February 10, 2004

Mr. Stan Dembkowski, Director
Operating Plant Services
Siemens Westinghouse Power Corporation
4400 Alafaya Trail, MC650
Orlando, FL 32826-2399

SUBJECT: DRAFT SAFETY EVALUATION REGARDING REFERENCING THE SIEMENS TECHNICAL REPORT NO. CT-27332, REVISION 2, "MISSILE PROBABILITY ANALYSIS FOR THE SIEMENS 13.9 M^2 RETROFIT DESIGN OF LOW-PRESSURE TURBINE BY SIEMENS AG" (TAC NO. MB7964)

Dear Mr. Dembkowski:

On March 5, 2003, Siemens Westinghouse Power Corporation submitted Technical Report (TR) CT-27332, Revision 2, "Missile Probability Analysis for the Siemens 13.9 M^2 Retrofit Design of Low-pressure Turbine by Siemens AG," to the staff for review, supplemented by letter dated August 8, 2003. Enclosed for Siemens Westinghouse Power Corporation's review and comments is a copy of the staff's draft safety evaluation (SE) for TR CT-27332, Revision 2, "Missile Probability Analysis for the Siemens 13.9 M^2 Retrofit Design of Low-pressure Turbine by Siemens AG."

Pursuant to 10 CFR 2.790, we have determined that the enclosed SE does not contain proprietary information. However, we will delay placing the SE in the public document room for a period of ten working days from the date of this letter to provide you with the opportunity to comment on the proprietary aspects only. If you believe that any information in the enclosure is proprietary, please identify such information line-by-line and define the basis pursuant to the criteria of 10 CFR 2.790. After ten working days, the draft SE will be made publicly available, and an additional ten working days are provided to you to comment on any factual errors or clarity concerns contained in the SE. The final SE will be issued after making any necessary changes, and will be made publicly available. The staff's disposition of your comments on the draft SE will be discussed in the final SE.

To facilitate the staff's review of your comments, please provide a marked-up copy of the draft SE showing proposed changes. Number the lines in the marked-up SE sequentially and provide a summary table of the proposed changes.

In the event of any comments or questions, please contact Brian Benney at (301) 415-3764.

Sincerely,

/RA/

Stephen Dembek, Chief, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Project No. 721

Enclosure: Draft Safety Evaluation

cc w/encl:
Mr. Peter Bird, Principal Engineer
Steam Turbine Service Engineering
Siemens Westinghouse Power Corporation
4400 Alafaya Trail, MC DV220
Orlando, FL 32826-2399

In the event of any comments or questions, please contact Brian Benney at (301) 415-3764.

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DRAFT SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TECHNICAL REPORT NO. CT-27332, REVISION 2

"MISSILE PROBABILITY ANALYSIS FOR THE SIEMENS 13.9 M^2 RETROFIT DESIGN OF

LOW-PRESSURE TURBINE BY SIEMENS AG"

SIEMENS WESTINGHOUSE POWER CORPORATION

PROJECT NO. 721

1.0 INTRODUCTION

By letter dated March 5, 2003, and supplement dated August 8, 2003, Siemens Westinghouse Power Corporation (SWPC) submitted for NRC review and approval its missile probability analysis for the Siemens 13.9 m^2 retrofit design of low-pressure (LP) turbine rotors in Technical Report No. CT-27332, Revision 2, "Missile Probability Analysis." The NRC approved on February 3, 1998, the SWPC missile analysis methodology for General Electric (GE) nuclear LP steam turbine rotors for up to 87,600 operating hours between disc inspections providing that no cracks are detected in the discs. The current technical report justifies the external missile generation probability in extending the disc inspections of the Siemens 13.9 m^2 retrofit design of LP rotors for up to 100,000 operating hours with quarterly test frequency for the main turbine stop and control valves as previously approved. SWPC intends to facilitate the process for applicants that plan to reference this technical report in their future plant-specific applications on turbine missiles by demonstrating that the calculated missile generation probability for the Siemens 13.9 m^2 retrofit design of LP turbine rotors would satisfy the NRC's turbine system reliability criteria. Recently, the NRC approved the latest version of the Siemens turbine missile methodology (the Siemens methodology) in a safety evaluation (SE) dated July 22, 2003, "Safety Evaluation Regarding Referencing the Siemens Westinghouse Topical Report, 'Missile Analysis Methodology for General Electric (GE) Nuclear Steam Turbine Rotors by Siemens Westinghouse Power Corporation (SWPC)'." The positions established in that SE have also been used in evaluating the current submittal.

2.0 REGULATORY EVALUATION

General Design Criterion (GDC) 4 requires that structures, systems, and components (SSCs) important-to-safety be protected against the effects of missiles that might result from equipment failures. The steam turbine is considered to be one of these components because if its massive rotors fail at a high rotating speed during normal operating conditions of a nuclear unit, high energy missiles could be generated that have the potential of damaging safety-related SSCs.

In the past, evaluation of the likelihood of turbine missiles as related to public health and safety followed Regulatory Guide (RG) 1.115, "Protection Against Low-Trajectory Turbine Missiles," and three Standard Review Plan (SRP, NUREG-0800) sections: Section 10.2, "Turbine Generator"; Section 10.2.3, "Turbine Disk Integrity"; and Section 3.5.1.3, "Turbine Missiles." As specified in SRP Section 3.5.1.3, the probability of unacceptable damage from turbine missiles is expressed as the product of the following items: (1) the probability of turbine missile generation resulting in the ejection of turbine disk (or internal structure) fragments through the turbine casing, P_1, (2) the probability of ejected missiles perforating intervening barriers and striking safety-related SSCs, P_2, and (3) the probability of struck SSCs failing to perform their safety functions, P_3. Over the years the NRC staff has shifted its emphasis in the review of turbine missile issues from the strike and damage probability, P_2 x P_3, to the missile generation probability, P_1. The minimum reliability requirement for loading the turbine and bringing the system on line was established in Appendix U of NUREG-1048, Supplement No. 6, "Safety Evaluation Report Related to the Operation of Hope Creek Generating Station," as: $P_1<10^{-4}$ for favorably oriented turbines and $P_1<10^{-5}$ for unfavorably oriented turbines. Currently, the maintenance and inspection of turbine rotors and valves are based on the P_1 calculation, operating experience of similar equipment, and inspection results. These are the criteria that future plant-specific applications using the Siemens methodology will be required to meet.

3.0 TECHNICAL EVALUATION

The prior SWPC submittal dated May 16, 2002, which was evaluated in the July 22, 2003 SE, contains the Siemens methodology and some rotor-specific information regarding GE and Siemens rotors. However, since the emphasis was on the Siemens methodology, not actual application of it, complete information for a certain product line of rotors was not submitted for the NRC review. The current submittal, however, applies to only Siemens 13.9 m^2 retrofit design of LP turbine rotors. Since complete rotor-specific information was not reviewed in the July 22, 2003, SE and there are multiple plants having these Siemens retrofit design rotors, treating the current submittal as a topical report is warranted.

In the current submittal, the probability of an external missile P_1 is expressed as $P_1 = \sum(P_{2r} \text{ X } P_{3r} + P_{1o})$, where P_{2r}, the probability of disk burst up to 120 percent of the rated speed, can be obtained by multiplying the probability of initiation, P_{2ri}, to the probability of crack growth to the critical depth, P_{2rg}; and P_{3r} is the probability of casing penetration given a disk burst up to 120 percent of the rated speed. The derivation and discussion of this equation is contained in the NRC staff's July 22, 2003 SE. That SE also includes the NRC staff's positions regarding acceptable values for some key deterministic and probabilistic parameters used in a typical turbine missile analysis considering disk burst and casing penetration. In its August 8, 2003, response to the NRC's request for additional information (RAI) regarding these input parameters, SWPC states that only two input parameters are not consistent with the NRC staff recommendation: the maximum crack depth for considering crack branching and the friction coefficient for considering turbine casing penetration. This evaluation discusses these two parameters and two other technical areas which were not reviewed in the July 22, 2003, SE.

3.1 Factor Affecting the PDBURST Result P_{2rg} - Crack Branching Effect

PDBURST is a computer program that calculates P_{2rg}, the probability that an assumed crack in a turbine disk will grow to the critical depth. The deterministic part of the PDBURST computer program is based on linear elastic fracture mechanics (LEFM), with the disk burst failure defined as the critical condition when the calculated crack depth equals the critical crack depth. The Siemens methodology includes a crack branching effect and a Siemens stress corrosion cracking (SCC) crack growth rate in the disk burst failure criterion. SCC in turbine disk keyways and bores have been found to yield multiple, irregular-branched cracks. These secondary, branched cracks would share the crack opening displacement at the tip of a main crack, causing a reduction in the stress intensity factor for the main crack. The NRC accepted the use of the 3-inch crack depth for considering crack branching in the July 22, 2003, SE. SWPC, however, used a different value in its current submittal. Instead of justifying the use of this different depth, SWPC revised its turbine missile analysis in its response to the NRC RAI using the value accepted by the NRC, and documented the results in document CT-27332, Revision 2. The NRC staff finds this to be acceptable.

3.2 Factor Affecting the PDMISSILE Result P_{3r} - Friction Coefficient

PDMISSILE is a computer program that calculates P_{3r}, the probability of casing penetration given a disk burst up to 120 percent of the rated speed. The deterministic part of the PDMISSILE computer program is based on an energy balance equation that equates the external missile energy to the difference between the total missile energy at the moment of disk burst at a given rotor speed and the energy dissipation by blade deformation, blade crushing, blade bending, break-off blade vanes, friction between the missile and inner casing, and deformation of the inner casing up to breakage and penetration of the outer casing. In the July 22, 2003, SE, the NRC staff identified the friction coefficient as one of the seven random variables which are major contributors to the calculated probability of casing penetration.

In response to the NRC RAI, SWPC states that using an NRC-accepted value of 0.25 for the friction factor results in increased casing penetration probabilities for each disk. A sensitivity study was also performed by SWPC to evaluate the effects of friction coefficient on casing penetration probability. However, SWPC did not assess the impact of the increased casing penetration probability P_{3r} on the final probability of an external missile P_1 for each disk. The NRC staff performed independent calculations based on the results in Table 5 of CT-27332, Revision 2 and the sensitivity study results, and concluded that the increased casing penetration probability will not change SWPC's conclusion on extending the turbine disk inspection interval from 87,600 to 100,000 operating hours.

3.3 Residual Stresses

The July 22, 2003, SE discusses the Siemens turbine missile methodology without mentioning the residual stresses associated with a particular rotor disk. Since the current submittal discusses the application of the Siemens turbine missile methodology to a certain line of disk design, the disk tangential stresses, which were used in the LEFM analysis of PDBURST, include residual stresses. In regard to the NRC staff's concern over the basis for the proposed residual stress distribution (Figure 8 of the submittal), SWPC provided a Siemens technical paper, "Shrunk on Disk Technology in Large Nuclear Power Plants - the Benchmark against

Stress Corrosion Cracking," which contains the basis for the residual stress distribution along with analytical results and experimental verification. The NRC staff reviewed this paper, especially the discussion regarding the use of special heat treatment and rolling to induce compressive stresses at the disk surface. The paper indicates that the induced compressive stresses extend 50 mm into the disk surfaces as shown in Figure 8 of the submittal, and the effect of surface compressive stresses on the turbine SCC prevention is supported by test and operating data. Hence, the NRC staff agrees with SWPC's use of the residual stress distribution in this application.

3.4 Crack Initiation Probability

Similar to the issue discussed in Section 3.3 of this SE, the current submittal considers the crack initiation probabilities for turbine disks in its application of the Siemens turbine missile methodology to a certain line of disk design. However, these probabilities were presented in the submittal without sufficient explanation. Additional information regarding the calculation of these probabilities was provided by SWPC in its response to the NRC RAI. This information indicates that the calculation is based on 20 years of inspection data for 406 Siemens LP turbine rotor disks using the Poisson distribution. The information also contains calculations for the crack initiation probabilities. This approach, which has been commonly used in risk assessments of nuclear components with low failure rates, is considered acceptable to the NRC staff for this application.

3.5 Total Probability of an External Missile (P_1)

The total probability of an external missile P_1 for the unit at 100,000 hours inspection interval with quarterly valve test frequency of the overspeed protection system is determined to be 3.43E-5 in comparison to the NRC limiting value of 11.42E-5. The same probability for normal operation up to 120 percent rated speed at 100,000 hours of inspection interval is 1.5E-7 in comparison to the NRC limiting value of 1.0E-4 for a favorably oriented unit and 1E-5 for an unfavorably oriented unit. These probabilities are based on the stipulation that no crack is detected in the disk. Therefore, the calculated probabilities, which are lower than the NRC limiting values, are acceptable to the NRC staff.

4.0 <u>CONCLUSIONS</u>

The NRC staff has completed its review of Siemens Westinghouse Power Corporation's Technical Report (CT-27332, Revision 2), and concludes that based on the evaluation discussed above in Section 3.0 on the proposed turbine missile methodology application, it is acceptable to increase the disk inspection interval from 87,600 to 100,000 operating hours with quarterly test frequency for the main turbine stop and control valves provided that no cracks are detected. Because the conclusion is based on detection of no cracks in the turbine disks, all future plant-specific applicants that intend to apply this technical report to their Siemens' 13.9 m^2 retrofit design of LP turbine rotors need to state in their submittals:

a. The approximate date for the turbine disk inspection at the end of 100,000 operation of their rotors,

b. A commitment to inform the NRC about their turbine disk inspection results and plans to reduce the probability of turbine missile generation, P_1, for continued operation should cracks be detected in the inspection, and

c. Justification if applicants choose to perform additional turbine missile analyses in support of their plant-specific applications.

Principle Contributor: C. Sheng

Date: February 10, 2004