ENCLOSURE

SAFETY EVALUATION
OF THE
GENERAL ELECTRIC
TOPICAL REPORT NEDE-24011 AMENDMENT 8

GENERAL ELECTRIC STANDARD
APPLICATION FOR RELOAD FUEL,
AMENDMENT #8

March, 1985
CORE PERFORMANCE BRANCH

ENCLOSURE

1.0 INTRODUCTION

This SER evaluates the thermal-hydraulic stability licensing criteria proposed by General Electric in NEDE-24011 Amendment 8. The GE report NEDE-22277-P-1, "Compliance of the General Electric Boiling Water Reactor Fuel Designs to Stability Licensing Criteria" (Reference 14), is the principal document submitted in support of Amendment #8 to GESTAR. This evaluation has been supported by review and audit calculations performed by Oak Ridge National Laboratory under contracts FIN B0777 (TER-reference 8) and FIN B0794 (TER-reference 9). The results obtained by ORNL in their audit calculations and comparisons to plant data and experiments have been used by the staff to set the uncertainty value of GE's methodology and to determine the acceptability of GE's proposed licensing criteria.

2.0 DESCRIPTION OF GE'S THERMAL-HYDRAULIC STABILITY METHODS AND PROPOSED LICENSING CRITERIA

2.1 Thermal-Hydraulic Stability Analysis Methods

To investigate the stability of the large nonlinear dynamic BWR system the stability of individual components is evaluated before analyzing their interaction with the total system. For the BWR, these individual components are the channel and reactor core. The hydrodynamic stability of individual channels is analyzed and then the channels are coupled hydraulically and combined with neutronics and heat transfer to study the stability of the core. A linearized, small-perturbation frequency domain model, FABLE (1) is used to perform these calculations. Linear, small-perturbation theory is a special case of the general theory of nonlinear systems analysis. The interaction of the reactor core with the physical control systems associated with the nuclear steam supply and, hence, the total system stability, is investigated with the nonlinear plant transient simulator digital model, REDY (13).

Qualification of the analytical models is demonstrated by comparisons with operating plant tests. Control rod oscillator tests at several plants are used to provide open loop and closed loop response characteristics of the BWR subjected to reactivity perturbations. In addition, pressure setpoint oscillation tests provide system response characteristics for the neutron flux/core-exit-pressure transfer function. These test conditions are simulated using the REDY and FABLE models and the results are compared to test data. Qualification of the FABLE channel hydrodynamics model is performed by comparisons to electrically-heated channel experiments and data from operating reactor tests.

The output from the GE analysis is a limiting best estimate decay ratio.* This decay ratio is found in the low flow/high power portion of the power flow map at the intersection of the power flow curve and the rod block line under natural circulation conditions.

2.2 Stability Tests

The GE methods have been benchmarked against various operating plant test data. The principal data come from the tests performed at Peach Bottom[3] (1977, 1978), Vermont Yankee[5] (1981) and a recent test at an overseas BWR plant.

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* For an oscillatory response, the decay ratio is defined as the ratio of two subsequent peaks which are both on one side (i.e., above or below) of the average value of the oscillatory parameter. Decay ratio is used as a measure of a system's stability. For decay ratio <1.0, the system is damped and the oscillatory response decays, for decay ratio >1.0, the system is undamped and the oscillations increase in magnitude. For the special case of decay ratio = 1.0, limit cycle response is achieved, where the oscillations remain at a constant magnitude. Limit cycles are the characteristic response of nonlinear systems as they approach the stability threshold.

The possibility of instability in a BWR has been investigated since the start-up of early BWRs. These early tests oscillated a control rod within one notch position (6 inches) and measured the response of the reactor (core-exit-pressure and APRM signal). For modern higher-power density reactors, control rod oscillator tests are not desirable because of high cost and poor signal-to-noise ratios in large reactor cores. A technique using pressure perturbations was developed and stability tests were performed at the end of Cycle 2 and during Cycle 3 at Peach Bottom 2 in 1977 and 1978. These stability tests were performed at low core flows (near minimum pump speed) and at varying core powers (up to the design reference condition). During Cycle 3, the tests were performed at various cycle exposures to evaluate the effects of fuel exposure on stability.

The test results verified that the small pressure perturbation technique provides a simple method for determining BWR reactor core stability margins. In addition, stability data were obtained at decay ratio* conditions higher than those achieved in earlier control rod oscillator tests. Stability characteristics above the rated rod line at minimum pump speed were demonstrated with adequate margin to stability at all test conditions (maximum decay ratio = 0.5). Detailed descriptions of the Peach Bottom-2 stability tests during Cycles 2 and 3 can be found in References 3 and 4.

Success of the pressure perturbation technique used at Peach Bottom 2 and the desire for data close to the stability threshold led to stability tests at Vermont Yankee Nuclear Power Station in March 1981. The tests were performed before and after the first rod sequence exchange of fuel cycle 8. The stability tests were conducted at natural circulation flow, single-recirculation pump operation at minimum pump speed, and two-pump operation at minimum pump speed. The core power was varied to points extending above the rated rod line.

Limit cycle oscillations of average neutron flux as measured by the Average Power Range Monitor (APRM) Subsystem were achieved at the intersection of natural circulation and rated rod line without external pressure perturbations. Visual inspection of the control room APRM strip chart recordings showed that the amplitude of the APRM limit cycle oscillation could be distinguished from the normal APRM noise level. Thus, during this test occurrence of APRM limit cycle oscillations as the system stability approached limit cycle operation was observable in the control room through the regular instrumentation.

The APRMs and Local Power Range Monitors (LPRMs) oscillated in phase with a slight phase shift due to the time lag associated with fluid mass transport in the axial direction. No secondary effects of the limit cycle operation were noted and the oscillations remained bounded. The average operating conditions did not change, except for a slight power drift resulting from xenon burnout. The limit cycle oscillations were suppressed when a few control rods were inserted slightly. All other test conditions were stable including two points above the rated rod line at minimum recirculation pump speed. Reference 5 contains a detailed description of the tests and results.

Recent stability tests at an overseas BWR plant have also demonstrated the occurrence of limit cycle neutron flux oscillations at natural circulation and several percent above the rated rod line. The oscillations were again observable on the APRMs and LPRMs and were suppressed by minimal control rod insertion. It was predicted that limit cycle oscillations would occur at the operating state tested; however, the characteristics of the observed oscillations were different from those previously observed in other stability tests. Examination of the detailed test data of these more recent tests showed that some LPRMs oscillated out of phase with the APRM signal and at higher amplitudes than the core average. Although the regional oscillations were larger than the core average (6 to 7), margins to safety limits were maintained and the oscillations were detected and suppressed by control rod insertion.

2.3 GE Proposed Licensing Criteria

The final GE Proposed Licensing Criteria(12) were submitted in response to staff questions(11) and are as follow:

> The compliance of the General Electric Company's Boiling Water Reactor (BWR) Systems, exclusively using GE BWR fuel designs, to the stability criteria set forth in GDC-12 has been demonstrated. The bounding fuel thermal/mechanical analyses cover all licensed GE BWR fuel designs including those contained in GESTAR through Amendment 10. Future GE BWR fuel designs will also be in compliance provided that the following stability compliance criteria calculated using approved methods are satisfied.
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> 1. Neutron flux limit cycles, which oscillate up to the 120% APRM high neutron flux scram setpoint or up to the LPRM upscale alarm trip (without initiating scram) prior to operator mitigating action shall not result in exceeding specified acceptable fuel design limits (Safety Limit Minimum Critical Power Ratio and 1% Cladding Plastic Strain).
>
> 2. The individual channels shall be designed and operated to be hydrodynamically stable or more stable than the reactor core for all expected operating conditions (analytically demonstrated).
>
> These criteria will be evaluated on a generic fuel type basis for future fuel designs as they are added to GESTAR.

Because the stability compliance criteria are independent of plant specific characteristics, cycle-by-cycle decay ratios will not be evaluated for specific plants. However, the operational effects of introducing new fuel designs or special operating modes, will still be evaluated on a generic basis for representative NSSS product lines and fuel designs. The new fuel designs and extended operating modes will be evaluated using approved methods to determine their stability characteristics relative to current fuel designs (described above) which have demonstrated acceptable operational characteristics.

Based on the operating experience with current fuel designs, operator recommendations have been developed (SIL-380, Revision 1) (Reference 7) for high power density plants (e.g., BWR/4/5/6) which define a region of the operating map where operation is not recommended. In addition, a second region is defined in which increased monitoring of potential neutron flux oscillations is appropriate. If the stability performance of the new design is bounded by that of the current fuel designs then the plant performance is consistent with the basis for SIL-380, Revision 1 and these recommendations still apply. If the stability performance of the new design is not consistent with the current designs, then SIL-380 Revision 1 will be modified for that design such that the stability margins calculated at the boundaries of the monitored region will be maintained consistent with SIL-380 Revision 1.

3.0 STAFF EVALUATION

The staff has evaluated the GE proposed licensing criteria. This evaluation which is based on the input from two ORNL evaluation reports (8,9) and on numerous discussions with GE staff has resulted in the staff position stated in Section 4.0 of the SER. A summary of the ORNL TERs follows:

3.1 Review of General Electric Thermal-Hydraulic Stability Methodology (December 31, 1983)

In Reference 8, ORNL presents an evaluation of General Electric's methodology for calculating the stability of boiling water reactors for fuel reload licensing purposes. This evaluation is primarily based on comparative analysis of stability tests performed at Peach Bottom and Vermont Yankee versus results of GE's calculations for these tests.

ORNL compares decay ratios presented in a fuel reload submittal document with decay ratios both measured and recalculated at the end of cycle for that same fuel load. They also look at the impact that fitting procedures used by GE have on the numerical value determined from experimental data for the so-called measured decay ratio.

In this review ORNL concludes that a criterion specifying that the decay ratio (DR) shall be less than 0.8 should be set for GE's decay ratio calculations in fuel reload licensing submittals. If the 0.8 criterion is not met, a non-conformance region in the power-flow operating map must be defined; the reactor operator would be required to take a series of precautions to control the reactor within this region.

3.2 Evaluation of the Thermal-Hydraulic Stability Methodology Proposed by the General Electric Company, Part II (September 30, 1984)

Reference 9 contains ORNL's evaluation of the thermal-hydraulic stability methodology proposed by the General Electric (GE) Company to license reload fuel. The results of this evaluation complement the ones contained in the Reference 8 (Section 3.1) in which the capability of the General Electric Company to predict the stability of reload cores was evaluated.

The results of ORNL's initial review showed that calculated decay ratios are affected by two sources of error. One is input related because of the imprecision involved in calculating the operating conditions for which the stability will be a minimum during a fuel cycle. The other is related to core modeling, since it was shown that different decay ratios have been calculated for reactor core operating conditions which yielded equal experimental decay ratios. Based on the magnitude of the errors found in that review, ORNL proposed an acceptance criterion of decay ratio less than 0.8 for fuel reload calculations.

In NEDE-22277-P-1 (Reference 14) GE proposes two different approaches to demonstrate compliance with stability criteria for reload calculations:

Approach 1

Demonstrate that the calculated core and channel hydrodynamic decay ratio are less than 1.0 for all expected operating conditions.

Approach 2

This approach involves two steps:

(a) Demonstrate that each generic BWR fuel design satisfies the following compliance criteria:

(i) Neutron-flux limit cycles, which oscillate up to the 120% APRM high-neutron-flux scram setpoint (without initiating scram) shall not exceed specified acceptable fuel design limits

(ii) The individual channels shall be designed and operated to be hydrodynamically stable (decay ratio 1.0) or more stable than the reactor core for all expected operating conditions.

(b) Establish operator guidelines to terminate limit cycle oscillations.

The first approach was covered in ORNL's initial report (3.1), where ORNL recommends the threshold of 0.8 for decay ratio calculations to account for calculational uncertainties in predicting the 1.0 threshold proposed by GE. Reference 9 is related to the second approach.

The main points of this new GE proposal which need to be proven are whether:

(a) Neutron-flux limit cycles due to core-wide instabilities and oscillating up to 120% of rated average core power do not exceed current fuel design limits.

(b) The effects of limit cycles on fuel integrity can be calculated for generic fuel designs. This type of calculation is not necessary for every fuel reload.

(c) Local channel instability oscillations are not possible because the channels are designed and operated to be more stable than the core.

(d) If limit cycle oscillations occur the operator is capable of identifying and terminating them following the recommendations in SIL-380 Revision 1.

The results of the ORNL evaluation are:

(a) Core-wide limit cycles with the average power oscillating at frequencies greater than 0.25 Hz and up to 120% rated power are not likely to produce boiling transition and, thus, fuel integrity is likely to be maintained.

(b) The above result is applicable to generic fuel designs because these calculations depend mainly on the fuel geometry, and not on its neutronic characteristics.

(c) Local instabilities due to flow oscillations have been observed in recent experiments, and therefore, they are a possible phenomenon in BWR operation. In those experiments, the ratio of local to average power oscillations was a factor of five (i.e., the local power oscillated 60% while the average power oscillated only 12%) and the frequency of oscillation was close to 0.4 Hz. Assuming that this ratio and frequency remain approximately constant, our calculations show that boiling transition is not likely to occur even if the average power oscillates up to 120% of rated (i.e., the local power oscillates up to 600% of rated).* Therefore, local instabilities can be considered by the same standard as the reactivity instability [result (a)].

(d) The operator recommendations contained in SIL-380, if properly implemented, are considered to be sufficient to identify and terminate limit cycle oscillations.

Based on these results, the following recommendations were proposed:

(a) Stability calculations must be performed for each fuel reload.

(b) If the calculations show that the decay ratio is less than 0.8 for all expected operating conditions during that cycle, the stability licensing criterion is met.

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* Staff Comment-There is no proof or certainty that local/avg ratio is not higher than 6 to 1 - in fact it has been observed to be as high as 7 to 1 in recent tests. Therefore, monitoring of local oscillations is a very important ingredient in proper stability monitoring procedures.

(c) If for some expected operating condition the decay ratio is greater than 0.8, then:

(i) A nonconformance region should be determined in the power-flow operating map.

(ii) A procedure should be established to make the operator aware of the possibility of oscillations in that operating region.

(iii) Special operator instructions should be established to identify and terminate abnormal power oscillations should they occur.

(iv) Calculations should be performed showing that limit cycle oscillations up to the 120% APRM-high-neutron-flux scram point plus anticipated transients (such as generator load rejection with bypass failure) do not reduce the critical power ratio (CPR) below the safety limit CPR for the particular fuel design. (Note: this calculation might be performed for a generic fuel type and plant design).

4.0 STAFF POSITION - ACCEPTANCE CRITERIA FOR GE BWR FUEL DESIGNS FOR THERMAL-HYDRAULIC STABILITY

The staff finds the GE fuel reloads bounded by the conditions in Table 1 meet the stability criteria set forth in General Design Criteria 10 and 12 provided that the BWR being reloaded has in place operating procedures and Technical Specifications which assure detection and suppression of global and local instabilities. Such detection and suppression should cover all modes of operation with particular emphasis on natural circulation and single loop operation. Fuel reloads meeting these requirements need not perform cycle specific stability calculations. Technical Specifications which enforce the recommendations of GE SIL-380 would meet these requirements.

4.1 Exception to Acceptance Criteria for Plants Which Have Not Yet Implemented Improved Stability Technical Specifications

For GE reloads using Table 1 fuels in plants which have not yet implemented improved stability monitoring Technical Specifications the current practice of using the methods of NEDE-22277-P-1 to calculate a cycle specific decay ratio must be continued. This reload will be considered acceptable if the decay ratio is shown to be less than 0.80 for all possible operating conditions. BWR 2/3 type reactors using only the approved GE fuel types described in Table 1 have been shown to have adequate stability margins and therefore are acceptable and their reload cycles are exempted from the current requirement to submit a cycle specific stability analysis to the NRC.

4.2 New Fuel Designs

Should GE develop fuel designs in the future which exceed the bounds of Table 1 the prementioned acceptance criteria and exceptions may still be applied to such fuel if any of the following procedures are followed.

1. Show that the generic calculations presented in NEDE-22277-P-1 are applicable to the new fuel.

   OR

2. Redo the generic calculations presented in NEDE-22277-P-1 in order to expand the approved bounds of Table 1 to include new fuel.

   OR

3. Perform cycle specific calculations using the methods of NEDE-22277-P-1 and show the decay ratio to be less than 0.8.

TABLE 1

ACCEPTABLE FUEL TYPES & OPERATING CONDITIONS

Acceptable Fuel Types

All licensed GE BWR fuel designs contained in GESTAR (NEDE-24011-P-A-6 through Amendment 10).

e.g.

7x7
8x8
P8x8R
BP8x8R
GE8x8E
GE8x8EB

Acceptable Operating Conditions

All licensed modes of operation in GESTAR (NEDE-24011-P-A-6 through Amendment 10).

e.g.

1. Standard power/flow map in FSAR

2. Operating Flexibility Options in GESTAR
   a. Load Line Limit (LLLA)
   b. Extended Load Line (ELLLA)
   c. Increased Core Flow (ICF)
   d. Single Loop Operation (SLO)
   e. Feedwater Temperature Reduction (FWTR)

Acceptable Exposure Range

Initial cycle to equilibrium cycle exposure for limits approved in GESTAR (NEDE-24011-P-A-6 through Amendment 10).

5.0 REFERENCES

1. "Stability and Dynamic Performance of the General Electric Boiling Water Reactor," General Electric Company, Licensing Topical Report, January 1977 (NEDO-21506).

2. "General Electric Standard Application for Reactor Fuel," General Electric Company Proprietary, April 1983 (NEDE-24011-P-A-6 and NEDE-24011-P-A Country Supplements).

3. L. A. Carmichael and R. O. Niemi, "Transient and Stability Tests at Peach Bottom Atomic Power Station Unit 2 End of Cycle 2," Electric Power Research Institute, 1978 (EPRI NP-564).

4. F. B. Woffinden and R. O. Niemi, "Low Flow Stability Tests at Peach Bottom Atomic Power Station Unit 2 During Cycle 3," Electric Power Research Inistitute, 1981 (EPRI NP-972).

5. S. F. Chen and R. O. Niemi, "Vermont Yankee Cycle 8 Stability and Recirculation Pump Trip Test Report," General Electric Company, March 1982 (NEDE-25445).

6. R. B. Linford, "Analytical Methods of Plant Transient Evaluations for the General Electric Boiling Water Reactor," General Electric Company, Licensing Topical Report, February 1973 (NEDO-10802).

7. "BWR Core Thermal-Hydraulic Stability," General Electric Company, February 1984 (Service Information Letter 380, Revision 1).

8. J. M. Leuba & P. J. Otaduy, "Review of General Electric Thermal-Hydraulic Stability Methodology", ORNL, December 31, 1983.

9. J. M. Leuba & P. J. Otaduy, "Evaluation of the Thermal-Hydraulic Stability Methodology Proposed by the General Electric Company", ORNL, September 30, 1984.

10. Letter, J. F. Quirk to C. O. Thomas, "Submittal of Proprietary Report on Compliance of GE BWR Fuel Designs to Stability Licensing Criteria (NEDE-22277-P-1), dated November 6, 1984.

11. Letter, C. O. Thomas to H. C. Pfefferlen, "Request Number One for Additional Information on NEDE-24011, Rev. 6, Amendment 8, December 26, 1984.

12. Letter, H. C. Pfefferlen to C. O. Thomas, "Response to Request Number One for Additional Information on NEDE-24011, Rev. 6, Amendment 8, dated January 14, 1985.

13. R. B. Linford, "Analytical Methods of Plant Transient Evaluations for the General Electric Boiling Water Reactor," February 1973 (NEDO-10802).

14. G. A. WATFORD, "Compliance of the General Electric Boiling Water Reactor Fuel Designs to Stability Licensing Criteria", October 1984. (NEDE-22277-P-1)