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## SUMMARY

This report documents our review of the latest version of the STAIF system, which is the proposed methodology of Siemens Power Corporation to estimate the stability of a boiling water reactor (BWR). The latest version of the STAIF system is documented in “BWR Stability Analysis: Assessment of STAIF with Input from MICROBURN-B2,” EMF-CC-074(P) Vol 4, November 1999. Our review is based on the information contained in this report and information provided by the vendor during NRC meetings.

The latest version of the STAIF system is composed of two codes: (1) STAIF, which is a frequency domain stability code, (2) MICROBURN, which is a licensed 3-D steady-state core simulator. The latest version of the STAIF code can be interfaced to either the old simulator (MICROBURN-B) or to the latest version of the simulator (MICROBURN-B2). Note: the original, licensed, version of the STAIF system used a third code (MB2STF,) which is no longer used because its functionality has been integrated into STAIF.

The main conclusion from our review is that the STAIF code, when using input generated by MICROBURN (either -B or -B2,) can estimate the decay ratio of a BWR operating under normal conditions for both: (a) the fundamental (core-wide) and (b) the first azimuthal (out-of-phase or regional) modes. We also conclude that the STAIF system can estimate the channel thermal-hydraulic stability.

We estimate the accuracy of STAIF-calculated decay ratios to be of the order of ±0.2 for the first azimuthal (out-of-phase or regional) and the channel thermal-hydraulic stability modes. The STAIF accuracy for the fundamental (core-wide) stability mode is of the order of ±0.15. The range of decay ratios where we estimate that this accuracy level applies is between 0.0 and 1.1, which covers all the expected operating domain.

In addition to the review of the STAIF methodology, Siemens Power Corporation has requested a modification of the approved Enhanced 1A (E1A) Stability Long Term Methodology. This request requires a modification of the acceptance criteria for validation calculations of the E1A regions. The standard E1A criteria are applied to the calculated core-wide and channel decay ratios. Siemens Power Corporation has requested to modify this criteria by using the out-of-phase decay ratio calculated by STAIF instead of the channel decay ratio. We find this modification acceptable from the technical point of view.

As with all stability codes, input preparation is the major source of error; therefore, to maintain the above accuracy levels, any new calculations must use procedures similar to those used in the qualification report. We specify minimum requirements to maintain this accuracy for new calculations in our Technical Recommendations Section.

## STAIF BACKGROUND

STAIF is a frequency domain code that simulates the dynamics of a boiling water reactor. STAIF's main output is a series of transfer functions that define the linear dynamic behavior of: (1) the channel thermal-hydraulics, (2) the fundamental-mode coupled neutronics and thermal-hydraulics, and (3) the subcritical-modes coupled neutronics and thermal-hydraulics. STAIF estimates the decay ratios for the three above modes of oscillation using a mathematical procedure that is applied to the computed transfer functions.

The original version of STAIF is described in "STAIF, A Computer Program for BWR Stability Analysis in the Frequency Domain", EMF-CC-074(P) Vol 1, August 1993, and "STAIF Code Qualification Report", EMF-CC-074(P) Vol 2, September 1993. This version was reviewed and approved by the U. S. Nuclear Regulatory Commission for use as a best-estimate stability code and also for use in calculating exclusion regions for Long Term Stability Solutions.

This review concentrates on STAIF changes that have been made to accept input from the recently approved steady-state core simulator MICROBURN-B2. In addition to the MICROBURN-B2 interface, Siemens has implemented three major refinements to the code, which include a fine-tuning of the hydraulic correlations and two proprietary model improvements.

In addition to the model enhancements, Siemens has added a significant number of benchmark points to the STAIF validation data base. This data base now covers in depth all the expected operating range of applicability.

## ESTIMATE OF STAIF ACCURACY

In EMF-CC-074(P) Vol 4, Siemens has expanded significantly the benchmarks of the STAIF system against out-of-pile thermal-hydraulic tests as well as reactor tests. The reactor-test benchmarks have been performed for both core-wide and out-of-phase modes, and it includes data from jet-pump and internal-pump reactors.

### Thermal-Hydraulic (Channel) Stability

The STAIF channel stability qualification was performed by benchmarks against Karlstein stability tests, which includes new data for the ATRIUM-10 type bundle design. These tests included five different fuel bundle configurations, including partial-length rods and multi-function rod configurations. The operating conditions for these tests covered the expected operating conditions where channel instabilities are possible: bundle power from 2.5 MW to 5 MW, bundle flows from 4 kg/s to 6 kg/s, and subcoolings from 85 kJ/kg to 150 kJ/kg.

A total of 98 thermal-hydraulic stability tests were modeled with STAIF with a high degree of success. A review of the benchmark data supports the conclusion that channel decay ratios calculated by STAIF agree with the measured values to within ±0.2. Only one of the 98 cases analyzed had errors greater than ±0.2. By comparison, in the qualification of the previous version of STAIF [EMF-CC-074(P) Vol 2,] 5 of the original 43 cases had an error greater than ±0.2, indicating that the latest version of STAIF provides a significant performance improvement. We conclude that, with the proper input, STAIF can consistently estimate the channel thermal-hydraulic decay ratio to within ±0.2 under realistic operating conditions.

### Core-Wide Reactivity Stability

The core-wide reactivity instability capabilities of STAIF were benchmarked against the Peach Bottom-2 stability tests and Washington Nuclear Power Unit-2 stability measurements, as well as stability tests from four European reactors. Three of the benchmark conditions correspond to out-of-phase instability events.

A total of 41 reactor cases were benchmarked with STAIF with a range of measured decay ratios from 0.1 to 1.1. A review of the benchmark data supports the conclusion that core-wide decay ratios calculated by STAIF agree with the measured values to within ±0.15. For all 41 reactor cases benchmarked, only one case results in an error greater than 0.15; and this error is in the conservative direction (STAIF predicts a higher decay ratio than measured.)

Note: Siemens Power Corporation has requested the acceptance of a core-wide error criteria of ±0.1 for E1A validation calculations. The benchmark data does not support this error level because in four of the 41 cases STAIF calculates decay ratios with larger errors, and three of the four cases have non-conservative errors.

We conclude from this benchmark exercise that, with the proper input, STAIF can consistently estimate the core-wide decay ratio to within ±0.15 under realistic operating conditions.

**Out-of-Phase Reactivity Stability**

A limitation of reactor stability tests is that only the core-wide decay ratio can be measured unless an out-of-phase limit cycle is developed. Because of this limitation, only 3 of the 41 reactor cases benchmarked corresponded to clear out-of-phase instabilities (limit cycle); in all cases, STAIF predicted accurately the out-of-phase decay ratio. In the other 38 cases, the measured decay ratio corresponds to the core-wide mode; STAIF exhibited good agreement with the measured core-wide decay ratio, and it also showed that the out-of-phase decay ratio was smaller than 1.0 ± 0.2. Thus, a review of the benchmark data supports the conclusion that out-of-phase decay ratios calculated by STAIF agree with the measured values to within ±0.2.

## MODIFICATION TO ENHANCED-1A STABILITY ACCEPTANCE CRITERIA

The approved E1A stability acceptance criteria are defined as function of two parameters: the core-wide and the channel decay ratios. The standard E1A application requires that the calculated values be lower than an acceptance region that is defined as function of both the core-wide and channel decay ratio in NEDO-31960 "BWR Owner's Group Long Term Stability Solutions Licensing Methodology." The rationale behind this acceptance criteria is to provide protection against out-of-phase instabilities even though some older stability codes were not designed to calculate out-of-phase instabilities. Thus, a conservative approach based on the core-wide and channel decay ratio calculations was developed. Siemens Power Corporation has requested a change in this conservative criteria because the STAIF code has been validated for out-of-phase stability calculations; thus, they can use the direct out-of-phase decay ratio calculated for the E1A region-validation calculations.

From the technical point of view, this modification of acceptance criteria is acceptable because it provides the intended protection against instabilities outside the E1A regions. Thus, we recommend the following E1A region-validation criteria for codes that are validated for out-of-phase stability calculations:

(1) The calculated core-wide decay ratio must be lower than one minus the error for this calculation. In the case of STAIF, the core-wide decay ratio must be lower than 0.85.

(2) The calculated out-of-phase decay ratio must be lower than one minus the error for this calculation. In the case of STAIF, the out-of-phase decay ratio must be lower than 0.8.

(3) The calculated hot-channel decay ratio must be lower than one minus the error for this calculation. In the case of STAIF, the hot-channel decay ratio must be lower than 0.8.

## STAIF LIMITATIONS

STAIF qualification has been limited to relatively normal conditions in operating reactors. Thus, STAIF can only be used reliably to estimate decay ratios under these conditions. In particular, STAIF has not been qualified for extremely abnormal conditions, such as LOCAs or very-low-water-level conditions that may result during anticipated transients without scram..

STAIF has not been qualified for new passive reactors such as SBWR, where components like the extended upper plenum riser may affect the reactor stability. To use STAIF under conditions other than its qualification base, Siemens would have to justify its applicability.

Being a frequency domain code, STAIF cannot calculate nonlinear effects such as limit cycle amplitudes or critical heat flux effects of oscillations.

## CONCLUSIONS AND TECHNICAL RECOMMENDATIONS

Based on the present review, we conclude that the STAIF system as proposed by Siemens Power Corporation provides a reasonably accurate estimation of the linear stability of (1) the channel thermal-hydraulics mode, (2) the fundamental or core-wide coupled neutronics thermal-hydraulics mode, and (3) the out-of-phase or regional coupled neutronics thermal-hydraulics mode. We estimate the accuracy of STAIF-calculated decay ratios to be of the order of

(1) ±0.2 for the hot-channel decay ratio,
(2) ±0.15 for the core-wide decay ratio, and
(3) ±0.2 fir the out-of-phase decay ratio.

The range of decay ratios where we estimate that the above accuracy level applies is between 0.0 and 1.1, which covers all the expected operating domain.

Based on its technical merits, we recommend that the STAIF system be an acceptable methodology for best-estimate linear stability prediction of operating boiling water reactors. Note that for the purposes of this review, the STAIF system is the combination of two codes: MICROBURN (either -B or -B2,) and STAIF, and a set of input generating procedures described in Siemens documents EMF-CC-074(P), Volumes 1 and 2 and 4.

From the technical point of view, the proposed modification of E1A acceptance criteria is acceptable because it provides the intended protection against instabilities outside the E1A regions. Thus, we recommend the following E1A region-validation criteria for the STAIF code:

(1) The calculated core-wide decay ratio must be lower than 0.85.
(2) The calculated out-of-phase decay ratio must be lower than 0.8.
(3) The calculated hot-channel decay ratio must be lower than 0.8.

As with all stability codes, input preparation is the major source of error; therefore, to maintain the above accuracy, any new calculations must use procedures similar to those used in the qualification reports. To insure that input errors do not compromise the accuracy of the calculations, we recommend that best estimate STAIF calculations follow the input-generating procedures described in EMF-CC-074(P). The STAIF input must then be reviewed to guarantee that the following minimum requirements are satisfied:

(1) The core model must be divided in a minimum of 24 axial nodes

(2) The core model must be divided into a series of radial nodes (i.e., thermal-hydraulic regions or channels) in such a manner that
   (a) No single region can be associated with more than 20% of the total core power generation. This requirement guarantees a good description of the radial power shape, especially for the high power channels.
   (b) The core model must include a minimum of three regions for every bundle type that accounts for significant power generation.
   (c) The model must include a hot-channel for each significant bundle type with the actual conditions of the hot channel.

(3) Each of the thermal-hydraulic regions must have its own axial power shape to account for 3-D power distributions. For example, high power channels are likely to have bottom peaked shapes.

(4) The collapsed 1-D cross sections or point kinetics parameters must represent the actual conditions being analyzed as close as possible, including control rod positions.

(5) The STAIF calculation must use the "shifted Nyquist" or complex pole search feature to minimize the error at low decay ratio conditions.

In addition to best-estimate calculations, our technical review indicates that the STAIF system represents an adequate methodology to estimate *Exclusion Region* boundaries to be used with the so-called *BWR Stability Long Term Solutions*. Note that *Exclusion Region* calculations are not best-estimate and they require a well-defined input preparation procedure that has been specified by the Boiling Water Reactor Owners' Group (BWROG) and reviewed by the Nuclear Regulatory Commission. The so-called BWROG procedures are defined in NEDO-31960 "BWR Owner's Group Long Term Stability Solutions Licensing Methodology." Any departure from the established BWROG procedures to calculate *Exclusion Regions* must be justified.