SUMMARY REPORT

ON THE

TURBINE MISSILE DAMAGE PROBABILITY ANALYSIS FOR

NORTH ANNA UNITS 1 AND 2

FOR

VIRGINIA ELECTRIC AND POWER COMPANY

BY

STONE & WEBSTER ENGINEERING CORPORATION

(REF. CALC. 13075.01-NM(B)-388-DKA)

INTRODUCTION

This report provides an overview of a probability study on turbine missile damage at the North Anna site. It includes a summary of the findings, a brief discussion of the method by which they were obtained, and an interpretive discussion of their meaning. The analytical basis for the results and conclusions presented in this report can be found in Stone & Webster calculation 13075.01-NM(B)-388-DKA. The sole purpose of this report is to clearly present the findings of this calculation independent of the detailed technical justification upon which they are based. Due to the lack of P1 data for the HP Rotor, this summary is based on damage from the low pressure turbine hoods only.

Based on the characteristics of the HP Rotor and its postulated missiles, it is expected that the resulting increase due to the inclusion of the HP Rotor will be insignificant.

OBJECTIVE

The purpose of the calculation is to compute the total probability of incurring unacceptable damage to essential systems at the North Anna site as a result of a turbine failure. This is done to satisfy the requirements of Regulatory Guide 1.115 (Ref. 1) and Standard Review Plan 3.5.1.3 (Ref. 2). A conservative analysis and the acceptance criteria of 10^{-6}/annum, as allowed by Standard Review Plan 2.2.3 (Ref. 9), is used to arrive at an acceptable inspection frequency for the Westinghouse turbines.

Four distinct situations will be considered to arrive at the limiting case for minimum inspection frequency:

1. Damage to Unit 1 due to Low Trajectory Missiles
2. Damage to Unit 2 due to Low Trajectory Missiles
3. Damage to Unit 1 due to High Trajectory Missiles
4. Damage to Unit 2 due to High Trajectory Missiles

For each case above, the probability of damage will be calculated based on the failure probability of both turbines at the North Anna 1 and 2 site. The maximum value calculated for any case will be compared to the 10^{-6}/annum criteria to establish the governing inspection frequency.

The calculation is limited in scope to the two existing units at the North Anna site. However, the effect of turbine failures in future units is discussed on a qualitative basis.

ASSUMPTIONS

1. The failure of a disc from the low pressure hood is assumed to create three or four equal segments with the properties defined in Ref. 4. The probability of generating either 90 deg or 120 deg segments is assumed equal.

2. The only targets of high trajectory missiles are the roofs of structures and the only targets of low trajectory missiles are the walls of structures. (Since the containment dome has a projected area in both plan and elevation views, it is a target for both types of missile.)

3. Interior discs (discs 1-4) may have trajectories up to 5 deg off the plane of rotation. End discs (disc 5) may have trajectories from 5 deg to 25 deg off the plane of rotation, but only in the direction of the hood end.

4. For the purpose of calculating strike probabilities, the missile is assumed to be a point object.

5. The origin of internal disc missiles is located at the center of the hood and the origins of the outer disc missiles are assumed to be 6 feet to either side of the hood center.

6. If a missile penetrates a barrier, it is assumed to follow the same trajectory it had before striking the barrier, but the kinetic energy is reduced (i.e., the barrier is not a scattering source). If the missile does not penetrate a barrier, ricochets and secondary missiles are not considered.

7. In a barrier penetration analysis, only the velocity normal to the barrier surface is relevant.

8. No earthquake or pipe rupture occurs concurrently with the postulated failure of the turbine.

9. The column 9 line is the divider between Units 1 and 2.

10. For the destructive overspeed case, it is assumed ι... the failure rate for any one of the 20 low pressure turbine discs is 1/20 of the total.

11. The failure of the high pressure rotor is assumed to create eight equal segments with the properties defined in Ref. 4. All missiles created are assumed to originate at the center of the high pressure hood and have trajectories up to 5 deg off the plane of rotation.

12. It is assumed that, for every fragment created by a low pressure disc failure or a high pressure rotor failure, there will be corresponding cylinder and blade ring fragments as detailed in Ref. 4.

13. When using the modified NDRC formula for calculating missile perforation, it is adequate to use the average missile diameter, since the equation is reasonably insensitive to this parameter in the normal range of turbine missile diameters.

METHOD

The probability of unacceptable missile damage is computed from:

$$P = \sum_{i=1}^{2} \sum_{j=1}^{3} \sum_{n=1}^{21} P_{1ijn} \sum_{t-1}^{T} \sum_{s=1}^{S_{jn}} \frac{1}{S_{jn}} \sum_{m=1}^{M_{jin}} L_{ijns} (P_2 P_3)_{ijntsm}$$

where P = Total probability for incurring damage during period between inspections

P_1 = Disc failure probability for inspection interval considered

P_2 = Strike probability, assuming disc failure

P_3 = Probability that the impacting missile will cause unacceptable damage

i = Unit number of turbine being considered

j = Operating condition at which failure occurs

= 1 = 100 percent rated speed
= 2 = 120 percent overspeed
= 3 = 191 percent destructive overspeed

n = Turbine disc under consideration. There are a total of 21 discs per turbine, 20 low pressure wheels, and one high pressure rotor.

t = A target

T = Total number of targets

M = Number of fragment types as ociated with disc n (i.e., disc, cylinder, and blade ring fragments per Ref. 4)

L = Number of fragments of each type generated by a disc failure

= 8 for high pressure rotor
= 3 or 4 for low pressure wheels

S = Number of variations in L considered for disc n

= 1 for high pressure rotor
= 2 for low pressure wheel

An analysis using the above equation has been done twice to find the probability using two different criteria for unacceptable missile damage:

<u>Criterion "A"</u> - Using the modified NDRC formulas for scabbing and perforation, a missile will be considered to produce unacceptable damage if it perforates the final concrete barrier if lined by steel or produces backface scabbing if unlined.

<u>Criterion "B"</u> - Using the CEA-EDF formula for perforation (considered the best of current perforation formulas, Ref. 6), a missile will produce unacceptable damage only if it perforates the final barrier (i.e., scabbing is not considered).

The analysis using the above equation and Criterion "A" has six major steps:

1. Define target areas and locations with respect to the turbine hoods. This is done by defining the target, usually as an entire structure containing essential equipment, but occasionally as only a portion of a structure. The areas, locations, and structural protection of the targets are derived from Stone & Webster drawings of the North Anna Power Station.

2. Using the modified National Defense Research Council (NDRC) formula and the missile properties from Ref. 4, calculate the minimum concrete thickness required to prevent backface scabbing (T_s) and the minimum concrete thickness required to prevent perforation (T_p) for each missile.

3. Eliminate targets for which $P_3 = 0$ or for which redundant or alternative systems can be identified for every essential system within the target. This is straightforward for high trajectory missiles since the missiles come approximately straight down and hit the target structures directly without interacting with any other barriers. For low trajectory missiles, essential targets may be in the shadow of barriers. Important barriers include the turbine support, the moisture separators, roofs, walls, and the turbine hall operating floor (at shallow impact angles). These barriers and the possible range of missile trajectories are evaluated by manual analysis to determine which structures defined in step 1 (or which portions of structures) are actually targets.

4. Calculate the probability of perforating the containment dome and cylinder for each missile based on its velocity normal to the target surface at impact. The containment liner has been conservatively neglected in this analysis.

5. Calculate strike probabilities using the MA-057 computer code.

6. Manually sum the terms in the probability equation. Detailed analysis at this step may consider refinement in target areas.

The analysis was then repeated using Criterion "B" as follows:

1. Since disc 2 has a P_1 value which comprises more than 99 percent of the total P_1 value for the turbine for the 100 percent and 120 percent cases, only the probability due to disc 2 is modified. Probabilities for other discs are conservatively assumed to be identical to those calculated in the analysis using Criterion "A."

2. The probability at the 191 percent speed case is not reanalyzed, but is reduced by the probability found for disc 1 which only produces scabbing damage. Disc 1 accounts for approximately 75 percent of the total probability for high trajectory missiles and approximately 25 percent of the total for low trajectory missiles.

3. It is not necessary to repeat steps 1, 3, or 5, as these are identical for both analyses.

4. The CEA-EDF perforation formula is used to calculate the minimum concrete thickness required to prevent perforation for disc 2 and its associated fragments.

PENETRATION EQUATIONS

I. BALLISTIC RESEARCH LABORATORY (BRL) FORMULA

For steel barriers, calculate the perforation thickness T_p using the Ballistic Research Laboratory (BRL) formula:

$$T_p^{3/2} = \frac{E}{17{,}400\ k^2 d^{3/2}}$$

where T_p = Steel wall thickness required to prevent perforation (in)

E = Energy of the missile normal to barrier (ft-lb)

k = Constant depending on the steel ($k \approx 1$)

d = Diameter of the missile (in)

Since the turbine missile is not cylindrical, the diameter may be approximated by

$$d = \sqrt{4A/\pi}$$

where A is the missile cross-sectional area.

II. MODIFIED NATIONAL DEFENSE RESEARCH COUNCIL (NDRC) FORMULA

For concrete barriers, use the modified National Defense Research Council (NDRC) formula to calculate the penetration depth:

$$G(x/d) = K\ Nd^{0.20} D\ (V/1000)^{1.80}$$

where

$$G(x/d) = \begin{cases} (x/2d)^2, & \text{for } x/d \leq 2.0 \\ (x/d-1), & \text{for } x/d > 2.0 \end{cases}$$

K = Concrete penetrability factor = $180/\sqrt{f'_c}$

N = Missile shape factor = 0.84 (blunt-nosed)

d = $\sqrt{4A/\pi}$, missile diameter (in)

D = W/d^3, the calibre density of the missile (lb/in^3)

V = Velocity (ft/sec)

x = Penetration depth (in)

W = Missile weight (lb)

TO CALCULATE SCABBING THICKNESS

The penetration depth, x, can be converted to T_s, the concrete wall thickness required to prevent scabbing, using:

$$T_s/d = 7.91\ x/d - 5.06\ (x/d)^2, \text{ for } x/d \leq 0.65$$

$$T_s/d = 2.12 + 1.36\ x/d \quad , \text{ for } x/d > 0.65$$

TO CALCULATE PERFORATION THICKNESS

The NDRC perforation thickness can be found using the NDRC penetration depth, x, and

$$T_p/d = 3.19\ x/d - 0.718\ (x/d)^2, \text{ for } x/d \leq 1.35$$

$$T_p/d = 1.32 + 1.24\ x/d \quad , \text{ for } x/d > 1.35$$

III. CEA - EDF PERFORATION FORMULA (REF. 6)

For concrete barriers, use the CEA-EDF formula to calculate the minimum thickness required to prevent perforation by solid missiles:

$$T_p = 0.765\ (f_c')^{-3/8} \left(\frac{W}{d}\right)^{1/2} V^{3/4}$$

where T_p = Concrete wall thickness required to prevent perforation (in)

f_c' = Concrete strength (psi)

W = Missile weight (lb)

d = Missile diameter (in)

V = Missile velocity (ft/sec)

CALCULATION CONSERVATISMS

In order to demonstrate the conservative nature of this calculation and defend the use of an acceptance criteria of 10^{-6} per year, as allowed by S.R.P. 2.2.3 (Ref. 9), the conservatisms are presented below.

a. The analysis did not take full advantage of the separation of redundant systems due to the extensive research required to properly generate this input.

b. The cross-sectional areas of the entire safety-related structures were used in calculating the strike probability values, P2. For perforation considerations this is extremely conservative, since only strikes to the cross-sectional area of the actual safety-related equipment and components would result in damage. For scabbing considerations, equipment not in the direct path of a missile might still be affected by secondary missiles, but secondary missiles have a much lower damage probability P3, so using the area of the entire structures instead of just the safety-related parts is definitely conservative.

c. The perforation protection provided by tank walls and the containment liner has been neglected. The containment cylinder is lined with 3/8 inch of steel and the dome has a 1/2-inch liner. For a typical missile with a diameter of 20 inch and a weight of 2,500 lb, the velocity required to perforate the liner acting alone is:

    119 ft/sec for the dome and 96 ft/sec for the cylinder (using BRL formula, see method section)

d. Current analytical methods to predict scabbing and perforation are known to be conservative. This is most noticeable in the scabbing predictions.

e. Using the 28-day compressive strength of concrete, fc', to calculate penetration distances is conservative. Concrete continues to gain strength throughout its life and typically achieves a strength of 120 percent fc' by the end of its first year.

f. Due to the complexity of evaluating the numerous shielding structures and components between the turbine and the targets, only the moisture separator, turbine pedestal, and turbine room floor were considered.

DESIGN INPUT

The following areas contain systems essential to shut down the plant, maintain it in a safe shutdown condition, and/or limit off-site exposures. This list is based on the assumption that no earthquake or pipe rupture occurs concurrently with the postulated turbine failure:

Reactor Containment
Main Steam Valve Area
Control Room
Relay Room
Auxiliary Building
Fuel Building (portions only)
Cable Vault
Cable Tunnel
Fuel Oil Pump House and Tanks
Decay Tanks - Waste Gas
Condensate Storage Tank
Service Water Pump House and Piping
Auxiliary Feedwater Pipe Tunnel

Other conceivable targets were eliminated.

Turbine missile properties are provided in Ref. 4.

Missile generation probabilities are provided in Ref. 5 and 8.

CONCLUSIONS

Using the more conservative of the two analytical methods in this calculation, North Anna Units 1 and 2 have acceptable probabilities of damage due to turbine failure, if the turbines are inspected at an interval not to exceed one year of actual operation. This acceptable inspection interval can be increased by as much as eight months if the less conservative approach (Criterion "B") is used.

It should be noted that the single most important factor influencing the total probability values is the P1 value for the destructive overspeed case. Westinghouse currently provides a value of 1.7×10^{-6} for this quantity. If this value can be further reduced by periodic valve testing, it should be possible to extend the acceptable interval between turbine inspections.

SUMMARY OF RESULTS

Numerical results based on one year of continuous operation are summarized in Tables I and II for the following two criteria:

	Criterion "A" (Table I)	Criterion "B" (Table II)
1.	The initiation of back-face scabbing constitutes unacceptable damage. (Uses modified NDRC formula for scabbing)	Scabbing is neglected, as the probability of resulting damage is considered small
2.	Uses 28-day concrete strergth (f_c') of 3,000 psi.	Since concrete has aged for several years a 20 percent increase in fc' is used. fc' = 3,600 psi.
3.	Uses modified NDRC formula for perforation as recommended by NRC in Ref. 1.	Uses more accurate perforation formula recently developed by CEA-EDF.

Based on the conservatism inherent in the method of analysis (see list of calculation conservatisms at end of methods section), the acceptance criteria of 10^{-6} per year should be compared to the total probability value for each unit-trajectory combination.

Numerical results based on two years of continuous operation are summarized in Tables III and IV. Use acceptance criteria of 2×10^{-6} for these tables.

Some rough guidelines, relative to the effect of future units at the North Anna site on the results of this calculation, are given in Table V.

TABLE I

BASED ON: CRITERION "A" AND P1 VALUES FROM WESTINGHOUSE
(REF. 5 AND 14)

TOTAL DAMAGE PROBABILITY FOR ONE YEAR
CONTINUOUS OPERATION

UNIT - TRAJECTORY	PERCENT OF RATED SPEED 100%	120%	191%	TOTAL
Unit 1 - Low Traj.	2.536×10^{-7}	4.28×10^{-9}	6.546×10^{-7}	0.912×10^{-6}
Unit 1 - High Traj.				
Due to Unit 1 Turbine	1.35×10^{-7}	8.42×10^{-10}	5.229×10^{-8}	
Due to Unit 2 Turbine	9.72×10^{-9}	2.12×10^{-10}	2.395×10^{-9}	
Total	1.45×10^{-7}	1.054×10^{-9}	5.469×10^{-8}	2.00×10^{-7}
Unit 2 - Low Traj.	2.91×10^{-7}	4.25×10^{-9}	6.432×10^{-7}	0.938×10^{-6}
Unit 2 - High Traj.				
Due to Unit 1 Turbine	1.09×10^{-8}	2.38×10^{-10}	3.602×10^{-9}	
Due to Unit 2 Turbine	1.79×10^{-7}	1.44×10^{-9}	2.802×10^{-8}	
Total	1.90×10^{-7}	1.68×10^{-9}	3.162×10^{-8}	2.232×10^{-7}

TABLE II

BASED ON: CRITERION "B" AND F1 VALUES FROM WESTINGHOUSE (REF. 5 AND 14)

TOTAL DAMAGE PROBABILITY FOR ONE YEAR CONTINUOUS OPERATION

UNIT - TRAJECTORY	PERCENT OF RATED SPEED 100%	120%	191%	TOTAL
Unit 1 - Low Traj.	1.94×10^{-13}	1.059×10^{-13}	4.763×10^{-7}	4.763×10^{-7}
Unit 1 - High Traj.				
Due to Unit 1 Turbine	1.019×10^{-9}	9.355×10^{-11}	1.554×10^{-9}	
Due to Unit 2 Turbine	3.90×10^{-10}	6.686×10^{-11}	1.591×10^{-9}	
Total	1.409×10^{-9}	1.604×10^{-10}	3.145×10^{-9}	4.714×10^{-9}
Unit 2 - Low Traj.	2.857×10^{-12}	1.059×10^{-13}	4.706×10^{-7}	4.706×10^{-7}
Unit 2 - High Traj.				
Due to Unit 1 Turbine	2.283×10^{-9}	1.032×10^{-10}	2.860×10^{-9}	
Due to Unit 2 Turbine	2.923×10^{-8}	7.336×10^{-10}	3.360×10^{-9}	
Total	3.151×10^{-8}	8.368×10^{-10}	6.22×10^{-9}	3.857×10^{-8}

TABLE III

BASED ON: CRITERION "A" AND P1 VALUES FROM WESTINGHOUSE
(REF. 5 AND 14)

TOTAL DAMAGE PROBABILITY FOR TWO YEARS
CONTINUOUS OPERATION

	PERCENT OF RATED SPEED			
UNIT - TRAJECTORY	100%	120%	191%	TOTAL
Unit 1 - Low Traj.	1.37×10^{-5}	1.727×10^{-7}	1.309×10^{-6}	1.518×10^{-5}
Unit 1 - High Traj.				
Due to Unit 1 Turbine	7.66×10^{-6}	3.53×10^{-8}	1.046×10^{-7}	
Due to Unit 2 Turbine	0.52×10^{-6}	0.87×10^{-8}	4.79×10^{-9}	
Total	8.18×10^{-6}	4.40×10^{-8}	1.094×10^{-7}	8.333×10^{-6}
Unit 2 - Low Traj.	1.56×10^{-5}	1.71×10^{-7}	1.286×10^{-6}	1.706×10^{-5}
Unit 2 - High Traj.				
Due to Unit 1 Turbine	6.46×10^{-7}	1.03×10^{-8}	7.024×10^{-9}	
Due to Unit 2 Turbine	1.00×10^{-5}	6.03×10^{-8}	5.604×10^{-8}	
Total	1.07×10^{-5}	7.06×10^{-8}	6.324×10^{-8}	1.083×10^{-5}

Note: Acceptance criteria is 2×10^{-6}

TABLE IV

BASED ON: CRITERION "B" AND P1 VALUES FROM WESTINGHOUSE (REF. 5 AND 14)

TOTAL DAMAGE PROBABILITY FOR TWO YEARS CONTINUOUS OPERATION

UNIT - TRAJECTORY	PERCENT OF RATED SPEED 100%	120%	191%	TOTAL
Unit 1 - Low Traj.	1.21×10^{-10}	4.37×10^{-11}	9.526×10^{-7}	9.528×10^{-7}
Unit 1 - High Traj.				
Due to Unit 1 Turbine	8.585×10^{-8}	3.818×10^{-9}	3.108×10^{-9}	
Due to Unit 2 Turbine	2.194×10^{-8}	2.772×10^{-9}	3.182×10^{-9}	
Total	1.078×10^{-7}	6.59×10^{-9}	6.29×10^{-9}	1.207×10^{-7}
Unit 2 - Low Traj.	1.728×10^{-9}	4.37×10^{-11}	9.412×10^{-7}	9.430×10^{-7}
Unit 2 - High Traj.				
Due to Unit 1 Turbine	1.349×10^{-7}	4.418×10^{-9}	5.72×10^{-9}	
Due to Unit 2 Turbine	3.369×10^{-6}	3.099×10^{-8}	6.72×10^{-9}	
Total	3.504×10^{-6}	3.54×10^{-8}	1.244×10^{-8}	3.552×10^{-6}

Note: Acceptance criteria is 2×10^{-6}

TABLE V

EFFECTS OF FUTURE UNITS ON CALCULATION RESULTS

On Total Probability For:	Effect of Missiles From Unit 3	Unit 4	Total
Unit 1 - Low Trajectory Case	None	None	None
Unit 2 - Low Trajectory Case	Increase of $\approx$ 1%	None	Increase of $\approx$ 1%
Unit 1 - High Trajectory Case	Increase of $\approx$ 4%	Increase of $\approx$ 1%	Increase of $\approx$ 5%
Unit 2 - High Trajectory Case	Increase of $\approx$ 9%	Increase of $\approx$ 4%	Increase of $\approx$ 13%

Note: Prior to the operation of a future unit, it has zero probability of damaging the existing units.

Assumptions:

1. The missiles generated from future units were assumed to be identical to those of the existing units.
2. Turbine hood configuration and disc trajectories were also considered identical to the existing units, except future units were considered to have three low pressure hoods instead of two.

REFERENCES:

1. Regulatory Guide 1.115, Rev. 1, "Protection Against Low-Trajectory Turbine Missiles," USNRC, July 1977.

2. Standard Review Plan 3.5.1.3, Rev. 1, "Turbine Missiles," USNRC.

3. Regulatory Guide 1.117, Rev. 1, "Tornado Design Classification," USNRC, April 1978.

4. CT-24821, "Turbine Missile Report," Westing..ouse Electric Corporation, August 1980.

5. CT-24822, "Results of Probability Analyses of Disc Rupture and Missile Generation," Westinghouse Electric Corporation, August 1980.

6. George E. Sliter, "Assessment of Empirical Concrete Impact Formulas," Journal of The Structural Division, May 1980.

7. MA-057 Computer Code, "Strike Probability Analysis for Turbine Missiles," User Manual, Stone & Webster Engineering Corporation, Reissued October 1979.

8. "Analysis of The Probability of The Generation and Strike of Missiles from a Nuclear Turbine," Westinghouse Electric Corporation, March 1974.

9. Standard Review Plan 2.2.3, "Evaluation of Potential Accidents," USNRC.