FLORIDA POWER CORPORATION

CRYSTAL RIVER UNIT 3

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ENCLOSURE 2

SIEMENS TECHNICAL REPORT CT-27438, "MISSILE PROBABILITY ANALYSIS REPORT PROGRESS ENERGY CRYSTAL RIVER 3," REVISION 1A (FOR PUBLIC RECORD)

Siemens Technical Report

CT-27438 Revision 1A

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Missile Probability Analysis Report		Orlando, FL	08/05/2011

Missile Probability Analysis Report
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Crystal River 3

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Project
BB281-18m^2

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Missile probability analysis is presented for the Siemens BB281-18m^2 retrofit design of LP turbines. These modern upgraded designs are used in various applications including replacement of Westinghouse original BB281 nuclear LP rotors and internals. This specific report is prepared for Crystal River 3.

Results of the analysis indicate that the missile probabilities remain below the Nuclear Regulatory Commission (NRC) limits of 1E-5 per year for an unfavorably oriented unit for up to 100,000 operating hours between disc inspections providing that no cracks are detected in the discs.

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Contents

1 Introduction

This report is prepared to document the missile analysis performed and methodology used for the BB281-18m^2 design at Crystal River 3. The analysis and methodology used are in compliance with the most recent Nuclear Regulatory Commission (NRC) Acceptance Letter[9] and Safety Evaluation Report[10] for Siemens design of LP rotors.

2 Analysis Methodology

The most significant source of turbine missile is a burst-type failure of one or more bladed shrunk-on disks of the low-pressure (LP) rotors. Failures of the high-pressure (HP) and generator rotors would be contained by their respective casings, even if failure occurred at maximum conceivable overspeed of the unit. There is a remote possibility that some minor missiles could result from the failure of couplings or portions of rotors which extend outside the casings. These missiles would be considerably less hazardous than the LP disk missiles, due to low mass and energy and therefore, will not be considered.

The probability of an external missile (P_1) is evaluated by conservatively considering two distinct types of LP shrunk-on disk failures, namely:

1) failure at normal operating speed up to 120% of the rated speed P_r and

2) failure due to run-away overspeed greater than 120% of rated speed P_o for all LP disks as follows:

$$P_1 = P_r + P_o = \sum_{i=1}^{N} P_{1r} \cdot P_{2r}^{i} \cdot P_{3r}^{i} + \sum_{i=1}^{N} P_{1o} \cdot P_{2o}^{i} \cdot P_{3o}^{i}$$

where:

P_1 probability of an external missile

P_r probability of an external missile for speeds up to 120% of rated speed

P_o probability of an external missile for speeds greater that 120% of rated speed

N, i total and current number of the disks

P_{1r} probability of turbine running up to 120% of rated speed (Conservatively assumed = 1.0)

P_{2r}^{i} probability of disk # i burst up to 120% of rated speed due to stress corrosion crack growth to critical size

P_{3r}^{i} probability of casing penetration given a burst of the disk # i up to 120% of rated speed

P_{1o} probability of a run-away overspeed incident (>120% of rated speed) due to failure of overspeed protection system

P_{2o}^{i} probability of disk burst given run-away overspeed incident (Conservatively assumed = 1.0)

P_{3o}^{i} probability of casing penetration given a burst of the disk # i at run-away overspeed (Conservatively assumed = 1.0)

The overspeed probability P_{1o} is a function of the maintenance and test frequency of the speed control and overspeed protection system.

The probability of normal operating speeds up to 120% of the rated speed is assumed to be 1.0. It is also conservatively assumed that, given the overspeed protection system fails the probability of a disk # i burst and that of casing penetration of the burst fragments are also 1.0 each for all disks.

Finally, the expression for the external missile probability could be re-written as:

$$P_1 = P_r + P_o = \sum_{i=1}^{N} P_{2r}^{i} \cdot P_{3r}^{i} + P_{1o}$$

Therefore, the only remaining values that need to be quantified are P_{2r}^{i} , P_{3r}^{i} and P_{1o} .

The methodology for evaluation of these probabilities is described in the following sections.

2.1 NRC Criteria for Missile Probability

The US Nuclear Regulatory Commission (NRC) has defined criteria governing nuclear steam turbine start-up, continued operation and shut down requirements.

Two power plant layouts, namely unfavorable and favorable orientations, have been identified as shown in Fig. 1.

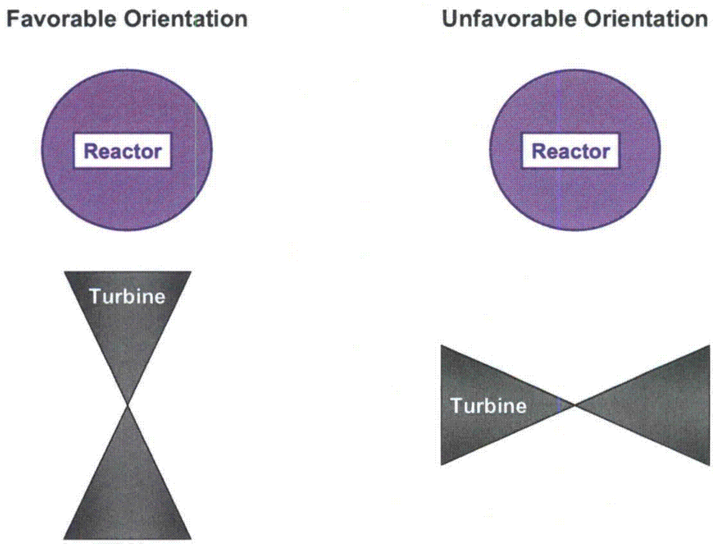


Fig. 1: Nuclear turbine unit orientation relative to reactor building

Table 1 shows the allowable limits for the probability of external missile from the steam turbine – generator unit (P_1) for start-up and continued operation. The overspeed protection system test with maintenance frequencies and disk inspection intervals must be selected to ensure that these criteria are satisfied.

Favorably Oriented Turbine	Unfavorably Oriented Turbine	Required Licensee Action
(A) $P_1 < 10^{-4}$	$P_1 < 10^{-5}$	This is general, minimum reliability requirement for loading the turbine and bringing the system on line
(B) $10^{-4} < P_1 < 10^{-3}$	$10^{-5} < P_1 < 10^{-4}$	If this condition is reached during operation, the turbine may be kept in service until the next scheduled outage, at which time the licensee is to take action to reduce P_1 to meet the appropriate A criterion before returning the turbine to service
(C) $10^{-3} < P_1 < 10^{-2}$	$10^{-4} < P_1 < 10^{-3}$	If this condition is reached during operation, the turbine is to be isolated from the steam supply within 60 days, at which time the licensee is to take action to reduce P_1 to meet the appropriate A criterion before returning the turbine to service
(D) $10^{-2} < P_1$	$10^{-3} < P_1$	If this condition is reached during operation, the turbine is to be isolated from the steam supply within 6 days, at which time the licensee is to take action to reduce P_1 to meet the appropriate A criterion before returning the turbine to service

Table 1: Turbine System reliability Criteria (NRC GUIDE NUREG-1048 Table U1)[3,4]

3 Integrity Analysis

3.1 Stress Corrosion Cracking (SCC)

When materials such as used in turbine disks (Fig. 2) are exposed to sustained high tensile stress and an aggressive moist environment, cracks can potentially initiate and grow with time. Figure 2 shows the configuration of the replacement BB281-18m^2 rotor, inner and outer casing.

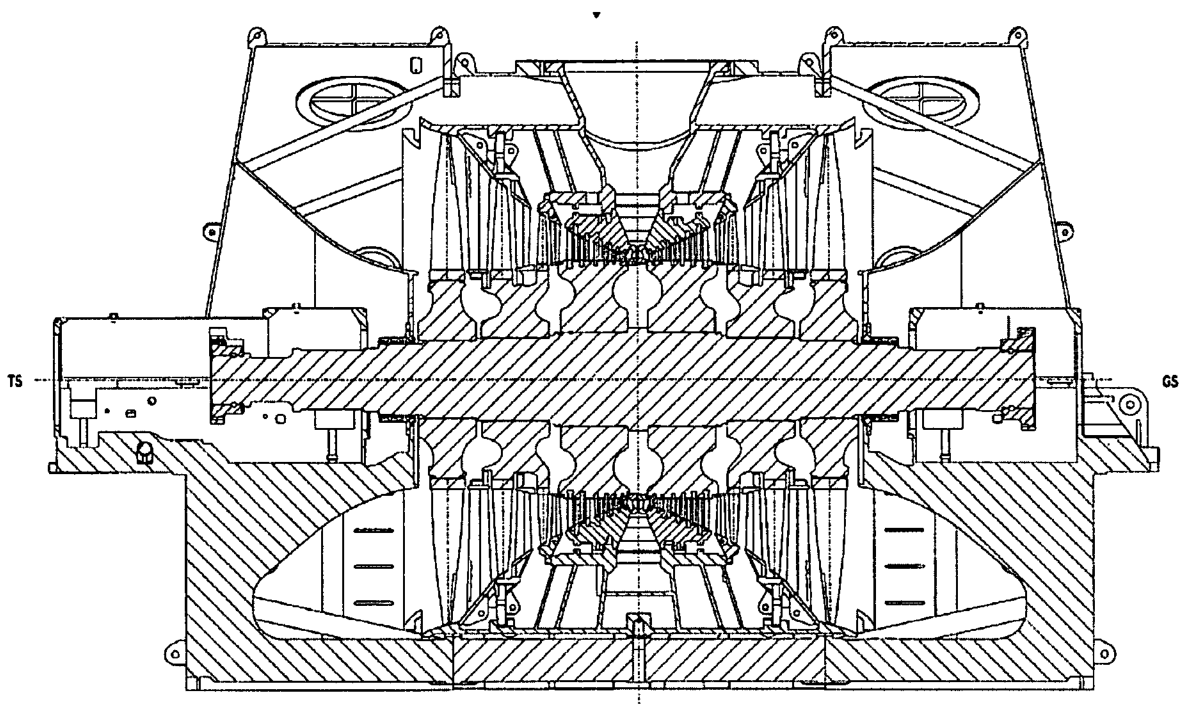


Fig. 2: Rotor with shrunk-on disks

This phenomenon is known as Stress Corrosion Cracking (SCC). Low pressure steam turbine shrunk-on disks with high stresses at the bore are susceptible to stress corrosion cracking. As a crack initiates and then grows with operating time, the stress intensity factor associated with the crack also increases. When the stress intensity factor approaches the critical stress intensity factor for the material which is the fracture toughness property, a disk burst condition occurs. Alternatively, a critical crack corresponding to the material fracture toughness is calculated, and a burst condition is considered to occur when the crack size equals the critical crack size.

Siemens has conducted extensive studies into the SCC behavior of materials used for rotor disks. The results of the investigations can be summarized as follows.

SCC consists of a crack initiation period in which pitting or cracks are formed which is followed by a crack growth period.

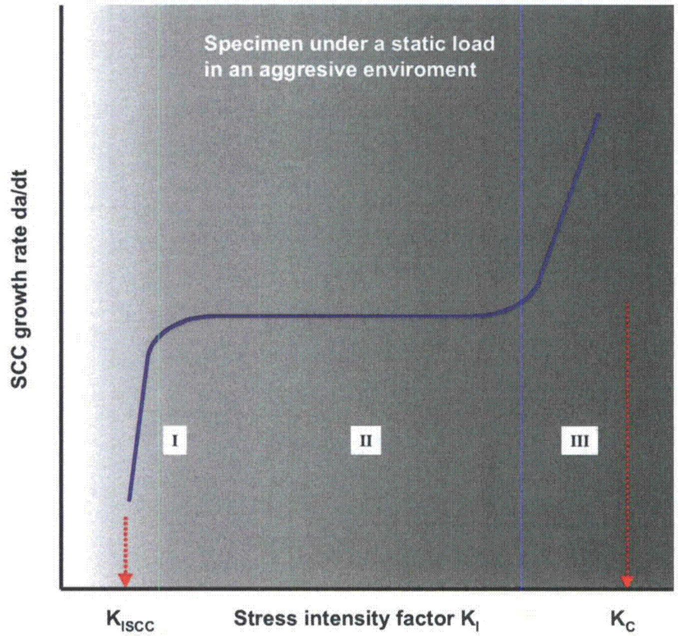


Fig. 3: Schematic dependency SCC growth rate versus stress intensity factor

Fig. 3 shows schematically the SCC growth rate as a function of the applied stress intensity factor K_I, which exhibits three distinct regions. Region I shows that no crack growth occurs below a threshold value of K_{ISCC} (typically of the order of about 20-30 MPa·√m). During region II SCC growth rate is largely independent of the stress intensity level, until K_I approaches the material fracture toughness level. Then in region III SCC growth rate increases rapidly leading to fracture.

Impurities in steam, conditions promoting flow stagnation such as crevices, steam condensation, ratio of stress to yield strength and level of yield strength significantly influence the potential for SCC.

In high purity water with a conductivity of < 0.2μS/cm, SCC initiation is influenced primarily by the quenching and tempering process which establishes the material's yield strength value. If the yield strength exceeds approximately 1085 MPa (157 ksi), the material becomes susceptible to SCC due to hydrogen embrittlement. Up to this threshold, no stress corrosion crack initiation occurred even when operating stress exceeded the yield strength in notched specimens. This result is not affected by the purity of steel. Under high purity water conditions, even nonmetallic inclusions (e.g. Al_2O_3, MnS etc.) do not act as crack starters at the material surface. Such inclusions do not influence the resistance to

stress corrosion cracking. This even applies to water with low oxygen content as well as to oxygen saturated water. Pit formation was also not found under these corrosive conditions.

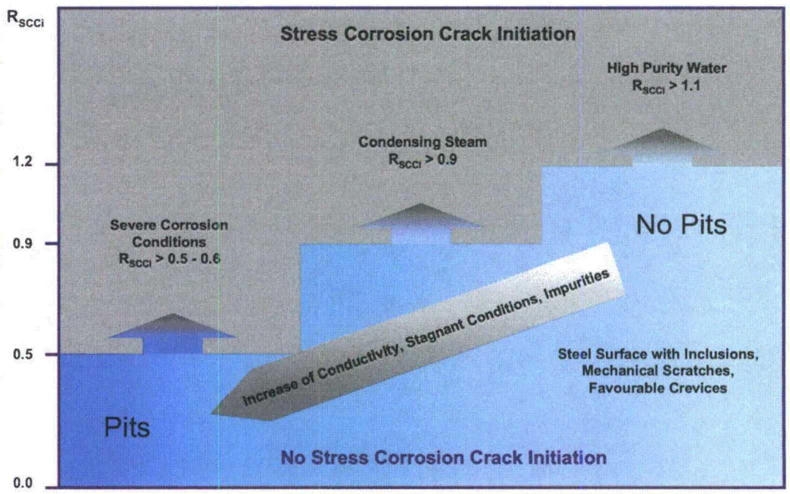


Fig. 4: Stress corrosion crack initiation of LP turbine rotor steels with 0.2% offset yield strengths < 1000 MPa (145 ksi)

The findings from extensive testing, power plant experience and review of literature were used to develop Fig. 4. For yield strengths less than 1000 MPa (145 ksi), this figure shows operating stress to yield strength ratios at which stress corrosion crack initiation can be expected for specific environment conditions. As shown in the figure, an improvement of the operating environment permits high stress levels up to and above the yield strength level of the material. The diagram also shows that for stress levels below 60% of the yield strength, stress corrosion cracking did not occur even under severe corrosion conditions.

3.2 Failure Assessment Procedure

Because of the large disk bore diameter, defects on the bore surface can be analyzed using the basic fracture mechanics model for the case of a semi-elliptical surface crack in an infinite plate subjected to tension loading σ_{eff}. This leads to the expression for the critical crack size a_{crit} at which a disk would rupture due to brittle fracture (within the "small scale yielding" approach) given by:

$$a_{crit} = \frac{Q}{1.21 \cdot \pi} \cdot \left(\frac{K_{Ic}}{\sigma_{eff}} \right)^2 ,$$

where:

K_{Ic} = Fracture toughness,

σ_{eff} = Effective tangential bore stress due to the combined action of centrifugal loads and residual compressive stresses (manufacturing) corresponding to Fig.5.

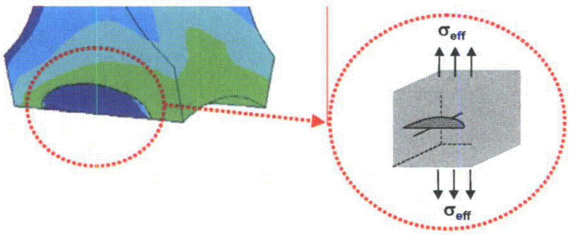


Fig. 5: Fracture mechanics model

The crack shape parameter Q is a combination of the square of the complete elliptical integral of the second kind and "small scale yielding" correction:

$$Q = E(k)^2 - 0.212\left(\frac{\sigma}{\sigma_Y}\right)^2$$

It can be for computational reasons approximated by the expression:

$$Q = 1 + 1.464 \cdot \left(\frac{a}{c}\right)^{1.65} - 0.212 \cdot \left(\frac{\sigma}{\sigma_Y}\right)^2$$

3.3 Stress Analysis

The finite element analysis of the rotor with the shrunk-on disks (Fig. 2) was conducted to determine the temperature and stress distribution due to the combined effect of shrink fit, thermal and centrifugal mechanical loads. The disk material is 26NiCrMoV14-5.

Temperature (Fig. 6) and tangential stress (Fig. 7) distributions in the disks are computed using Finite Element Analysis (FEA). All appropriate loading conditions must be considered in order to obtain the appropriate stress distributions for input to the fracture mechanics evaluation in the location of interest.

[

]

Fig. 6: Temperature distribution
(Units in Degrees C)

Note: Degrees F = 1.8 x Degrees C + 32

[

]

Fig. 7: Tangential stress distribution
(Units in MPa)

Note: ksi = MPa/6.89

Fig. 8 applies to a typical first disc and shows schematically the blue-colored compressive stress region (the width about 50 mm, 2 inches) and red-colored tensile stress region in the disk after special heat treatment during manufacturing. The corresponding distribution of the residual stress is presented as a brown line. The tangential stress distribution at 20% overspeed near the disk bore at the maximal stress location is shown as a red line. The combined effective stress distribution is presented as a dashed blue line.

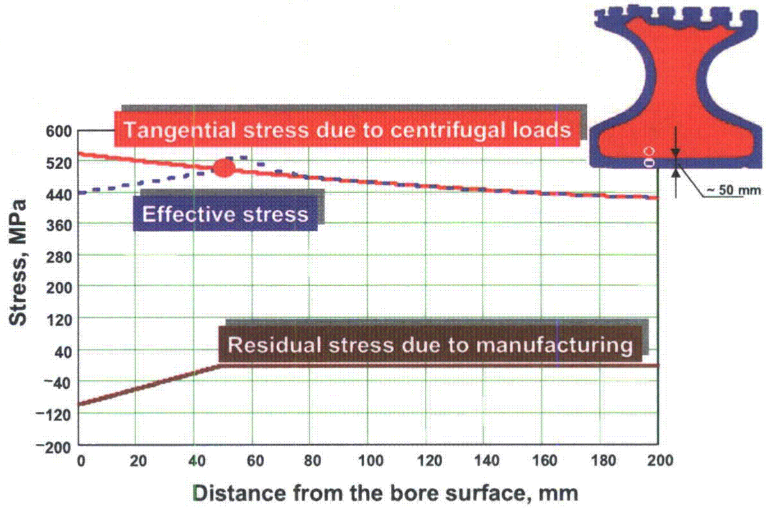


Fig. 8: Tangential (at 120% of rated speed), residual and effective stress distribution in the disk #1
Note: ksi = MPa/6.89

3.4 Probabilistic Fracture Mechanics Analysis

For probabilistic computations, Siemens has developed a numerical Monte-Carlo simulation code, PDBURST. As a failure condition the brittle fracture mode is assumed:

$$a_{cr}(K_{Ic}, \sigma_Y, \sigma, \xi, k) \leq a_i + \int_0^t \dot{a}(\sigma_Y, T)\,dt\,.$$

Where:

a_{cr} = Critical crack size,

a = Current crack size,

a_i = Initial crack size,

t = Operating time duration,

ξ = Crack shape factor (crack depth to crack length ratio),

K_{Ic} = Fracture toughness,

k = Branching factor,

σ = Applied load due to tangential stress at bore,

σ_Y = Yield strength, and

T = Temperature.

For probabilistic analysis the critical crack size is defined as that given by the equation in Section 3.2 or 100 mm (4 inch) whichever is smaller. The 100-mm (4 inch) limit is purely based on the applicability limitation of linear-elastic fracture mechanics concept and does not necessarily represent an imminent burst condition.

A brief description of selected random variables is given below.

3.4.1 Load

It is assumed that FE Analysis provides accurate results within 5% of tolerance due to the uncertainties in geometry as well as thermal and mechanical loads. A normal distribution is assumed. The mean values are shown in Table 2.

	Disk # 1	Disk # 2	Disk # 3
Metal temperature [°C]	[ ]	[ ]	[ ]
Tangential stress [MPa]	[ ]	[ ]	[ ]

Table 2: FE computation results

3.4.2 Crack Branching Factor

The branching factor k is assumed to be normally distributed with a mean of 0.65 and a standard deviation of 0.175, whereby

$$k = \begin{cases} 0.65 \; if \; Crack\,Depth \; \leq \; 3 \; in \\ 1 \quad otherwise \end{cases}$$

3.4.3 Fracture Toughness

The normal distribution has been used in describing scatter in fracture toughness data with a mean of [ ] MPa $\cdot\sqrt{m}$ ([ ] ksi $\cdot\sqrt{in}$) and standard deviation of [ ] MPa $\cdot\sqrt{m}$ ([ ] ksi $\cdot\sqrt{in}$).

3.4.4 Yield Strength

The yield strength values are assumed to be distributed normally with mean and standard deviation values based on internal investigation data:

Disk # 1: σ_Y = [ ] MPa and std. deviation = [ ] MPa); [ ] ksi and std. deviation = [ ] ksi

Disk # 2 and 3: σ_Y = [ ] MPa and std. deviation = [ ] MPa); [ ] ksi and std. deviation = [ ] ksi

3.4.5 SCC Growth Rate

As shown in Fig. 3 the stress corrosion cracking (SCC) rate is assumed to be independent on the stress intensity level. The main parameters influencing the SCC rate are temperature, material yield strength and water chemistry. Based on field measurements and laboratory test data the empirical equations for SCC rates were developed. For the probabilistic analysis, the following SCC rate is used:

$$\frac{da}{dt} = \exp(-4.968 - \frac{7302}{T+460} + 0.0278 \cdot \sigma_Y),$$

Where the SCC rate is given in inches/hour, temperature T in °F and the material yield strength σ_Y in ksi.

The log-normal distribution of this SCC rate with a standard deviation of 0.578 is assumed.

3.4.6 Initial Crack Size

The initial crack size is zero for the initial operating cycle and a value of a_i = 3 mm (0.12 inch) is assumed for subsequent operating cycles due to indication detectability limits.

3.4.7 SCC Initiation Model

Since SCC initiation is not understood well enough to be quantifiable as a function of time, it is modeled based on the observed cracking experience of the turbine disks in the field.

3.4.7.1 "Old" Approach

To date a total of over 82 Siemens #1 disks and 324 latter disks from 41 ten and eight disk LP rotors in operation have been inspected or re-inspected world wide over the last 20 years. Two of the newest six disk design rotors have been in operation only since September 1996 and eight more installed during 1997-99. Obviously, the number of these inspected six-disk rotors will continue to increase as time moves forward.

Only one #1 disk on a ten disks design rotor was found to have SCC type ultrasonic indication in the disk hub surface. There were no cracks in the higher stressed keyways. This finding was after 67,600 operating hours. This design did not have the benefit of design induced compressive residual stresses on the disk hub bore. Subsequent inspections found crack growth rate to be 3-4 mm (0.12 inch) per year. An investigation of the cause showed that the disk hub surface was contaminated by microscopic Ni-rich and S-rich particles, which were inadvertently introduced and pressed into the surface during the time of manufacture. This probably acted as the crack starter. Manufacturing procedures were redefined to preclude such occurrences in the future. Small indications were also found on two of the 324 latter disks. The nature of these indications could not be ascertained but are likely to be due to water erosion or SCC. Details of these findings have been reported earlier [5]. These two findings were on the inlet side of the TE and GE disk #4 of the same rotor. This rotor was also of ten disks design unit without induced residual stresses of the disk hub bore. The indications were found after 53,000 operating hours. Evaluation found no limitation to designed operating life, the rotor was returned to service and additional investigation to this time has not been possible due to the disks being in service.

Conservatively, assuming that all of the above indications are due to SCC and using standard statistical evaluation procedures, the crack initiation probabilities at 90% confidence level for each of the disks are as shown in Table 3.

Disk	Crack Initiation Probability, yr^{-1}
1	[ ]
2	[ ]
3	[ ]

Table 3: Crack Initiation Probability

3.4.7.2 Modern Approach

The probability of crack initiation in a given disk is estimated from the inspection data of turbine disks and the probability value depends on the disk # and the location of indication, i.e. either the keyway or hub bore. Thus, the crack initiation probability is treated as a binomial variant and estimated directly from field data showing the number of cracks found and the number of disks inspected for each disk type. The probability of crack initiation in a disk # i :

$$q_i = \begin{cases} \dfrac{\text{number of \#i disks with cracks}}{\text{number of inspected \#i disks}} \\ 1-(0.5)^{1/(\text{number of inspected \#i disks})}, \text{ if the number of \#i disks with cracks} = 0 \end{cases}$$

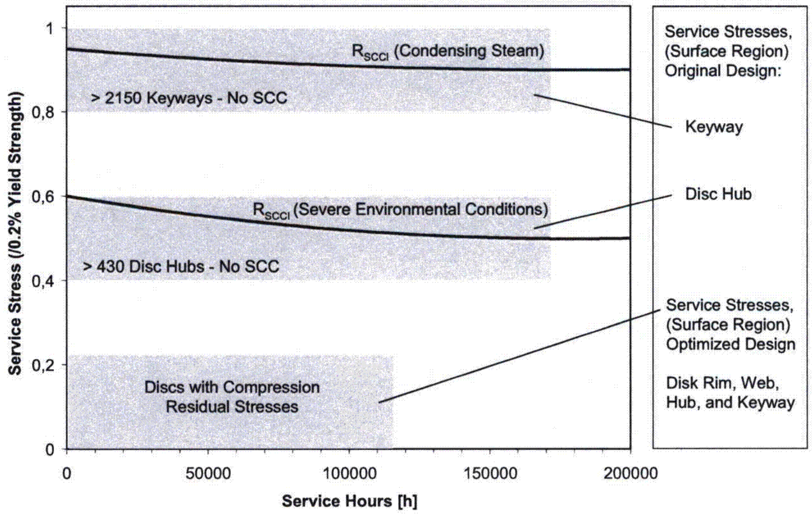


Fig. 9: Results of the investigation on crack initiation

Based on the investigation results [7,8] shown in Fig. 9 the following crack initiation probabilities q_i can be calculated:

Keyway area: q_i = [ ] yr^{-1} (2150 investigated keyways without any indication)

Disk hub area: q_i = [ ] yr^{-1} (more than 430 investigated disks without any indication)

For the probabilistic calculations, the more conservative “old” approach was assumed.

4 Probability of Casing Penetration for Speeds up to 120% of Rated Speed

4.1 Criterion for Casing Penetration Given a Disk Burst

The criterion for an internal missile fragment penetrating the surrounding blade ring and inner and outer casing structure is stated as follows:

$$E_i \geq E_d,$$

where

E_i is the total initial energy of the internal missile due to burst;

E_d is the total energy dissipated due to various resisting factors

A generic description of the procedure is as follows:

4.1.1 Initial Energy

The size of the angular segment of the disk with the blades is determined by maximizing the translational energy of the internal missile. The total energy of the missile segment is given by

$$E_i = \frac{1}{2} \cdot I \cdot \omega_b^2$$

Where:

I = Polar moment of inertia of the missile segment;

ω_b = Rotational speed at burst.

4.1.2 Energy Dissipation

Energy dissipation factors considered include blade crushing, blade bending, loss of blade mass due to break off, friction between missile fragment and inner casing structure, deformation of the stationary blade ring and inner casing up to breakage and penetration through the outer casing structure.

4.1.3 Calculation Results

Based on the Monte Carlo simulation technique in computer code PDMISSLE with 10^6 calculations, the probability of casing penetration at 120% rated speed was previously determined for the BB281 fleet of designs (Refs. 9 & 10). The casing penetration probabilities were found to be [ ] yr^{-1} for disk 1, [ ] yr^{-1} for disk 2 and [ ] yr^{-1} for disk 3, assuming a friction coefficient of 0.25.

5 Overspeed Event

Run-away overspeed events (>120% of rated speed) are due to failure of the overspeed protection system which consists of speed monitoring devices, trip and fast closure of steam stop and control valves. Siemens evaluates nuclear and fossil unit control systems together due to common control components, with the older fossil units adding conservatism [1, 2 and 6]. Based on the upper confi-

dence limit evaluations, overspeed probability values shown in Table 4 are used for typical valve test frequencies.

Valve Test Frequency	Probability of Overspeed, Yr^{-1}
Weekly	$1.6 \cdot 10^{-7}$
Monthly	$9.0 \cdot 10^{-7}$
Quarterly	$3.0 \cdot 10^{-6}$

Table 4: Overspeed probability values

For the probabilistic calculations for Crystal River 3, the customer advised that quarterly valve test intervals applied and accordingly were used in the analysis.

6 Probabilistic Simulation Results

The probabilistic results were generated using a Monte Carlo simulation technique involving successive deterministic fracture mechanics calculations using randomly selected values of variables described in the Sections 3.4 and 4.1. One million simulations were performed for each disk. Reproducibility and consistency of results was tested using various random number generators and random number seeds.

The results of calculations are representatively shown in Table 5.

	Disk #1	Disk #2	Disk #3
P_{2ri}	[ ]	[ ]	[ ]
P_{2rg}	[ ]	[ ]	[ ]
$P_{2r} = P_{2ri} \cdot P_{2g}$	[ ]	[ ]	[ ]
P_{3r}	[ ]	[ ]	[ ]
$P_r = P_{2r} \cdot P_{3r}$	[ ]	[ ]	[ ]
$\sum_{i=1}^{4} P_r$	[ ]	[ ]	[ ]

Table 5: Representative calculation for the 100,000 hours inspection interval

Since $P_{1o} = 3.42 \cdot 10^{-5}$, which is $3.0 \cdot 10^{-6}$ per year for 100,000 hours, the total probability of an external missile (P_1) for the unit at 100,000 hours inspection interval is:

$$P_1 = 1.74 \cdot 10^{-7} + 3.42 \cdot 10^{-5} = 3.44 \cdot 10^{-5} < 11.42 \cdot 10^{-5} \text{ (NRC limit value for 100,000 hours)}$$

Results are graphically illustrated in Figures 10 and 11 for quarterly valve test frequency of the overspeed protection system. Figure 10 compares the external missile probability including overspeed with the NRC limit of 1E-5 per year for an unfavorably oriented unit as a function of the inspection interval in hours. Figure 11 shows the external missile probabilities for normal operation up to and including 120% speed.

Figures 10 and 11 illustrate that as long as no cracking is detected, the new BB281-18m2 rotors can be safely operated for 100,000 hours between inspections. In Figures 10 and 11, the BB281 original light disc rotors [Ref. 11], which were prone to disc stress corrosion cracking (SCC) and the BB281 modified heavy disc and key plate (HDKP) rotors of 1984 [Ref. 12] were added for comparison to the

new BB281-18m2 replacement rotors. Turbine overspeed probability of $3.0 \cdot 10^{-6}$ per year (see Table 4) was assumed in the P_1 calculations for all rotors for consistency.

FIGURE 10

BB281-18m^2 DESIGN

COMPARISON OF EXTERNAL MISSILE PROBABILITIES INCLUDING OVERSPEED WITH NRC LIMIT

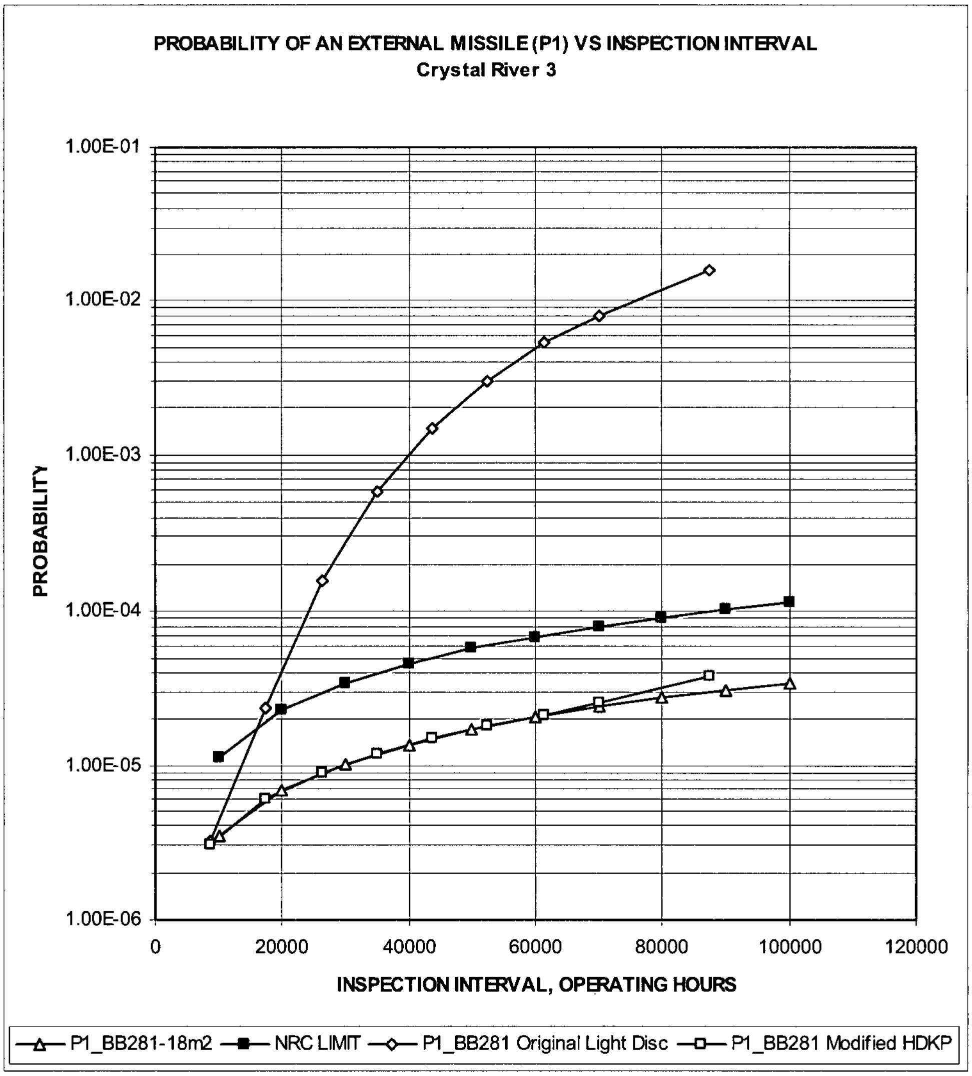
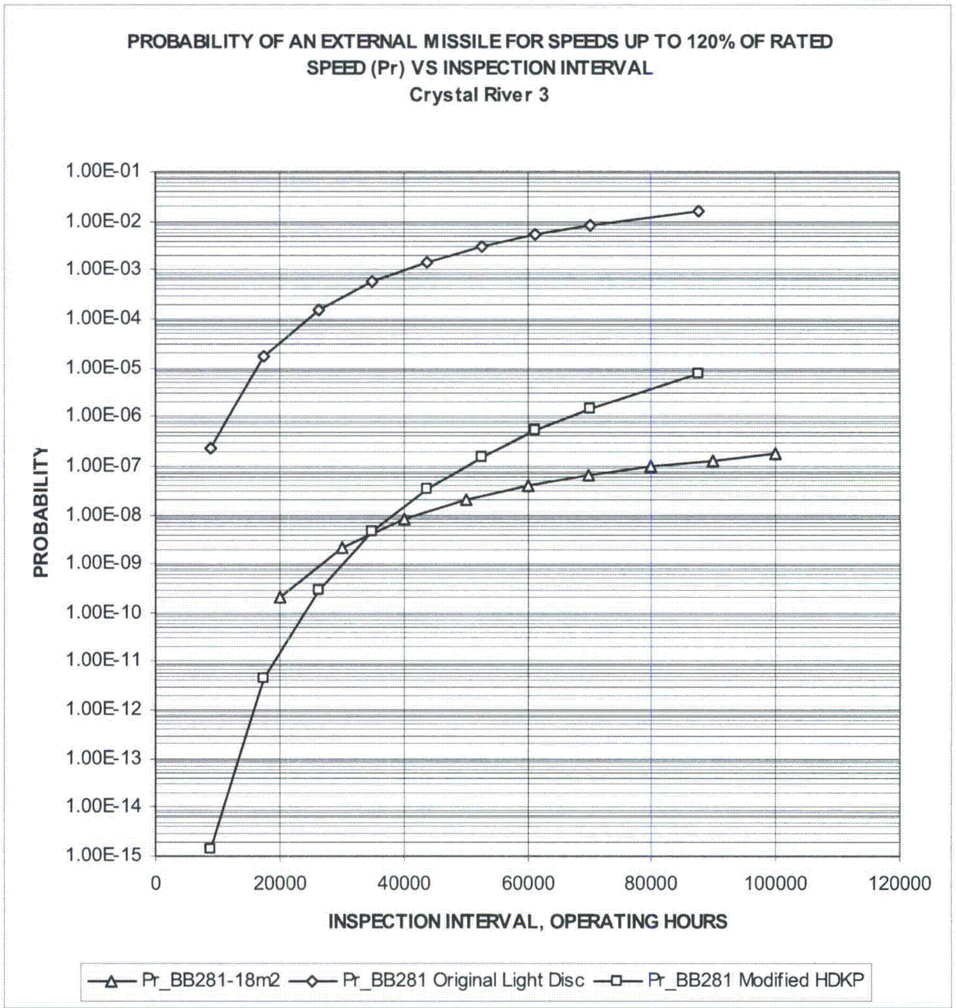


FIGURE 11

BB281-18m^2 DESIGN

EXTERNAL MISSILE PROBABILITIES FOR OPERATION UP TO 120% OF RATED SPEED



7 Conservatism in Methodology

Some conservatisms used in this report's assumptions and analysis are:

1. Residual compressive stresses introduced during manufacturing are conservatively assumed to be about –100 MPa (14.5 ksi). Figure 7 shows more realistic values of compressive residual stresses, which are much higher. The shrink fit and centrifugal stresses during normal operation, when combined with residual compressive stresses will reduce the final stresses to well below the threshold for stress corrosion cracking.
2. The crack initiation probabilities are based on the "old approach", which is applicable to ten and eight disc designs. Crack initiation probabilities could have been based on the "modern approach" with more up to date crack initiation data. This would have significantly lowered the probabilities.
3. Crack growth rates, documented as part of the Westinghouse methodology, are used in the analysis. These crack growth rates are the most conservative available. Siemens water chemistry assumptions are documented in STIM-11.002, "Turbine Steam Purity", which will be provided in the Instruction Book update for the turbine upgrade.
4. The probability of achieving speeds up to 120% of rated speed during normal operating conditions is conservatively assumed to be 1.0. More realistically, the probability of achieving speeds from 100% up to 120% of rated speed is a small value typically less than about 2E-3. Speeds exceeding 107% to 110% by control system design are uncommon. Speeds above 100% are limited by generator synchronization.
5. The missile probability up to 120% speed curve shown in Figure 11 is conservative at inspection intervals approaching 100,000 operating hours since they essentially represent the probability of a crack size exceeding 100 mm and not necessarily failure as discussed in section 3.4.
6. The probabilities of both burst and casing penetration for a run-away overspeed event greater than 120% of rated speed are conservatively set to be 1.0 for all discs. In reality, only the heaviest pieces with the worst geometry at significantly higher than 120% speed would penetrate the casing below the final burst speed. And then even less that 50% of those missiles would be thrown upward as downward trajectory missiles would impact balance of plant equipment only, such as the condenser.

8 References

[1] "Engineering Report ER-8605a, "Probability of Disk Cracking Due to Stress Corrosion - Connecticut Yankee Replacement LP Rotors", Utility Power Corporation Proprietary Information, July 1986, Rev A, June 1987.

[2] "Engineering Report ER-8611, "Turbine Missile Analysis for 1800 rpm Nuclear LP-Turbines with 44-inch Last Stage Blades", Utility Power Corporation Proprietary Information, July 1986, Rev 1, June 1987.

[3] U.S. Nuclear Regulatory Commission, Regulatory Guide (RG) 1.115, U.S. Nuclear Regulatory Commission, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", July1981.

[4] U.S. Nuclear Regulatory Commission NUREG - 1048 including Appendix U & Table U.1.

[5] "Missile Probability Analysis Methodology for Limerick Generating Station, Unit 1&2 with Siemens Retrofit Turbines", June 18, 1997.

[6] Ornstein, H. L.: "Operating Experience Feedback Report – Turbine-Generator Overspeed Protection Systems", U.S. Nuclear Regulatory Commission Report, NUREG-1275, Vol. 11, 1995.

[7] W. David, J. Ewald, F. Schmitz: „Grenzbelastungen zur Vermeidung von Spannungsrißkorrosion an ferritischen Rotorwerkstoffen“, VGB-Konferenz „Korrosion und Korrosionsschutz in der Kraftwerkstechnik“, 29. und 30. November 1995, Essen.

[8] W. David, J. Ewald, F. Schmitz: „Grenzbelastungen zur Vermeidung von Spannungsrißkorrosion an ferritischen Rotorwerkstoffen“, Korrosionsschäden in Kraftwerken, 9. VDI Jahrestagung Schadensanalyse, 1. und 2. Oktober 1997, Würzburg.

[9] Letter from Mr. Herbert N. Berkow, NRC Director, to Mr. Stan Dembkoski, SWPC Director, dated March 30, 2004, Subject: Final Safety Evaluation Regarding Referencing the Siemens Technical Report No. CT-27332, Revision 2, "Missile Probability Analysis for the Siemens 13.9m^2 Retrofit Design of Low-Pressure Turbine by Siemens AG", TAC No. MB7964.

[10] Safety Evaluation by the Office of Nuclear Reactor Regulation, Technical Report No. CT-27332, Revision 2, "Missile Probability Analysis for the Siemens 13.9m^2 Retrofit Design of Low-Pressure Turbine by Siemens AG", Siemens Westinghouse Power Corporation (SWPC)", Project No. 721, March 30, 2004.

[11] CT-24114, Revision 1, March 1981, "Turbine Missile Report, Results of Probability Analyses of Disc Rupture and Missile Generation for Florida Power Corporation, Crystal River Station, Unit No. 3, Serial Numbers 13A3511-1, 23A3512-1 and 23A3513-1", Westinghouse Electric Corporation.

[12] Westinghouse Service Orders TAE91971 (LP1 Rotor TN1111) and TAE91972 (LP2 Rotor TN1112), Rotor Assembly Alteration Refurbishment, August 1984.

APPENDIX A

Resolution of Comments

1. Progress Energy Comment: Reference 10. Has the NRC issued a SER for the 18M2 LP Turbine Design?

Siemens Response: Yes. The NRC approved our methodology in the SER including terminology giving it generic applicability to other products of the "advanced disk design" concept.

2. Progress Energy Comment: Table 1 indicates action is required when P1 > 10^{-5}. Figure 10 indicates P1 is > 10^{-5} after 30,000 operating hours and the NRC P1 limit curve changes with operating hours. Please explain this and document the P1 difference between Table 1 and Figure 10 in the report.

Siemens Response: The probabilities listed in Table 1, which is also found in NUREG 800 as Table 3.5.1.3-1, are in terms of occurrences per year. Figure 10 shows the cumulative probability of occurrence, or the probability of an occurrence per hours of operation. These numbers are not directly comparable.

The "NRC Limit" curve represents a probability of 10^{-5} occurrences/year as it accumulates over the course of 100,000 hours. While the cumulative probability of occurrence exceeds 10^{-5} after 30,000 hours, that is considerably more than one year and thus at no time does the annual probability exceed 10^{-5} occurrences per year.