mentioned previously. For Cycles 3 and 5, the agreement was much better, the largest difference being 4.8%. For $F_{\Delta H}$, the largest absolute difference was 2.8%.

3.8 Boron Rundown Curves

Critical boron concentrations from measured HFP, equilibrium xenon and samarium conditions were compared to both W and NUSCO 3D ANC model predicted boron rundown curves for three operating cycles. NUSCO and W predictions are generally identical and the measurements from three operating cycles, taken at the time of INCORE power distribution measurements, show good agreement with predicted values.

4.0 SUMMARY AND CONCLUSIONS

The licensee has performed substantial benchmarking using currently accepted W reload design methodologies. This effort consisted of detailed comparisons of the calculated physics parameters with the measurements obtained from operating Millstone Unit 3 as well as with W predictions. In general, the NUSCO ANC predictions agreed well with measurements. All startup test predictions fell within the required review and acceptance criteria. In addition, comparisons between power operation measurements and NUSCO ANC predictions for boron rundown, peaking factors, and power distributions show good agreement. This effort demonstrated the capability of NUSCO to use the W computer program package for application to Millstone Unit 3 using the W Relaxed Axial Offset Control (RAOC) power distribution control limit calculational procedure (Ref. 10).

Based on the analyses and results presented in the topical report, the staff concludes that the W methodology, as validated by NUSCO, can be applied to steady-state PWR reactor physics calculations for the Millstone Unit 3 reload design applications discussed in the above technical evaluation. The accuracy of this methodology has been demonstrated to be sufficient for use in design applications, including PWR reload physics analysis, generation of transient analysis inputs, startup predictions and plant reactivity computer inputs.

As in similar approvals, application of the approved package is to be limited to the fuel configuration and core design parameters verified in the topical report. Changes in the fuel vendor or introduction of significantly different fuel designs may require further validation by the licensee.

5.0 REFERENCES

1. Letter from J. F. Opeka (NUSCO) to Document Control Desk (USNRC), "Millstone Nuclear Power Station, Unit No. 3, Physics Methodology for PWR Reload Design," dated March 8, 1995.

2. NUSCO-152, Addendum 4, "Physics Methodology for PWR Reload Design," Northeast Utilities Service Company, January 3, 1995.

3. WCAP-11596-P-A, "Qualification of the PHOENIX-P/ANC Nuclear Design System for Pressurized Water Reactor Cores," November 1987.

4. WCAP-10965-P-A, "ANC: A Westinghouse Advanced Nodal Computer Program," December 1985.

5. WCAP-6073, "LASER - A Depletion Program for Lattice Calculations Based on MUFT and THERMOS," April 1966.

6. WCAP-2048, "The Doppler Effect for a Non-Uniform Temperature Distribution in Reactor Fuel Elements," July 1962.

7. WCAP-13524-P, "APOLLO - A One Dimensional Neutron Diffusion Theory Program," October 1992.

8. WCAP-8498, "INCORE Power Distribution Determination in Westinghouse Pressurized Water Reactors," July 1975.

9. ANSI/ANS-19.6.1 (1985) "Reload Startup Physics Tests for Pressurized Water Reactors".

10. WCAP-10216-P-A, "Relaxation of Constant Axial Offset Control/FQ Surveillance Technical Specifications," June 1983.

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