UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

OF THE TOPICAL REPORT ENTITLED

"PROBABILISTIC EVALUATION OF REDUCTION IN TURBINE VALVE TEST FREQUENCY" WCAP-11525

I. INTRODUCTION

Westinghouse has prepared a Topical Report, WCAP-11525, entitled "Probabilistic Evaluation of Reduction in Turbine Valve Test Frequency," June 1987, in support of several owners of Westinghouse nuclear steam turbines. The nuclear power plants represented by this study currently have technical specifications or other requirements that call for weekly or monthly turbine valve testing. Periodic valve testing requires a temporary power reduction. This increases the plant vulnerability to tripping during such transients. Also, it may add to the number of thermal cycles for the piping, valves, and turbine. The Topical Report presents a probabilistic analysis with the objective of relaxing the turbine valves test frequency requirements.

The physical arrangement of the turbine valves, as well as the trip and control logic that operates them, affect the likelihood of occurrence of overspeed events. The function of the turbine valves is to control and limit the turbine speed and, in case of loss of load, trip the turbine by stopping the steam supply. Valve testing provides an assurance of the valve's reliability and limits the potential for turbine overspeed. This minimizes the likelihood of turbine missile generation and resulting damage to safety systems. Therefore, the valve test interval affects the estimated reliability for the valve to perform its intended function upon demand. The failure of a turbine valve to perform its function, in turn, affects the probability of turbine overspeed and missile ejection. The probability of turbine missile ejection, given an overspeed event, has been calculated for each turbine using detailed plant-specific data. The Topical Report shows the results of calculations for each of the turbines under study.

This is an evaluation of the probabilistic study presented in the Topical Report, WCAP-11525. Section II below provides a description of speed control systems and of various turbine trips. Section III provides an assessment of the probabilistic analysis and analysis assumptions presented in the Topical Report. Section IV contains conclusions.

II. TURBINE VALVES AND SPEED CONTROL

Turbines are equipped with several valves which control turbine speed during normal plant operation and protect them from overspeed during abnormal conditions. These valves are the turbine Control Valves (CVs), Stop Valves (SVs), Interceptor Valves (IVs), Reheat Stop Valves (RSVs), and Steam Dump Valves (SDVs). These valves are briefly discussed below.

CVs (or alternately governor valves) and SVs (or throttle valves) are located on the steam supply lines to the high pressure turbine. CVs are those valves that modulate the steam flow to the turbine in order to maintain the turbine at synchronous speed in response to any changes in speed or load demand. The CVs also are designed to close if the turbine speed exceeds a certain setpoint, and then slowly open to allow the turbine to return to normal speed.

SVs are designed to close on receipt of a signal that the turbine speed is exceeding normal design conditions. Closure of the SVs stops the flow of steam to the turbine. That, in turn, causes the turbine to slow down and eventually stop.

IVs and RSVs are located on the steam supply lines to the low pressure turbines. These valves operate in a similar fashion to that of the CVs and SVs. IVs and RSVs are of a butterfly design (disc pivoting on a center shaft).

SDVs are located on the steam lines connecting the high pressure and low pressure turbines. They are designed to open on a turbine trip or a loss of load signal to relieve steam pressure and reduce the likelihood of turbine overspeed. However, SDVs are slow acting in comparison with the SVs, CVs, IVs, or RSVs. Steam dump flow paths can be blocked manually by motor-operated valves.

Turbine control is accomplished by a mechanical-hydraulic system which acts rapidly to throttle the CVs until the turbine returns to normal speed. In the event that turbine speed continues to increase, other protective measures are available to prevent excessive overspeed. Some of these measures are: (a) The overspeed protection controller activates with loss of load and automatically opens solenoid valves which drain the control oil and cause the CVs and IVs to close, terminating the steam supply. (b) The mechanical overspeed trip. This will activate at a preset value, typically within 111% of rated speed. The assembly consists of an eccentric weight, trigger cup valve and dump valve. (c) The electrical trip mechanism will activate with system separation. It consists of a solenoid and plunger valve. The plunger valve drains the autostop oil, closing the turbine valves and/or opening the SDVs.

The plants in this study have been placed into seven "variation groups" according to the arrangement of their turbine valves, control and trip systems, and turbine type. The plants in each group can be represented by a single overspeed fault tree analysis.

Variation group 1 plants have two steam lines leading to the high pressure turbine (HPT), each via a SV and its bypass valve leading to two CVs. Thus, a total of four CVs allow steam into the HPT. The low pressure steam exits the HPT and enters each of the two low pressure turbines (LPTs) via two moisture separators and reheaters (MSRs), two RSVs, and two IVs.

Variation group 2 plants have four SV bypass valve combinations each of which leads to a CV, with a total of four CVs steam to the HPT. The low pressure steam exits the HPT and enters three LPTs and six normally-closed SDVs. The low pressure steam enters each LPT via two MSRs. Also, the low pressure steam enters each normally-closed SDV via a normally-open motor operated valves.

Variation group 3 plants have a control valve arrangement similar to that of variation 2, and an LPT valve arrangement similar to that of variation 1 (with two or three LPTs), but without SDVs. Variations 4 and 6 are combinations of variations 1, 2, or 3. There is no variation 5.

Variations 7 and 8 plants have four steam lines each leading to a throttle valve. Each pair of throttle valves leads to a common steam chest, which in turn leads to two governor valves. Thus, a total of four governor valves allow steam to the HPT. The LPT valve arrangement for these two variations is similar to that of variation 3. The control and trip system logic is different for variations 7 and 8.

Table 1 lists the plants and their variation group number. The SVs of plant variations 1, 2, 3, 4 and 6 are of the swing check (clapper type) valve, while those of variations 7 and 8 are of the plug type valve. The CVs are of the plug type. Each clapper type SV has a bypass valve that is designed to equalize automatically the pressure on both sides of the stop valve before it opens. The bypass valve is a normally-closed, air-to-open type valve.

III. ANALYSIS AND EVALUATION

A. Turbine Classifications

It was found that among the plants represented in the Topical Report there are significant differences in the controls, arrangements, and types of turbine valves. On the basis of this diversity, the plants were put in different "variation groups", as described in Section II above (see Table 1). An overspeed analysis of one group is intended to apply generically to all plants in that group. However, there remained some plant-specific differences that required consideration. The plant-specific differences were handled in a conservative manner. For example, some of the plants in variation 3 have six IVs while others have only four such valves. Since the six-IV plants would be more susceptible to IV failures than their four-IV counterparts, the former was used to provide a bounding analysis of overspeed. Similarly, some redundant overspeed protection systems, such as the Independent Emergency Overspeed Protection System, exist only on eight of the nineteen plants. Therefore, for conservatism, this feature was not modeled in the analyses.

B. Missile Ejection Probability

Turbine missiles can be generated at any speed. For a given speed, the probability of missile generation depends on the likelihood of existence of rotor flaws that can lead to its rupture at that speed. Therefore, the probability of turbine missile ejection can be divided into two components: the probability that the turbine attains a certain speed, and the probability that the rotor integrity is inadequate at that speed (e.g., the probability that rotor flaws exist with sizes equal to or greater than the critical flaw size for that speed).

Effective means of reducing the risk of turbine missile ejection include: (1) regular testing of turbine valves that control turbine speeds to assure their proper operation and enhance their reliability, and (2) regular inspection of the low pressure turbine rotors to assure their integrity.

Although a turbine missile may be ejected at or below normal operating speeds, the probability of such occurence is very small compared to high turbine speed conditions. Therefore, the emphasis in this report has been placed on missile ejection at high turbine speeds (specifically, overspeed conditions).

Overspeed events are divided into three speed ranges: (a) Design Overspeed (this is defined as 120% of rated turbine speed for those turbines with RSVs and IVs, and 132% of rated speed for turbines without RSVs and IVs); (b) Intermediate Overspeed (defined as 132% of rated speed for turbines with RSVs and IVs, and 136% of rated speed for turbines without RSVs and IVs); and (c) Destructive Overspeeds (these are speeds greater than 170% of rated speed). Although the probability of missile generation as a function of turbine speed increases progressively and is a continuous function, the analyses carried out at the above overspeed conditions are considered representative of the missile generation vulnerability of a turbine.

The formula used for calculating missile generation probabilities is:

$$P = P(a) \times P(m/a) + P(b) \times P(m/b) + P(c)$$

Where P = annual probability of turbine missile ejection,
P(a) = annual probability of design overspeed,
P(b) = annual probability of intermediate overspeed,
P(c) = annual probability of destructive overspeed,
P(m/a) = conditional probability of missile ejection at design overspeed,
P(m/b) = conditional probability of missile ejection at intermediate overspeed.

P(a), P(b), and P(c) were calculated using the fault trees developed for each turbine variation, and using the different valve test intervals. Westinghouse found that these probabilities are sensitive to the turbine rotor inspection interval [see item (2) above]. These probabilities will be discussed further in Section III.E below. The conditional probability P(m/a) was obtained from previous plant-specific analyses conducted by Westinghouse for various low pressure turbine rotors.

These plant-specific analyses are based on methods described in Reference 1. If a rotor-specific value of P(m/a) was not available, data judged to be representative of that rotor design was used. The conditional probability P(m/b) also was evaluated by Westinghouse and found to be about five to fifteen times P(m/a). It should be noted that in the above formula the probability of missile ejection given a destructive overspeed is assumed to be 1.0.

C. Analysis Methodology and Assumptions

In the following subsections a discussion of the analysis, methodology, and assumptions is provided.

1. Fault Tree Top Logic:

The top logic for the three overspeed categories identified above, namely design, intermediate, and destructive overspeeds involves two fundamental events. These are: (a) a loss of the turbine load, and (b) a failure of the turbine valves to isolate the steam supply in time to avoid turbine overspeed.

Westinghouse estimates that, on the basis of many years of experience, turbine separation occurs with a mean frequency of 0.5 per year, and a variance of 0.14 (Reference 2). These mean and variance values apply to all PWRs. However, when only plants with Westinghouse turbine-generators were considered, a mean frequency of 0.39 and a variance of 0.084 were determined. For conservatism, the higher values of 0.5 and 0.14 were used in this analysis.

The failure of the turbine valves to isolate may be due to hardware or control logic malfunctions, both of which are modeled in the fault trees.

2. Common Cause Failures:

Common cause failure was included in the fault trees when the failure logic required the random failure of two or more identical components. Examples of this type of failure include the failure of two solenoid valves to open, or failure of two or more IVs to close. Clogging of autostop oil lines, emergency trip fluid lines, or primary drain lines may lead to malfunction of more than one valve. For conservatism, drain line clogging was assumed to prevent valve closure, although it is expected to result only in a longer valve closure time. The Topical Report lists the redundant components subject to this type of failure and their associated Beta factors.

3. Human Error:

In the case of an overspeed event, turbine valve actuations take place so rapidly that an operator has no time to react in order to mitigate such an event. Therefore, operator action to mitigate an overspeed event was not modeled. However, malfunctions due to an operator inadvertently closing one or more steam dump motor-operated valves have been included in the fault tree. This human error was modeled as failure-to-restore after inspection or maintenance and compounded by failure-to-detect the valve improper position during a walk-around. The failure-to-restore probability for this error was obtained from Reference 3. With an assumed recovery factor of 0.2, the mean failure probability and variance for this human error was determined to be 2.5E-4 and 8.78E-7, respectively.

4. Maintenance Outage:

Maintenance and inspection of turbine valves is assumed not to occur during normal power operation. However, in plants with variation 2 valve arrangement, one steam dump valve may be in maintenance during normal power operation. Therefore, for this variation of plants maintenance outage was modeled in the fault tree.

5. Valve Failure Combinations:

Valve failures in the fault trees accounted for direct mechanical failures as well as failures due to power supplies, control logic, or support systems (e.g., emergency stop fluid, or auto-stop oil). Valve failure combinations determine the branching in the fault trees that lead to various overspeed categories. For example, failure of a CV or an IV to close on demand will lead to a design overspeed. Also, if a SV and its corresponding CV both fail to close on a turbine trip signal a destructive overspeed will result. Occurrence of an intermediate overspeed depends on the particular turbine valves arrangement. Table 2 shows valve failure combinations and the various types of overspeed.

D. FAILURE DATA

The primary source of basic failure data in the study is the operating experience of Westinghouse steam turbines (References 4 and 5). Westinghouse has maintained and updated records of valve testing, surveillance, maintenance, and reported modes of failure. A compilation of the number of component malfunctions and years of service is provided in the Topical Report. Westinghouse states that the component malfunction compilation was done in a conservative manner. For example, some valve degradations which may not have disabled the valve were added as malfunctions. This tends to overestimate conservatively the likelihood of turbine overspeed.

The compiled malfunctions were divided into two categories: demand, and time-related malfunctions. This categorization is based on the operating nature of the component under consideration. Time-related malfunctions were further divided into three subcategories, depending on the time between scheduled tests.

(a) One subcategory has the turbine valves and associated components. The failure rates for this subcategory are directly proportional to the mean time intervals between tests. To show the effect of changing the time interval between tests on the probability of missile generation the calculations were repeated using time intervals of 1 month, 3 months, 6 months, and 1 year.

(b) The second subcategory has some components that were assumed conservatively to have a fixed annual test interval or mission time. The assumption of an annual test interval is conservative since the successful function of many components is demonstrated during normal operation. For example, degradation of the CV speed changer can be detected if unacceptable speed deviations are observed.

(c) The third subcategory has some components that are continuously-operating. The degradation or malfunction of this type of component is detectable readily during normal plant operation. For example, degradation of the turbine speed sensing device can be detected during routine load changes. For conservatism, this subcategory was assumed to have a 2 month mission time.

The transformation of the basic service data into failure rates suitable for fault tree analysis involved the following two steps:

1. The median failure rate and the 95% percentile for each component was determined using the Chi-squared function.

2. From the information obtained from step 1 above, the mean failure rates and variances were determined on the basis of a lognormal probability distribution.

The resulting means and variances were used to calculate the missile ejection probabilities for each of the plants represented in the Topical Report.

However, it came to the attention of the staff that Westinghouse issued a Customer Advisory Letter (CAL) 87-03, dated August 24, 1987 to advise its customers of some reported turbine valve failures (Reference 6). Those failures were observed on Building Block BB-296 turbines with a steam chest, in which the throttle valves (alternately known as SVs) failed to close on demand under test conditions. The valve failures were found to be repeatable under similar conditions. If one or more throttle valves fail to close on a turbine trip and a loss of load occurs, destructive overspeed will occur unless both governor valves on that steam chest close. In its CAL 87-03, Westinghouse recommends that for BB-296 turbines with a steam chest, the throttle valves (or SVs), the governor valves (or CVs), IVs, and RSVs should be tested monthly.

Westinghouse conducted a reevaluation of turbine overspeed probability for the above type of turbines, taking into consideration the increased failure rates. It was found that the missile ejection probability at those plants could be significantly higher than previously indicated unless the actions recommended by Westinghouse were implemented. Plants with BB-296 turbines, as represented by the Topical Report, are St. Lucie Units 1 and 2, and Shearon Harris (variations 7 and 8 in Table-1). Westinghouse was asked whether the above findings affect the report conclusions relative to other plants. Westinghouse responded (through the owners group representative - see Reference 7) by stating that the valve failures described in their CAL-87-03 apply only to plants with BB-296 turbines and steam chests and, therefore, do not affect plants other than those identified above.

E. Results

The calculation of the total probability of missile ejection due to overspeed is based on the formula discussed above. Since the values of the conditional probabilities P(m/a) and P(m/b) are sensitive to the low pressure rotor inspection interval (see Section B above), two sets of calculations were conducted, Case 1 and Case 2. Case 2 calculations assumed a turbine rotor test interval of 1 year longer than that of Case 1. As would be expected, due to the longer rotor test interval, Case 2 resulted in higher missile ejection probabilities. The staff review focused on Case 2. However, conclusions about the validity of the analysis approach and methodology may apply equally to either case.

The Topical Report presents the results of the calculations of the mean annual probabilities of turbine missile ejection in table form as well as graphically, for every plant represented in the study. This is based on valve test intervals of 1 month, 3 months, 6 months, and 12 months. The results indicate the following:

1. The calculated values show a gradual but steady increase in missile ejection probabilities corresponding to increases in the mean time between tests of turbine valves.

2. P(a) and P(b) are several orders of magnitude greater than P(c). However, P(c) contributes the most to the total annual probability of missile ejection.

3. P(c) is more sensitive to valve test interval changes than either P(a) or P(b).

From the above it can be concluded that changes in turbine valve test intervals can have a significant effect on the total probability of missile ejection. The calculated missile ejection probabilities are Westinghouse proprietary information.

IV. CONCLUSIONS

The staff has completed its review of the subject Topical Report and concludes that the analyses have accounted for plant-specific design variations and failure rates, common cause failures, and human errors. The staff concludes that in preparing the subject Topical Report, Westinghouse has used acceptable methodology and assumptions. Therefore, the subject report is acceptable as a methodology reference. The Topical Report may be used to enable licensees to recalculate the missile ejection probabilities for their plants to account for significant changes in valve failures, control and trip system anomalies, turbine rotor inspection intervals, or any other factors which may affect the potential for overspeed or missile generation.

As discussed in Section D above, the failure data used to calculate the missile ejection probabilities in the subject report is representative of all plants listed in that report with the exception of St. Lucie Units 1 and 2, and Shearon Harris. This is due to recent experience with failure of valves similar to those found on the above three plants. Licensing action for these three plants, based on the Topical Report, should be supported also by evidence that the failure data used in the subject report is representative of the plant. Alternately, a reanalysis should be submitted. Such reanalysis may use the methodology of this Topical Report.

V. REFERENCES

1. "Procedures for estimating the Probability of Steam Turbine Disc Rupture from Stress Corrosion Cracking," WSTG-1-P-A, Westinghouse Steam Turbine Generator Division, May 1981 (Revised July 1, 1987) [Proprietary].

2. "Development of Transient Initiating Event Frequencies for Use in Probabilistic Risk Assessments," NUREG/CR-3862, U.S. Nuclear Regulatory Commission, May 1985.

3. Swain, A.D. H.E. Guttman: "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," NUREG/CR-1278, August 1983.

4. "Analysis of the Probability of the Generation and Strike of Missiles from a Nuclear Turbine," Westinghouse Steam Turbine Division, March 1974 (Revised July 1, 1987).

5. "Analysis of the probability of a Nuclear Turbine Reaching Destructive Overspeed," WSTG-3-P-A, Westinghouse Steam Turbine Generator Division, July 1984 (Revised July 1, 1987) [Proprietary].

6. Letter, D. Musolf, Northern States Power Co. to Director of NRR, Additional Information Related to Turbine Valve Test Frequency Reduction, November 14, 1988.

7. Conference call with participants: S. Diab, and D. DiIanni of NRC, and Ron Meyers of Northern States Power Co., dated October 27, 1988.

Dated:

<u>Principal Contributor</u>:

S. Diab

Table - 1
Represented Plants and Turbine
Valve Variation Type

UTILITY	PLANT	VARIATION TYPE
Carolina Power & Light	H.B. Robinson 2	4
	Shearon Harris	8
Con. Edison Co. of N.Y.	Indian Point 2	2
Consumers Power Co.	Palisades	3
Florida Power & Light	Turkey Point 3 & 4	1
	Saint Lucie 1 & 2	7
Maine Yankee Atomic Power	Maine Yankee	3
Northern States Power	Prairie Island 1 & 2	4
Pacific Gas & Electric	Diablo Canyon 1 & 2	3
New York Power Authority	Indian Point 3	2
Public Service Electric & Gas	Salem 1 & 2	3
Wisconsin Electric Power	Point Beach 1 & 2	6
Wisconsin Public Service	Kewaunee	4

Table - 2
Valve Failure Combinations
Leading to Overspeed

	Turbines with RSVs + IVs	Turbines w/o RSVs + IVs
Design Overspeed	$\geq$ one CV OR $\geq$ one IV fail to close	-
Intermediate Overspeed	$\geq$ one RSV AND $\geq$ one IV fail to close	$\geq$ one SDV fail to open OR $\geq$ one SVBV + CV fail to close
Destructive Overspeed	$\geq$ one SV + $\geq$ one CV fail to close	$\geq$ one SV + $\geq$ one CV fail to close