UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO AMENDMENT NO. 144 TO FACILITY OPERATING LICENSE NO. DPR-20

CONSUMERS POWER COMPANY

PALISADES PLANT

DOCKET NO. 50-255

1.0 INTRODUCTION

By letter dated October 23, 1989 (Ref. 1) and supplemented by additional letters dated August 24, 1990 (Ref. 2), June 25, 1991 (Ref. 3) and April 1, 1992 (ref.3a), Consumers Power Company (CPC) submitted proposed Technical Specification (TS) changes to Facility Operating License DPR-20 for the Palisades Plant to allow replacement of the current one-eighth core symmetric basis incore analysis computer program (INCA), (Ref. 4), with a new full-core basis incore analysis computer program (PIDAL), (Ref. 5). The supplemental submittals provided additional information and clarifications to the TS and did not alter the initial No Significant Hazards determination published March 7, 1990.

A need to deviate from one-eighth core symmetric fuel loading patterns has developed due to limitations on core reload designs resulting from reactor vessel fluence concerns. Quarter-core symmetric loading patterns will be required to meet the goals established for reduction of fast neutron fluence to the reactor vessel while maintaining sufficient margin to thermal limits, and without reducing operating fuel cycle length. The current INCA model also has limited ability to detect and calculate actual power asymmetries that might occur (e.g., misaligned control rods). In addition, the original uncertainty evaluation for the specific INCA program application at Palisades was not clearly documented by the vendor, resulting in added conservatism being applied to the assumed measurement uncertainties.

The proposed TS changes would:

(1) increase the minimum required number of operable incore detectors from 50 percent to 75 percent of the total possible detectors to compensate for the change from one-eighth core to quarter-core symmetric patterns,

(2) clarify the measurement uncertainty factors to be applied to the linear heat rate and the radial peaking factor limits and change their values to be consistent with the revised incore analysis program, and

(3) change the method of determining the excore detector system calibration factors from the incore measurements to be consistent with the revised incore program.

The review was accomplished in two phases, with technical meetings of NRC staff and Palisades engineering personnel being held on July 9, 1990 (Ref. 6) and September 23, 1991 (Ref. 7) to discuss questions concerning the methodology development and the uncertainty analyses performed to justify the new model.

The first phase was performed in conjunction with a review of the Cycle 9 TS change submittal package and focused on the basic methodology improvements and on the benchmarking calculations performed by CPC as described in Reference 1. Questions on the incorporation of quadrant power tilt corrections into the uncertainty analyses were developed at this time.

The second phase concentrated on the uncertainty analysis, with the additional calculations performed in response to NRC staff questions resulting in the revised submittal of Reference 2.

2.0 BACKGROUND

Palisades is a first-generation Combustion Engineering (CE) pressurized water reactor (PWR) with a unique core design consisting of 204 15x15 fuel bundles and 45 cruciform control blades. The core power distribution is monitored by self powered Rhodium (Rh) incore detectors in a maximum of 45 instrumented fuel assemblies. Each instrument location contains five axial Rh detectors (40cm in length) equally spaced with centers at 10, 30, 50, 70, and 90 percent of the active fuel height. Currently only 43 incore locations are available; two locations are reserved for use by the reactor vessel level monitoring system.

The Rh detectors, of standard design for CE type incore monitoring systems, are manufactured by Reuter-Stokes of Canada. Current Palisades practice is to replace all incore detectors each operating cycle. These Rh detectors, by a neutron-beta reaction, produce a current directly proportional to the incident neutron radiation at each detector location. This current flows through a load resistor producing a voltage which is converted to a digital millivolt reading and is then passed to the primary information processor (PIP) data-logger. The PIP logs the detector readings, computes the background and depletion sensitivity corrections and provides these and other plant measured statepoint parameters to the incore analysis system computer.

The incore detector signals (millivolts) measured by the PIP are first corrected for Rh depletion and background noise. The instrumented fuel assembly power integral over each axial detector segment are then determined by the application of pre-calculated power-to-signal conversion ratios (W-prime factors). The W-primes are supplied by the current fuel vendor, Siemens Nuclear Power (SNP), as part of each core reload physics design package and are obtained from fine spatial mesh, few-group, two-dimensional, PDQ diffusion theory calculations using NRC-approved methods (Ref. 8). An uninstrumented assembly which has a core-symmetric instrumented assembly available can use those detector signals to infer assembly segment powers. For uninstrumented locations with no symmetric detector signals available the assembly powers are inferred using coupling coefficients to adjacent instrumented neighbors. This process allows the determination of a measured or inferred radial core power distribution at each of the five axial detector levels. A detailed axial power shape is then inferred using a five mode Fourier curve fit to the five detector level power integral for each assembly.

The incore analysis program is periodically executed to determine the measured reactor core power distribution. Based on this analysis the following TS surveillances may be performed:

Applicable Tech Specs	Specific Item
3.23.1	Linear Heat Generation Rate (LHGR) Within Limits
3.23.2	Radial Peaking Factors Within Limits
3.23.3	Quadrant Power Tilt Within Limits
3.1.1.g	Axial Power Shape Within Limits
3.11.1.a	Incore Detector Operability
3.11.1.b	Calculate Set Points for the Incore Alarm System
3.11.2.a	Calculate Target Axial Offset & Allowable Power Level for the Excore System
3.11.2.b	Excore System Calibration for ASI Monitoring
3.11.2.c	Excore System Calibration for Quadrant Power Tilt Monitoring
3.11.2.a,b,c	Excore System Calibration for LHGR Monitoring

The TS 3.23.1 LHGR limits ensure that the peak cladding temperature (PCT) will not exceed 2200 degrees F in the event of a loss-of-coolant accident (LOCA). The LHGR (and the related 3D nuclear pin peaking factor, F_Q) is continuously monitored by either the PIP incore high alarm set points or by the excore monitoring system axial shape index (ASI) and allowable power limit (APL) alarms. In order to calculate the incore alarm set points and to calibrate the excore monitoring system, the incore analysis program must calculate the local LHGR by applying pin-to-box factors to the inferred "measured" 3D nodal power distribution. These pin-to-box factors are local peaking factors which are also supplied as part of the W-prime library by the current fuel vendor from a cycle-specific PDQ model of the Palisades reactor core. The calculated local peak pin powers are converted to local linear heat rates for comparison with the TS limits.

The TS 3.23.2 radial peaking factor limits ensure that the assumptions used in the analyses for establishing margin to DNB, LHGR and for the thermal margin/low-pressure (TM/LP) and the variable high power RPS trip set points remain valid. This requires verification of the two radial peaking factors defined by TS 1.1. The assembly radial peaking factor (F^A_r) is the maximum ratio of an individual fuel assembly power to the core average assembly power integrated over the total core height, including radial tilt. This factor is determined directly from the 2D assembly radial power distribution resulting from axial collapsing of the inferred measured 3D nodal power distribution. The total rod peaking factor (F^T_r) is the maximum product of the ratio of individual assembly power to core average assembly power times the highest local peaking factor integrated over the total core height, including radial tilt. This factor results from applying the local peaking factors to the 3D nodal power distribution and then collapsing it axially to two dimensions.

Technical Specification 3.23.3 requires verification of the quadrant power tilt (T_q), defined by TS 1.1 as the difference between the nuclear power in any core quadrant and the average in all quadrants, to ensure that design safety margins are maintained. Operation is not restricted with tilts up to 5 percent. Larger tilts, not to exceed 10 percent, require verification of radial peaking factor limits and/or reduction to less than 85 percent of rated power. Tilts exceeding 10 percent require reduction to less than 50 percent power and verification of radial peaking factor limits and tilts greater than 15 percent require shutdown to hot standby conditions within 12 hours.

Technical Specification 3.1.1.g establishes limits on the core average axial power shape to ensure that the axial power profiles assumed in the development of the primary coolant inlet temperature Limiting Condition for Operation (LCO) bound the measured axial profiles. The axial power shape, referred to as the axial offset (AO) or the axial shape index (ASI), is defined in TS 1.1 as the power in the lower half of the core minus the power in the upper half of the core divided by the sum of the powers in the lower half and upper half of the core. The excore system continuously monitors the ASI and is calibrated to the incore analysis program measured core average axial offset.

Technical Specification 3.11.1.a requires the determination of the operability of sufficient incore detectors to allow the incore analysis program to perform the required TS surveillances and the generation of the PIP incore alarm set points. Currently, at least 50 percent of the individual detectors must be operable including at least two incores per axial level per core quadrant.

Technical Specification 3.11.1.b requires the generation of PIP high alarm set points in order to protect the core from high local power densities by continuously comparing the directly measured incore detector signals to the alarm set points. The alarm limit factors, one for each of the five axial incore detector levels, are calculated by the incore analysis program and are equivalent to the minimum margin to the LHGR TS limit as measured for each detector level.

Technical Specification 3.11.2 requires the calculation of the target axial offset and the allowable power level, along with the verification that the excore monitoring system is calibrated for monitoring the LHGR, the ASI, and the quadrant power tilt. The target axial offset is derived from the core average axial offset measured by the incore analysis program and provides the basis for calibrating the excore detectors ASI monitoring function. The measured power distribution also provides the target or baseline quadrant power tilts which are used to calibrate the excore quadrant power tilt monitoring function. The allowable power level is calculated based on the limiting measured LHGR and ensures that the core LHGR limits are protected within a given band of the axial offset. The TS verification that the excore system is calibrated is performed by comparing the measured core average axial offset and quadrant power tilts to the analogous values recorded by the four power range (safety) excore detectors. If any excore reading differs from the equivalent incore measured value by more than the allowable margin, that channel is declared inoperable and is recalibrated based on the incore measurements.

Each time the periodic TS requirements are performed, a complete set of detector alarm limits are created for loading into the PIP for use until the next required update.

3.0 EVALUATION

The evaluation of the proposed PIDAL incore analysis computer program is covered in three sections. The differences in basic methodology and assumptions between the PIDAL and INCA models are discussed first. Second, the uncertainty analyses and benchmarking comparisons between the two models are covered. Finally, certain limitations and restrictions to be placed on the initial application of the new model during the first cycle of operation with one-eighth core symmetric loading patterns are discussed.

3.1 Methodology

General

The current INCA method used to analyze incore detector data and to infer the Palisades measured core power distribution, the linear heat generation rate (LHGR) and the radial peaking factors was developed by Combustion Engineering (CE) as described in Reference 4. The three-dimensional nuclear pin peaking factor (F_Q) is defined as the ratio of the maximum linear heat rate in any fuel rod to the average linear heat rate in the core. The original INCA model defined F_Q as the product of three separate and independent components: F_r, F_z, and F_p. Peaking factor, F_r is the assembly-to-core average power peaking factor; F_z is the assembly average axial power peaking factor, and F_p is the maximum pin-to-assembly average power peaking factor.

The major methodology difference between the two models is that the proposed PIDAL program always models the reactor power distribution on a full-core basis whereas the current INCA model must assume one-eighth core symmetry. The incore data collection procedure, including the background and depletion corrections, and the incore detector signal to assembly segment power integral conversion using vendor supplied constants are equivalent. The axial power distribution interpolation technique, including the use of theoretical axial boundary conditions derived using the NRC-approved vendor XTG nodal model (Ref. 9), is also the same. The fuel and control rod exposure calculations are performed in the same manner for both models. Finally, the TS analysis procedure is equivalent. The only significant methodology differences between

PIDAL and INCA are in the determination of the measured radial power distribution and the quadrant power tilts as summarized below.

Radial power distribution

The INCA analysis assumes octant symmetric loading and operation of the reactor core, allowing the reflection of all incore instruments into one representative core octant. The Palisades core design is such that if all 43 available incore detector strings are mapped into one octant then each of the 28 assembly locations within the octant will have at least one detector string. Three octant locations have four symmetric detectors; six octant locations have two symmetric detectors; and the remaining nineteen locations have a single detector string.

In the process of collapsing to an octant, INCA averages the symmetric incore detector powers to a single value. For failed incore detector segments with no available symmetric values, INCA determines pseudo-detector powers from a finite difference technique approximation to the neutron flux diffusion equation based on the one group equivalent migration area and infinite multiplication factor of the adjacent assemblies. At this point INCA has a complete two-dimensional radial power distribution at each of the five axial detector levels for the core octant.

The PIDAL program does not average symmetric detector powers and performs a full-core analysis using each individual detector reading, which accounts for any actual core asymmetry. For uninstrumented locations the power is inferred by direct solution of the coupling coefficient matrix representing each radial location at each of the five axial levels. This allows failed detector locations to be treated directly as uninstrumented, without additional approximation.

Quadrant power tilt

Since the basic INCA method determines the detailed power distribution for only one core octant, an estimate of the individual quadrant powers must be constructed. INCA performs this by first determining the ratio of measured-to-predicted detector powers for each operable detector and fitting these ratios to a multi-term trigonometric fit as a function of both core radius and azimuthal angle at each of the five axial detector levels. This radial curve fit is used to construct an estimate of the measured power distribution for each location in the full core. From this estimated full-core power distribution, the quadrant power integrals and quadrant power tilts are then calculated.

Since PIDAL [illegible] determined the full core power distribution based on actual (not averaged) detector powers, the quadrant power integral and tilt values are directly calculated. In addition, PIDAL compares each possible combination of two- and four-way symmetric detector sets at each of the five axial levels. This allows early identification of localized power asymmetry, such as might result from mispositioned control rods.

3.2 Uncertainty Analysis

General

The uncertainty analysis for the original INCA method is documented in Reference 4.

As defined in the TS and discussed in Section 2.0, the peaking factors of interest for Palisades are F_Q, F^A_r, and F^T_r. Three separate components for the uncertainty associated with determination of the above peaking factors are considered. These are referred to as the "box measurement," the "model synthesis," and the "pin-to-box" uncertainties:

> The box measurement component is defined as the uncertainty associated with measuring segment powers in the instrumented detector locations.
>
> The model synthesis component is the uncertainty associated with using both the radial and axial power distribution synthesis techniques employed to calculate a full-core 3D nodal power; specifically, for the radial coupling to the uninstrumented locations and for the axial curve fitting used to obtain an axial (nodal) power shape from the five detector segment powers.
>
> The pin-to-box component is the uncertainty associated with using the local peaking factors supplied in the fuel vendor physics data library to represent the pin power distribution within each assembly.

To adequately address the above uncertainties, it is necessary to mathematically re-define the individual peaking factors in terms of these components. Since the current fuel vendor for Palisades is Siemens Nuclear Power (SNP), CPC has chosen to utilize the SNP breakdown as described in their St. Lucie-1 uncertainty analysis (Ref. 10). This allows CPC to directly incorporate the SNP-derived pin-to-box uncertainty component into their overall uncertainty.

For the purposes of the uncertainty analysis of the PIDAL statistical model (Ref. 11), CPC has separated the above factors into individual components which can be investigated and quantified independently and then statistically recombined into the appropriate uncertainty values for the TS surveillance requirements.

The specific form of the peaking factors used by CPC is as follows:

$$F(q) = F(r) * F(s) * F(L) * F(z)$$

$$F(Tr) = F(r) * F(sa) * F(L)$$

$$F(Ar) = F(r) * F(sa)$$

where:

F(r) = ratio of the assembly relative power to the relative power of the detector measurements within that assembly.

F(s) = relative power associated with a single incore detector measurement.

F(sa) = relative power associated with the average of the detector measurements within a single assembly.

F(L) = peak local pin power within an assembly relative to the assembly average power.

F(z) = ratio of the peak planar power in an assembly to the assembly average power.

CPC uses standard forms for the sample means (x-bar), standard deviations (s), and root-mean-square (rms) differences. Based on the mean, the standard deviation and the sample size, the 95/95 tolerance limit (bias plus-or-minus the reliability factor) was determined for each component, assuming that the percent difference (error) between calculated values and measured data are normal distributions. The individual variances (or standard deviations) are defined in standard terms and are combined statistically by assuming that the individual uncertainty components are independent.

3.3 Summary

The Palisades staff has performed an extensive uncertainty analysis based on data from Cycles 5, 6, and 7 which operated with one-eighth core symmetric loading patterns. In addition, operating data from Cycle 8 has been benchmarked and Cycle 9 was modeled in parallel to verify that the ongoing uncertainty values were bounded by the previous uncertainty analysis. CPC also incorporated an improved SNP NRC-approved methodology (Ref. 8) for W-prime generation for quarter-core symmetric loadings and verified its application as part of the Cycle 8 benchmarking analysis.

The use of PIDAL to replace INCA for TS requirements is acceptable. The proposed reduction of the current uncertainty values assumed for LHGR (F_Q) from 10 to 6.23 percent and for F^T_r from 5 to 4.55 percent; respectively, and the proposed increase of the uncertainty value for F^A_r from 3 to 4.01 percent is also acceptable with the following restrictions:

> The proposed uncertainty values for F_Q, F^T_r, and F^A_r of 6.23, 4.55, and 4.01 have been justified for one-eighth core operation. However, until sufficient data is acquired in a quarter-core operation mode (either rotational or reflective) such that:
>
> (a) the assumption of independence of the individual uncertainty components has been verified,
>
> and
>
> (b) the validity of the planar normalization of the Fr component has been verified,

then the licensee must justify the uncertainty values either,

(1) by periodic comparison with the previous uncertainty analysis before updating any parameters,

or

(2) by application of an additional 5% uncertainty (due to a and b above) giving values of 6.5, 4.8, and 4.2, respectively

until sufficient data is accumulated during the operating cycle to formally justify the assumptions. Restrictions of this type were discussed with the licensee on September 23, 1991 and were documented as commitments in the licensee's letter dated April 1, 1992.

The licensee has proposed to increase the number of incore detectors required to be operable from 50% to 75% of the available individual detectors. This is more restrictive than the CE Standard Technical Specification (STS) requirement used for other plants, where only 75% of the available detector locations (with four-out-of-five individual detectors operable) are required, and is acceptable. In addition, the existing requirement that two detectors per axial level per quadrant are operable is retained.

In the case of failed detectors, it appears that adequate penalty is determined to allow operation with up to 25% failure rate. This allowed failure rate is consistent with industry practice for full core monitoring (CE STS).

In the case of quadrant power tilt, the proposed increase (Ref. 12) in uncertainty for power tilts exceeding 2.8% is appropriate and sufficient to restrict operation while allowing time for the determination of the cause of the apparent tilt.

Although the pool of data (between cycles) was not confirmed with standard statistical techniques, by both inspection of the data and accounting for the similarity of loading/operating patterns, cycle pooling appears to be appropriate for Cycles 5, [illegible] and 7. However, this condition will not necessarily be true for quarter-core (rotational/reflective) loadings or for future operating strategies. Therefore, before incorporating additional cycles into the statistical data base, the pooled data should be demonstrated by commonly accepted techniques such as the Bartlett test (Ref. 13).

A more formal procedure will also be required for testing data for normality (Ref. 14) before incorporation into the uncertainty data base and before removing the additional uncertainty that may be required by the assumption of separability of the F(r) and F(sa) components. Alternately, the use of non-parametric statistical techniques (Refs. 15 and 16) could be considered, with the appropriate equivalent number of degrees of freedom (Ref. 17), with the more conservative tolerance limit applied.

In summary, the staff discussed with the licensee aspects of their uncertainty analyses at a meeting on September 23, 1991. Besides the application of an additional uncertainty, under certain circumstances (as discussed above), the following items were documented as licensee commitments in CPC letter dated April 1, 1992.

(1) The derivation of the W-prime and pin-to-box factors and the generation of input to the PIDAL XTG nodal model is limited to the use of the current fuel vendor (SNP) NRC-approved methods.

(2) The licensee currently replaces all 43 rhodium detector strings each operating cycle and will notify the staff of any future plans to re-use detectors.

(3) In addition, during the initial cycle of operation with a quarter-core loading, the licensee will review the PIDAL uncertainty components after the performance of each 31-day surveillance analysis before updating the PIP alarm and calibration factors.

(4) Also, before additional operating cycle data is added to the uncertainty analysis data base, the data pooled by cycle and the assumptions of the separability of the individual uncertainty components and the normality of the error distributions will be verified using more commonly accepted statistical techniques.

4.0 CONCLUSIONS

Based on the evaluation discussed above, the staff concludes that the proposed TS changes to allow the use of a new full-core basis incore analysis program are acceptable. However, during the initial startup with a quarter-core loading pattern (either rotational or reflective) and after achieving 50 percent power and before initially exceeding 85 percent rated power, the licensee will, as documented in CPC letter dated April 1, 1992, confirm that the model uncertainty is bounded by the previous uncertainty analysis or will apply appropriate penalty factors per Section 3.3 of this Safety Evaluation.

5.0 STATE CONSULTATION

In accordance with the Commission's regulations, the Michigan State official was notified of the proposed issuance of the amendment. The State official had no comments.

6.0 ENVIRONMENTAL CONSIDERATION

The amendment changes a requirement with respect to the installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20. The staff has determined that the amendment involves no significant increase in the amounts, and no significant change in the types, of any effluents that may be released offsite, and that there is no significant increase in individual or cumulative occupational radiation exposure. The Commission has previously issued a proposed finding that this amendment involves no significant hazards consideration and there has been no public comment on such finding (55 FR 8221). Accordingly, this amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of this amendment.

7.0 CONCLUSION

The staff has concluded, based on the considerations discussed above; that: (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

Principal Contributor: E. Kendrick

Date: April 3, 1992

8.0 REFERENCES

1. Letter from K. W. Berry (CPC) to USNRC, "Technical Specification Change Request - Incore Analysis Program," dated October 23, 198[illegible]

2. Letter from G. B. Slade (CPC) to USNRC, "Technical Specification Change Request - Incore Analysis Program - Revision 1," dated August 24, 1990.

3. Letter from G. B. Slade (CPC) to USNRC, "Technical Specification Change Request - Incore Analysis Program - Additional Information," dated June 25, 1991.

3a. Letter from G. B. Slade (CPC) to USNRC, "Additional Information," dated April 1, 1992.

4. T. G. Ober, W. B. Terney, G. H. Marks, "INCA Method of Analyzing In-Core Detector Data in Power Reactors," CENPD-145-P, April 1975.

5. G. A. Baustian, "The CPCo Full Core PIDAL System Software Description," Revision 4, P*PID*89002, June 5, 1989.

6. Memo from B. E. Holian to J. A. Zwolinski, "Summary of Meeting with Consumers Power Company, Palisades Incore Analysis Methodology (TAC No. M75059)," dated July 20, 1990.

7. Memo from B. E. Holian to J. A. Zwolinski, "Summary of Meeting with Consumers Power Company (CPC), Palisades Plant - Incore Analysis (TAC No. M75059), dated October 24, 1991.

8. F. B. Skogen, "Exxon Nuclear Neutronics Design Methods for Pressurized Water Reactors," XN-75-27(A), Supplement 4, December 1985.

9. R. B. Stout, "XTG - A Two Group Three-Dimensional Reactor Simulator Utilizing Coarse Mesh Spacing (PWR Version)," XN-CC-28(A), Volume 1, Rev. 5, July 1979.

10. "Exxon Nuclear Analysis of Power Distribution Measurement Uncertainty for St. Lucie Unit 1," XN-NF-83-01(P), January 1983.

11. G. A. Baustian, "The CPCo Full Core PIDAL System - Uncertainty Analysis," Rev. 2, GAB*90*06, August 15, 1990.

12. G. A. Baustian, "PIDAL Quadrant Power Tilt Uncertainty," EA*GAB*90*06, August 14, 1990.

13. "Probability and Statistics for Engineers and Scientists," Walpole and Myers, MacMillian Publishing Company, 1972.

14. "Assessment of the Assumption of Normality (Employing Individual Observed Values)," ANSI N15.15-1974, October 1973.

15. W. J. Conover, "Practical Nonparametric Statistics," J. Wiley & Sons, Inc., 1971.

16. P. N. Somerville, "Tables for Obtaining Non-parametric Tolerance Limits," Annals of Mathematical Statistics, Vol. 29, No. 2, June 1958.

17. D. B. Owen, "Factors for One-Sided Tolerance Limits and for Variable Sampling Plans," Sandia Corporation Monograph, SCR-607, March 1963.