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

November 29, 1982

Docket No. 50-155
LS05-82-11-082

Mr. David J. VandeWalle
Nuclear Licensing Administrator
Consumers Power Company
1945 West Parnall Road
Jackson, Michigan 49201

Dear Mr. VandeWalle:

SUBJECT: SEP TOPIC III-4.B, TURBINE MISSILES
BIG ROCK POINT

Enclosed is our final evaluation of SEP Topic III-4.B. It is based on a Safety Analysis Report which you supplied on June 9, 1982, and other information supplied by you and on Docket No. 50-155.

The evaluation concludes that turbine protection system modification should be considered during the integrated assessment. This is because the present system has no redundancy for isolating the turbine from the steam supply during large transients.

You are requested to review the turbine and turbine protection system descriptions for accuracy since much of this was obtained from unclear drawings and verbally.

The evaluation will be a basic input to the integrated safety assessment of your facility. It may be changed in the future if your facility design is changed or if NRC criteria are modified before completion of the integrated assessment.

Sincerely,

Dennis M. Crutchfield

Dennis M. Crutchfield, Chief
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Enclosure:
As stated

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SEP REVIEW

OF

TURBINE MISSILES

TOPIC III - 4.B

FOR THE

BIG ROCK POINT PLANT

BIG ROCK POINT PLANT

TABLE OF CONTENTS

I. INTRODUCTION

The safety objective of TOPIC III - 4.B is to assure that structures, systems, and components important to safety are adequately protected from potential turbine missiles. Of those systems important to safety, this SER Topic is primarily concerned with safety-related systems; i.e., those structures, systems, or components necessary to perform required safety functions and to ensure:

a. The integrity of the reactor coolant pressure boundary,
b. The capability to shut down the reactor and maintain it in a safe shutdown condition, or
c. The capability to prevent accidents that could result in potential offsite exposures that are a significant fraction of the guideline exposures of 10 CFR Part 100, "Reactor Site Criteria" (Ref. 1).

II. REVIEW CRITERIA

According to General Design Criterion 4, of Appendix A to 10 CFR Part 50 Ref. 2), nuclear power plant structures, systems, and components important to safety shall be appropriately protected against dynamic effects, including the effects of missiles. Failures that could occur in large steam turbines of the main turbine-generator have the potential for ejecting large high-energy missiles that can damage plant structures, systems and components. Typical safety-related systems are listed in Regulatory Guide (RG) 1.117 (Ref. 3).

During the past few years the results of turbine inspections at operating nuclear facilities show that cracking to various degrees has occurred at the inner radius of turbine wheels, also referred to as disks. (Refs. 4 and 5) The staff has been following this development closely and, together with respective turbine manufacturers, is in the process of developing criteria and procedures for establishing turbine wheel inspection frequencies, and guidance for turbine overspeed system maintenance and testing to preclude wheel failures. In view of current experience and NRC safety objectives (Ref. 6), we are emphasizing the turbine missile generation probability (i.e., turbine generator system integrity and reliability) in our reviews of the turbine missile issue and eliminating the need for elaborate and somewhat ambiguous analyses of strike and damage probabilities given an assumed turbine failure rate, as described in Regulatory Guide 1.115 (Ref. 7) and Standard Review Plan (SRP) Section 3.5.1.3 (Ref. 8).

The staff concludes, based on our reviews of many facilities, that the probability of a turbine missile striking and damaging a safety system is in a relatively narrow range depending on turbine orientation. More refined analyses or additional calculations for other facilities are unlikely to change this conclusion. Therefore, expensive and time consuming strike probability analyses on the part of applicants/licensees and/or the NRC staff are judged to be unwarranted. The new approach, discussed in Section IV of this SER Topic, improves turbine generator system reliability by review and regulation of the probability of generating missiles.

III. RELATED SAFETY TOPICS AND INTERFACES

The scope of review for this SEP Topic was limited to avoid duplication of effort since some aspects of the review were performed under related topics. The related topics and their subject matter are identified in Table 1. Each of the related topic reports contains the acceptance criteria and review guidance for its subject matter. Topic XV-18 is particularly significant since a turbine failure resulting in the rupture of the turbine casing is approximately equivalent to a main steam line failure outside containment, which for a BWR releases primary coolant steam and radioactivity to the environment. Hence,

TABLE 1

RELATED SAFETY TOPICS AND INTERFACES

TOPIC #	TITLE
VII-3	Systems Required for Safe Shutdown
IX-3	Station Service and Cooling Water Systems
IX-5	Ventilation Systems
XV-3	Loss of External Load, Turbine Trip, Loss of Condenser Vacuum, Closure of Main Steam Isolation Valve (BWR), and Steam Pressure Regulation Failure (Closed)
XV-7	Reactor Coolant Pump Rotor Seizure and Reactor Coolant Pump Shaft Break
XV-18	Radiological Consequences of Main Steam Line Failure Outside Containment (BWR)

regardless of the probability of turbine missiles striking safety-related structures, systems, or components, the criteria of Topic XV-18 must be satisfied in order to meet the criteria of this SER Topic.

IV. REVIEW GUIDELINES

1. Safety Objective

According to current NRC guidelines stated in Standard Review Plan (SRP) Section 2.2.3 (Ref. 6) and R. G. 1.115 (Ref. 7), the probability of unacceptable damage to safety-related systems from turbine missiles should be less than or equal to one chance in ten million per year for an individual plant, i.e., $P_4 \leq 10^{-7}$ per year.

2. Past Review Procedure

The probability of unacceptable damage due to turbine missiles (P_4) is generally expressed as the product of (a) the probability of turbine failure resulting in the ejection of turbine disk (or internal structure) fragments through the turbine casing (P_1), (b) the probability of ejected missiles perforating intervening barriers and striking safety-related structures, systems, or components (P_2), and (c) the probability of struck structures, systems, or components failing to perform their safety function (P_3).

In the past, analyses for construction permit (CP) and operating license (OL) reviews assumed the probability of missile generation (P_1) to be approximately 10^{-4} per turbine year, based on the historical failure rate. (Ref. 9) The strike probability (P_2) was estimated based on postulated missile sizes, shapes, and energies, and on available plant specific information such as, turbine placement and orientation, number and type of intervening barriers, target geometry, and potential missile trajectories. The damage probability (P_3) was generally assumed to be 1.0. The overall probability of unacceptable damage to safety-related systems (P_4), which is the sum over all targets of the product of these probabilities, was then evaluated for compliance with the NRC safety goal. This logic places the regulatory emphasis on the strike probability, i.e., having established an individual plant safety goal of 10^{-7} per year or less, for the probability of unacceptable damage to safety-related systems due to turbine missiles, this procedure requires that P_2 be less than or equal to 10^{-3}. This approach requires a great deal of effort on the part of applicants/licensees and the staff due to its explicit disregard for the "actual" turbine reliability, and the difficulty of calculating P_2 in a relatively unambiguous and systematic manner.

3. New Procedure

The staff has made a complete shift of emphasis in the review of turbine missile evaluations, away from the review of strike probabilities to the review of missile generation probabilities. This shift of emphasis requires nuclear steam turbine manufacturers to develop and implement volumetric (ultrasonic) examination techniques suitable for inservice inspection of turbine rotors (without the need for removing the disks from the shaft), and to prepare reports for NRC review which describe their methods for determining turbine missile generation probabilities. These methods are to relate disk design, materials properties, and inservice volumetric inspection to the design overspeed missile generation probability, and to relate overspeed protection system characteristics, and stop and control valve design and inservice inspection and test intervals to the destructive overspeed missile generation probability. Following NRC acceptance of the methods and procedures described in these reports, the manufacturer will provide to applicants and licensees tables of missile generation probabilities versus time (inservice volumetric disk inspection interval for rated speed or design overspeed failure, and inservice valve testing interval for destructive overspeed failure) for their particular turbine, which will then be used to establish inspection schedules which meet the NRC safety objectives.

Applicants and licensees, with turbines from manufacturers who have not yet submitted reports to the NRC describing their methods and procedures for calculating turbine missile generation probabilities or who have submitted reports which are still being reviewed by the NRC, are expected to meet the following interim criteria, regardless of turbine orientation:

A. The inservice inspection program employed for the steam turbine rotor assembly is to provide assurance that disk flaws that might lead to brittle failure of a disk at speeds up to design overspeed will be detected. The turbine rotor design should be such as to facilitate inservice inspection of all high stress regions, including disk bores and keyways, without the need for removing the disks from the shaft. The inservice inspection program for the steam turbine rotor assembly is to include the following:

(a) The first inservice inspection of a new rotor or disk should be performed before any postulated crack is calculated to grow to more than 1/2 the critical crack depth. If the calculated inspection interval is less than the scheduled first fuel cycle, the licensee should seek the manufacturers guidance on delaying the inspection until the refueling outage. If the calculated inspection interval is longer than the first fuel cycle, the licensee should seek the manufacturers guidance for scheduling the first inspection at a later refueling outage.

(b) Disks that have been previously inspected and found to be free of cracks or that have been repaired to eliminate all indications should be reinspected using the same criterion as for new disks, as described in (a), calculating crack growth from the time of the last inspection.

(c) Disks operating with known and measured cracks should be reinspected before 1/2 the time calculated for any crack to grow to 1/2 the critical crack depth. The guidance described in (a) should be used to set the inspection date based on the calculated inspection interval.

(d) Under no circumstances is the inspection interval to exceed approximately 3 years or 2 fuel cycles.

Inspections during these refueling or maintenance shutdowns should consist of visual, surface, and volumetric examinations, according to the manufacturers procedures, of all normally inaccessible parts such as couplings, coupling bolts, LP turbine shafts, blades, and disks, and HP rotors. Shafts and disks with cracks of depth near to or greater than 1/2 the critical crack depth are to be repaired or replaced. All cracked couplings and coupling bolts should be replaced.

B. The inservice inspection and test program employed for the control and overspeed protection system should provide assurance that flaws or component failures in the overspeed sensing and tripping subsystems or in the main steam and reheat valves that might lead to an overspeed condition above the design overspeed will be detected. The inservice inspection program for control and overspeed protection system operability should include the following provisions:

(a) At approximately 3 year intervals, during refueling or maintenance shutdowns, at least one main steam governor valve, one main steam stop valve, one reheat intercept valve and one reheat stop valve are to be dismantled and visual and surface examinations conducted of valve seats, disks, and stems. If hazardous flaws or excessive corrosion are found in a valve, the valve is to be repaired or replaced and all other valves of that type dismantled and inspected. Valve bushings should be inspected and cleaned, and bore diameters should be checked for proper clearance.

(b) Main steam governor and stop valves and reheat intercept and stop valves are to be exercised at least once a week during normal operation by closing each valve and observing directly the valve motion as it moves smoothly to a fully closed position.

(c) At least once a month during normal operation each compartment of the electrohydraulic control system (which closes governor and intercept valves), and the mechanical overspeed trip mechanism and backup electrical overspeed trip (both of which trip the main governor and stop valves and reheat intercept and stop valves), is to be tested.

V. EVALUATION

The Big Rock Point Plant turbine generator, which is favorably oriented with respect to plant safety-related systems, was manufactured by the General Electric Company. During the past few years the results of turbine inspections at operating nuclear facilities show that stress corrosion cracking has occurred to various degrees at the inner radius of numerous turbine disks or wheels. Some of the turbines in which keyway cracks have been identified are of General Electric design. However, the turbine at the Big Rock Point Plant is unlike all other General Electric nuclear turbines. It is a relatively small, tandem compound, condensing, 3600 RPM turbine consisting of high pressure (HP) and low pressure (LP) elements, with no reheat stage. Both the HP and LP rotors are of integral construction made from solid forgings. Unlike the built-up type rotor, common to large LP elements, which consists of disks shrunk on to a shaft, the integral type rotor is not expected to be particularly susceptable to stress corrosion cracking and brittle failure. Nevertheless, since the initiation of operation in December 1962, Consumers Power Company has performed the following magnetic particle bucket and rotor inspections:

Date	Components Inspected	Results
April 1964	HP and LP buckets and rotors	No indications found
Feb. 1970	"	"
March 1977	"	"

The next magnetic particle inspection of the rotor assembly is scheduled for May 1983. Although no ultrasonic inspections have been performed or are planned, the staff finds this inspection program and schedules acceptable due to the inherent low probability for a design overspeed failure with subsequent missile production for the Big Rock Point Plant turbine design.

Steam from the steam supply is admitted to the HP turbine through a single steam line containing a single stop valve and a steam chest with four control valves, each control valve feeding steam to the high pressure nozzle plate section assigned to it. Since there is no moisture separator/reheater for this turbine, steam flows directly from the HP to the LP (through a single line). The Mechanical Hydraulic Control (MHC) system for the turbine provides two levels of protection against overspeed, the normal speed control system which closes all admission control valves on moderate overspeed and the emergency trip system which closes all steam valves on higher overspeed or other trip signals. The stop valve and admission control valves are spring closed and fail safe to the closed position.

The normal speed control system employs a mechanical fly-ball speed governor driven by a worm gear reduction from the main oil pump shaft, which is itself driven directly from the end of the turbine rotor. The fly-ball weights convert rotational speed to vertical motion to open or close a hydraulic pilot valve which adjusts the hydraulic system pressure. Control valve positions vary according to hydraulic system pressure to produce the desired alterations in turbine rotor speed. The four hydraulic actuated admission control valves are opened and closed in sequence under speed governor control, but will close together on an emergency overspeed trip.

Overspeed sensing for the emergency trip system is by an unbalanced, spring opposed plunger which is mounted on the end of the turbine rotor. As the turbine speed increases above rated speed, the plunger will move out away from the rotor until, at some pre-set speed, it strikes a stationary trip finger which unlatches a mechanical trip valve depressurizing the hydraulic system and causing the stop valve and control valves to close. A turbine shaft driven centrifugal hydraulic and lube system oil pump provides the pressurized oil necessary to open the stop and control valves, and keep them open during turbine operation.

Under normal operation, the steam admission control valves begin to close as soon as rated speed is exceeded, and for moderate transients are fully closed at between 106 and

107 percent of rated speed. The steam admission control valves can be closed individually. According to the Consumers Power Company control and overspeed protection systems maintenance program, these valves are tested at least once a week during normal operation by exercising each to their fully closed position, and the speed set is tested every refueling outage.

Should the normal speed control system fail or the unit experience a sudden load loss, the emergency mechanical overspeed protection system trips at 109.5 percent of rated speed. Either of two plungers, aligned at 180 degrees to each other, can trip the emergency system and close the stop valve. Obviously, the stop valve can not be exercised to full closure during operation. However, according to the licensee's maintenance program for the control and overspeed protection systems, the stop valve is partially closed daily, the hydraulic portion of the emergency overspeed trip system is tested weekly, and the complete overspeed is tested by actually raising turbine speed to the trip set point each refueling outage.

The Big Rock Point Plant overspeed protection system has a major flaw; it has no backup for the emergency overspeed trip system. In the event of a load loss, the normal control system is too slow to isolate the turbine and prevent a destructive overspeed failure. Consequently, the only protection from destructive overspeed on loss of load is a single mechanical overspeed trip system which hydraulically activates control and stop valves. The staff recommends that alterations to ensure the ability to isolate the turbine from the steam supply on loss of load, even if the mechanical overspeed trip system fails or the stop valve and one of the control valves fail, be factored into the integrated assessment for the Big Rock Point Plant.

VI. SUMMARY

The staff finds acceptable the licensee's inservice inspection program and schedule for assuring the integrity of the Big Rock Point Plant turbine rotors, and concludes that the design overspeed missile generation probability is sufficiently low to meet NRC safety objectives.

The Big Rock Point Plant turbine overspeed protection system has no system redundancy for isolating the turbine from the steam supply during large rapid transients. The staff concludes that the turbine missile risk for destructive overspeed failure deviates significantly from the staff acceptance criteria. Therefore, the staff recommends that incorporation of the necessary turbine generator system modifications to ensure the ability to isolate the turbine from the steam supply on loss of load, should either the mechanical overspeed trip system fail or the stop valve and one of the control valves fail, be factored into the integrated assessment for the Big Rock Point Plant.

VII. REFERENCES

1. Volume 10, Code of Federal Regulations, Part 100, "Reactor Site Criteria."

2. Volume 10, Code of Federal Regulations, Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants."

3. Regulatory Guide 1.117, "Tornado Design Classification," June 1976.

4. See NUREG/CR-1884, "Observations and Comments on the Turbine Failure at Yankee Atomic Electric Company, Rowe, Massachusetts" March 1981.

5. See Preliminary Notification of Event or Unusual Occurrence -- PNO - III - 81 - 104 -- "Crack in the hub of the eleventh stage wheel in the main turbine" at Monticello Nuclear Power Station, Nov. 24, 1981.

6. Standard Review Plan Section 2.2.3, "Evaluation of Potential Accidents," Rev. 2.

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

8. Standard Review Plant Section 3.5.1.3, "Turbine Missiles," Rev. 1.

9. S. H. Bush, "Probability of Damage to Nuclear Components," Nuclear Safety, 14, 3, (May-June) 1973, p. 187; and S. H. Bush, "A Reassessment of Turbine-Generator Failure Probability," Nuclear Safety, 19, 6, (Nov. - Dec.) 1978, p. 681.