U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

3.5.1.3 TURBINE MISSILES

REVIEW RESPONSIBILITIES

Primary - Materials ~~Engineering Branch (MTEB)~~and Chemical Engineering Branch (EMCB)[1]

Secondary - None

I. AREAS OF REVIEW

Although large steam turbines and their auxiliaries are not safety-related systems as defined by NRC regulations, certain failures that occur in these turbines can produce high-energy missiles that potentially threaten safety-related structures, systems, and components.[2] Plant designs are reviewed with the objective of establishing whether safety-related plant structures, systems, and components have adequate protection against the effects of potential turbine missiles. The primary review area is the evaluation of turbine missile generation~~, strike, and damage probabilities with respect to the safety-related missile targets~~ probability. ~~The review requires input from the Auxiliary Systems Branch (ASB) on target identification and from the Structural Engineering Branch (SEB) on barrier quality.~~[3]

~~MTEB reviews the turbine disc failure analysis, fracture toughness properties, turbine startup procedures, and inservice inspection as part of its primary review responsibility for SRP Section 10.2.3.~~[4]

Review Interfaces[5]

In addition, MTEB The EMCB[6] will coordinate other branches' evaluations that interface with the overall review of turbine missiles. These interfaces are as follows:

1.[7] SEB The Civil Engineering and Geosciences Branch (ECGB),[8] upon request, reviews the[9] turbine missile impact effects on steel and concrete barriers (e.g., penetration depth, scabbing, and structural response) as part of its primary review responsibility for SRP Section 3.5.3. The ECGB also reviews the turbine rotor failure analysis, fracture toughness properties, turbine startup procedures, and inservice inspection as part of its primary review responsibility for SRP Section 10.2.3.[10]

2. Power Systems Branch (PSB) The Plant Systems Branch (SPLB)[11] reviews the turbine overspeed protection, including overspeed sensing and tripping, as part of its primary review responsibility for SRP Section 10.2.

3. The[12] Mechanical Engineering Branch (MEB) (EMEB)[13] reviews the adequacy of the inservice testing program of pumps and valves as part of its primary review responsibility for SRP Section 3.9.6.

4. Equipment Qualification Branch (EQB) The EMEB[14] reviews the seismic qualification of instrumentation and[15] electrical system components and the SPLB reviews the environmental qualification of mechanical and electrical system components as part of its their[16] primary review responsibility for SRP Sections 3.10 and 3.11, respectively. The Instrumentation and Control Systems Branch (HICB), in cooperation with the EMEB and SPLB, reviews seismic and environmental qualification of instrumentation as part of its secondary review branch responsibilities for SRP Sections 3.10 and 3.11.[17]

5. ASB The SPLB[18] identifies structures, systems, and components to be protected from turbine missiles as part of its primary review responsibility for SRP Section 3.5.2.

For those areas of review identified above as being reviewed as part of the primary[19] review responsibility of other branches, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP section of the corresponding primary branch. sections.[20]

II. ACCEPTANCE CRITERIA

MTEB acceptance criteria are based on the plant design and layout satisfying the requirements of General Design Criterion 4 (Ref. 1), which requires that structures, systems, and components important to safety shall be protected against the effects of missiles that might result from equipment failures, in this case the steam turbine. Consideration of turbine missile protection is relevant for essential systems, i.e., those structures, systems, and components necessary to ensure:

- The integrity of the reactor coolant pressure boundary.

- The capability to prevent accidents that could result in potential offsite exposures that are comparable to the guideline exposures of 10 CFR Part 100, "Reactor Site Criteria."

- The capability to shut down the reactor and maintain it in a cold shutdown condition.

Specific criteria necessary to meet the relevant requirements of GDC 4 are as follows:

1. Plant designs with a favorable turbine generator placement and orientation, and adhering to the guidelines presented in Regulatory Guide 1.115 (Ref. 2) will be considered to be adequately protected against turbine missile hazards. Exclusion of safety-related structures, systems, or components from low trajectory turbine missile strike zones constitutes adequate protection against low trajectory turbine missiles. In those cases where exclusion of safety-related targets from the low trajectory missile strike zones is impractical (e.g., location dictated by site characteristics, such as a water intake structure for the ultimate heat sink) target size, shielding, or redundancy may be considered with respect to missile protection. The acceptance criterion is that the combined strike and damage probability for these targets be less than 10^{-3} per turbine failure.

2. Plant designs with unfavorable turbine-generator placement and orientation, such that safety-related structures, systems, or components are within the low trajectory turbine missile strike zones and are susceptible to potential missile damage, should have sufficient missile protection in terms of one or more of the following: missile barriers, target redundancy, turbine disc integrity, or overspeed protection.

   The SRP Section 2.2.3 risk acceptance guidelines that are used for potential accident situations in the vicinity of the plant will also be used in determining the sufficiency of protection against turbine missiles.

3. The following criteria apply exclusively to plants for which an application for a construction permit was submitted prior to 11/15/76: When the estimated turbine missile risks exceed the guidelines of SRP Section 2.2.3, the following requirements should be met:

   i. The design and on-line testing of the overspeed sensing and tripping system, including the main steam stop and control valves, and reheat stop and intercept valves, should be in accordance with SRP Section 10.2, as determined by the PSB. For Operating License reviews a determination should be made of whether increased valve testing should be required, based on cost-benefit considerations.

   ii. The applicant should submit a detailed strike and damage analysis with respect to all vulnerable targets (with the aim of assessing the margin available) and/or provide local shielding (if the above analyses indicate that SRP Section 2.2.3 guidelines are still exceeded). The procedures used for describing missile interactions with structural barriers and barrier damage analysis should conform to those of SRP Section 3.5.3. The SEB will review the interaction aspects of turbine missiles with respect to structural barriers and their damage analysis. The MTEB reviewer will perform an overall risk assessment of turbine missile hazard based on an independent evaluation of the detailed strike and damage analyses The MTEB will also review the adequacy of turbine disk integrity in accordance with SRP Section 10.2.3.[21]

1. In accordance with 10 CFR Part 50, Appendix A, General Design Criterion 4 (GDC 4), nuclear power plant structures, systems, and components important to safety shall be appropriately protected against dynamic effects, including those caused by missiles. Failure of large steam turbines in the main turbine generator has the potential to eject high-energy missiles that can produce such damage. The staff's overall safety objective is to ensure that structures, systems, and components important to safety are adequately protected from the effects of turbine missiles. Accordingly, consideration should be given to safety-related systems (i.e., those structures, systems, or components necessary to perform required safety functions) to ensure the following:

   a. The integrity of the reactor coolant pressure boundary;

   b. The capability to shut down and maintain the reactor in a safe condition; and

   c. The capability to prevent accidents that could result in potential offsite exposures, which represent a significant fraction of the guideline exposures specified in 10 CFR Part 100, "Reactor Site Criteria."

   Examples of safety-related systems that should be protected are described in Regulatory Guide 1.117.

2. The probability of unacceptable damage resulting from turbine missiles, P_4, is 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. Stated in mathematical terms, $P_4 = P_1 \times P_2 \times P_3$.

   In accordance with the guidance provided in SRP Section 2.2.3 and Regulatory Guide 1.115, the probability of unacceptable damage from turbine missiles should be less than or equal to 1 in 10 million per year for an individual plant (i.e., P_4 should be $\leq 10^{-7}$ per year per plant).

   Although the calculation of strike probability, P_2, is not difficult in principle (i.e., a straightforward ballistics analysis), in practice it requires numerous modeling approximations and simplifying assumptions to define the properties of missiles, interactions of missiles with barriers and obstacles, trajectories of missiles as they interact with and perforate (or are deflected by) barriers, and identification and location of safety-related targets. Specific approximations and assumptions tend to have a significant effect on the resulting value of P_2. Similarly, a reasonably accurate specification of the damage probability, P_3, is complicated by difficulties associated with defining the missile impact energy required to render safety-related systems unavailable to perform their safety functions and with postulating sequences of events that would follow a missile-producing turbine failure.

Because of the uncertainties associated with calculating P_2 and P_3, the staff concludes that such analyses are "order of magnitude" calculations only. On the basis of simple estimates for a variety of plant layouts, the strike and damage probability product can be reasonably assumed to fall in a range that depends on the gross features of turbine generator orientation.

a. For favorably oriented turbine generators, the product of P_2 and P_3 tends to be in the range of 10^{-4} to 10^{-3} per year per plant.

b. For unfavorably oriented turbine generators, the product of P_2 and P_3 tends to be in the range of 10^{-3} to 10^{-2} per year per plant

Favorably oriented turbine generators are located such that the containment and all, or almost all, safety-related structures, systems, and components outside containment are excluded from the low-trajectory hazard zone described in Regulatory Guide 1.115.

Because of inadequate data, controversial assumptions, and modeling difficulties as described above, the staff accepts a product of strike and damage probabilities of 10^{-3} per year per plant for a favorably oriented turbine and 10^{-2} per year per plant for an unfavorably oriented turbine. The staff does not encourage applicants to calculate P_2, P_3, or their product. The suggested values represent the staff's best estimate of the product of P_2 and P_3, based on the results of calculations performed at NRC and elsewhere (Refs. 5 and 14).[22]

3. Operating experience indicates that turbine disks crack (Refs. 6, 11, and 12), turbine stop and control valves fail (Refs. 7, 10, and 12), and disk ruptures can result in the generation of high-energy missiles (Refs. 9 and 12). Analysis (Refs. 7 and 8) indicates that missile generation can be modeled and the probability of generation can be strongly influenced by a suitable program of periodic inservice testing and inspection.

In general, two modes of turbine disk failure can result in turbine missile generation: (a) rotor material failure at approximately the rated operating speed and (b) failure of the overspeed protection system. Failure of turbine disks at or below the design speed (nominally, 120% of normal operating speed) can be caused by small flaws or cracks that grow to critical size during operation. Failure of the turbine disks at destructive overspeed (about 180% to 190% of normal operating speed) can result from failure of the overspeed protection system. The material properties of the turbine casing are of interest because secondary missiles could be generated if the casing fails or, alternatively, the casing could serve to arrest and contain missiles.

Design speed missile generation probability should be related to disk design parameters, material properties, and the inservice volumetric (ultrasonic) disk inspection interval. Destructive overspeed missile generation probability should be related to the turbine governor and overspeed protection system's speed sensing and tripping characteristics, the design and arrangement of main steam control and stop valves and the reheat steam intercept and stop valves, and the inservice testing and inspection intervals for system components and valves. In addition, fracture toughness properties of the turbine casing material in its operational environment should be evaluated. SRP Section 10.2 provides additional information regarding inspection and testing of turbine generator components. Further information regarding turbine missile generation mechanisms and probabilities can be found in References 5, 12, and 13 and the reports cited therein.[23]

4. The staff believes that maintaining an acceptably small value of missile generation probability, P_1, by means of a suitable program of periodic testing and inspection is a reliable method for ensuring that the objective of precluding generation of turbine missiles (and hence the possibility of damage to safety-related structures, systems, and components by those missiles) can be met. The NRC safety objective for turbine missiles (i.e., P_4 should be $\leq 10^{-7}$ per year per plant) is best expressed in terms of either of two sets of criteria applied to missile generation probability, P_1. All applicants are expected to commit to operating criteria (see Table 3.5.1.3-1) appropriate to the applicable turbine orientation. One set of criteria should be applied to favorably oriented turbines; the other should be applied to unfavorably oriented turbines.

This approach places responsibility on the applicant for initially demonstrating, and thereafter maintaining, an NRC-specified turbine reliability. Accordingly, the applicant should commit to conduct appropriate inservice inspection and testing throughout the life of the plant. This requires the applicant to demonstrate the capability to perform volumetric (ultrasonic) examinations suitable for inservice inspection of turbine disks and shafts and to provide reports describing the applicant's methods for determining turbine missile generation probabilities (Refs. 5, 13, and 14) for NRC review and approval.[24]

TABLE 3.5.1.3-1

PROBABILITY OF TURBINE FAILURE RESULTING IN THE EJECTION OF TURBINE DISK
(OR INTERNAL STRUCTURE) FRAGMENTS THROUGH THE TURBINE CASING (P_1)
AND REQUIRED LICENSEE ACTIONS[25]

CASE	PROBABILITY PER YEAR FOR A FAVORABLY ORIENTED TURBINE	PROBABILITY PER YEAR FOR AN UNFAVORABLY ORIENTED TURBINE	REQUIRED LICENSEE ACTION

A	$P_1 < 10^{-4}$	$P_1 < 10^{-5}$	This condition represents the 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 must take action to reduce P_1 to meet the appropriate Case A criterion before returning the turbine to service. Exemptions may be granted for valid technical reasons or to mitigate severe economic hardship.
C	$10^{-3} < P_1 < 10^{-2}$	$10^{-4} < P_1 < 10^{-3}$	If this condition is reached during operation, the turbine must be isolated from the steam supply within 60 days, at which time the licensee must take action to reduce P_1 to meet the appropriate Case 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 must be isolated from the steam supply within 6 days, at which time the licensee must take action to reduce P_1 to meet the appropriate Case A criterion before returning the turbine to service.

5. Applicants obtaining turbines from manufacturers that have prepared NRC-approved reports to describe their methods and procedures for calculating turbine missile generation probabilities are expected to meet criteria appropriate to the orientation of the turbine (see Table 3.5.1.3-1). Turbine manufacturers should provide applicants with tables of missile generation probabilities versus time (inservice volumetric disk inspection interval for design speed failure and inservice valve testing interval for destructive overspeed failure) for each turbine. These probabilities will be used to establish inspection and test schedules that meet NRC safety objectives.[26]

6. Applicants are expected to commit to the following program if turbines are obtained from manufacturers that have not submitted, or received NRC approval for, reports

describing their methods and procedures for calculating turbine missile generation probabilities:

a. An inservice inspection program should be used to detect disk flaws that could lead to brittle failure at or below design speed in the steam turbine rotor assembly. The turbine rotor design should facilitate inservice inspection of all high-stress regions, including disk bores and keyways, without removal of the disks from the shaft. The volumetric inservice inspection interval for the steam turbine rotor assembly should be established according to the following guidelines:

   (1) The initial inspection of a new rotor or disk should be performed before any postulated crack is calculated to grow to more than one-half the critical crack depth. If the calculated inspection interval is less than the scheduled first fuel cycle, the licensee should seek the manufacturer's guidance on delaying the inspection until the first refueling outage. If the calculated inspection interval is longer than the first fuel cycle, the licensee should seek the manufacturer's guidance for scheduling the first inspection during a later refueling outage.

   (2) Disks that have been inspected and found free of cracks or that have been repaired to eliminate all indications of cracks should be reinspected using the criterion described in (1) above; crack growth should be calculated from the time of the last inspection.

   (3) Disks operating with known and measured cracks should be reinspected before the elapse of one-half the time calculated for any crack to grow to one-half the critical depth. The guidance described in (1) above should be used to set the inspection date on the basis of the calculated inspection interval.

   (4) Under no circumstances should the volumetric inservice inspection interval for low-pressure (LP) disks exceed 3 years or two fuel cycles.

b. The offline inspection program should use visual, surface, and volumetric examinations during refueling or maintenance shutdowns (in accordance with the manufacturer's procedures) of all normally inaccessible parts such as couplings, coupling bolts, LP turbine shafts, blades and disks, and high-pressure (HP) rotors. Shafts and disks with crack depths at or near one-half the critical crack depth should be repaired or replaced. All cracked couplings and coupling bolts should be replaced.

c. The inservice inspection and test program should be used for the governor and overspeed protection system to provide further assurance that flaws or component failures will be detected in the overspeed sensing and tripping subsystems, main steam control and stop valves, reheat steam intercept and stop valves, or extraction steam non-return valves — any of which could lead to an overspeed condition above that specified by the design overspeed. The inservice inspection program for operability of the governor and overspeed protection system should include, at a minimum, the following provisions:

(a) For typical turbine governor and overspeed protection systems, at intervals of approximately 3 years during refueling or maintenance shut-downs, at least one main steam control valve, one main steam stop valve, one reheat intercept valve, one reheat stop valve, and one of each type of steam extraction valve should be dismantled. Visual and surface examinations of valve seats, disks, and stems should be conducted. Valve bushings should be inspected and cleaned, and bore diameters should be checked for proper clearance. If any valve is shown to have hazardous flaws or excessive corrosion or improper clearances, the valve should be repaired or replaced; all other valves of that type should also be dismantled and inspected.

(b) At least once a week during normal operation, main steam control and stop valves, reheat intercept and stop valves, and steam extraction non-return valves should be exercised 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 component of the electro-hydraulic governor system (which modulates control and intercept valves), as well as the mechanical overspeed trip mechanism and backup electrical overspeed trip (both of which trip the main steam control and stop valves and the reheat intercept and stop valves), should be tested.

The online test failure of any one of these subsystems mandates repair or replacement of failed components within 72 hours. Otherwise, the turbine should be isolated from the steam supply until repairs are completed. Refer to SRP Section 10.2 for additional information regarding inspection and testing of turbine generator components.

d. Operating criteria appropriate to the orientation of the turbine should conform to those described in Table 3.5.1.3-1.[27]

7. An applicant may propose to install barriers or to take credit for existing structures or features as barriers. Such a decision could be based on the applicant's deterministic judgment that a structure, system, or component is particularly vulnerable to destruction or unacceptable damage in the event of a turbine failure. The applicant should include specific details in the safety analysis report (SAR) supporting the need for such protection. If an applicant proposes to design or evaluate barriers to reduce or eliminate turbine missile hazards to equipment, the barriers should meet the acceptance criteria described in SRP Section 3.5.3. Additional design guidance is provided in Reference 4.[28]

Technical Rationale[29]

The technical rationale for application of these acceptance criteria to protecting safety-related structures, systems, and components from the effects of turbine missiles is discussed in the following paragraphs:[30]

Compliance with GDC 4, "Environmental and Dynamic Effects Design Bases," requires that components important to safety be designed to accommodate the effects of, and be compatible with, environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. Components are to be protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may be the result of equipment failure or of events and conditions outside the nuclear power unit.

The protection of safety-related structures, systems, and components form the effects of turbine missiles is discussed in this SRP section. The staff requires that the probability of damage to such equipment be calculated as less than 1 in 10 million per plant per year. Specific guidance regarding the arrangement, design, and inspection of turbine generators is provided to ensure that the probability of turbine missile damage will not exceed the limit value during the life of the plant.

Meeting the requirements of GDC 4 provides assurance that structures, systems, and components important to safety will be protected from the effects of turbine missiles and will be capable of performing their intended safety function.[31]

III. REVIEW PROCEDURES

The reviewer selects and emphasizes aspects of the areas covered by this SRP section as may be appropriate for a particular case. The judgment on areas to be given attention and emphasis in the review is based on an inspection of the material presented to see whether it is similar to that recently reviewed on other plants and whether items of special safety significance are involved.

Upon request from the primary reviewer, the ~~secondary~~ review interface[32] branches will provide input for the areas of review stated in subsection I of this SRP section. The primary reviewer obtains and uses such input as required to ~~assure~~ ensure[33] that this review procedure is complete.

The review procedure involves the following:

1. The plant layout ~~drawings are~~ is[34] reviewed to determine the relative placement of the containment and other[35] safety-related structures, systems, and components with respect to the turbine-generator unit(s). The orientation of the turbine is determined to be favorable or unfavorable according to the acceptance criteria offered in subsection II. Values of strike and damage probability are subsequently reviewed and compared with the acceptance criteria offered in subsection II.[36] ~~This review is focused on determining if the plant layout conforms to the turbine placement and orientation recommendations outlined in Regulatory Guide 1.115. If the orientation is such that all safety-related targets are excluded from the low trajectory turbine missiles, further review in this regard~~

is not necessary. This procedure also encompasses the possibility of having some safety-related targets within the strike zones when their placement is unavoidable. However, these systems must be protected against the effects of turbine missiles generated at design overspeed and destructive overspeed. As indicated in the Regulatory Guide 1.115, this condition is met if the size, placement, and/or shielding by barriers is such that the total strike and damage probability for all such targets within the strike zones is less than 10^{-3} per turbine failure. Adequate protection will also be identified with targets which are redundant and sufficiently independent (e.g., by separation distance or barriers) such that a turbine failure could not compromise two or more members of a redundant train.

The following specific information is necessary in order to perform the above review:

a. Dimensioned plant layout drawings (plan and elevation views).

b. Barriers (e.g., structural wall material strength properties, thicknesses).

c. Identification of safety-related structures, systems, and components in terms of location, redundancy, and independence (Ref. 3).

d. Identification of all turbine-generator units (present and future) in the vicinity of the plant being reviewed.

e. A quantitative description of the turbine-generator in terms of rotor shaft, wheels, steam valve characteristics, rotational speed and turbine internals pertinent to turbine missiles analyses. Postulated missiles should be identified in terms of missile size, mass, shape, and exit speed for design overspeed and destructive overspeed turbine failures. A description should be provided of the analysis used in estimating the missile exit speeds. The sense of rotation should be identified with respect to each turbine-generator under consideration.

   Most of this information can be obtained from the applicant's SAR. The relevant Standard Format Sections are 1.2, 3.5, 3.8, and 10.2.

2. Plants which do not conform to the recommendations of Regulatory Guide 1.115 should be reviewed on a case-by-case basis for each safety-related target. The review centers around the evaluation of the individual probability components in the relation

$$P = \frac{1}{N} \sum_{i=1}^{2} P_{1i} \sum_{j=1}^{N} P_{2ij} P_{3ij}$$

EQUATION DELETED

where

P = Total probability for incurring damage which exceeds the criteria described in subsection II, per turbine year.

N = Total number of distinct turbine missile sources per turbine generator unit, usually identified with the number of low pressure wheels.

P_{1i} = Probability for turbine failure leading to the ejection of missiles due to the i^{th} type of turbine failure.

P_{11} = 6×10^{-5} per turbine year for design over speed failures.

P_{12} = 4×10^{-5} per turbine year for destructive overspeed failures (Ref. 4).

P_{2ij} = The strike probability with respect to a barrier between the turbine and the target. In case of multiple barriers, it is equivalent to the probability for striking the final barrier between the turbine and the target. The j - index refers to the j^{th} wheel on the turbine rotor.

P_{3ij} = The probability for damaging the target. This can be either due to primary missile penetration of a barrier or due to the generation of secondary missiles (e.g., scabbing in concrete), or both.

It should be noted that in the case of multiple barriers the value of P will be determined by a combination of geometric considerations, missile deflections, and intermediate barrier penetration estimates (Ref. 5). The usual procedure is to estimate the portion of the total solid angle associated with each ejected missile that is subtended by the target in question. If there are no intermediate barriers, or if all barriers up to the final barrier are penetrated independently of missile state (i.e., energy, impact orientation) then P_{2ij} can be approximated by

$$P_{2ij} = \left(\frac{\Delta\theta_j}{\Delta\theta_{j,\max}}\right) \left(\frac{\Delta\phi}{\Delta\phi_{\max}}\right)$$

EQUATION DELETED

where

$\Delta\theta_j$ = Azimuthal angle subtended by the target with the respect to the j(th) wheel.

$\Delta\theta_{j,max}$ = Maximum azimuthal angle range of fragment trajectories ejected from the j(th) wheel.

= 10^{0} for inner wheels

= 25^0 for end wheels.

$\Delta\phi$ = Elevation angle subtended by the target.

$\Delta\phi_{max}$ = Maximum elevation angle range for a missile (e.g., for a single fragment the probability of any given elevation angle is uniformly distributed over 2π radians, ϕ_{max} = 360^0).

An additional factor f may be used to multiply the above relation if penetration of intermediate barriers is conditional on missile state. This can be done by considering the ratio of all missile states that penetrate the barrier to the total number of missile states. If there are M barriers, this may be expressed as

$$f_{ij} = \prod_{m=1}^{M} \frac{(All\ missile\ states\ that\ penetrate\ the\ m^{th}\ barrier)_{ij}}{(Total\ number\ of\ possible\ missile\ states)_{ij}}$$

EQUATION DELETED

where the i and j indices refer to the turbine failure mode and failed wheel, respectively.

Estimates of the potential for concrete penetration and/or scabbing are based on the missile penetration criteria described in SRP Section 3.5.3.

The evaluation of the overall probability P is performed by considering conservative as well as realistic estimates of all the individual parameters that are used in the analysis. The conservative and realistic estimates of P are used in conjunction with the risk acceptance guidelines described in SRP Section 2.2.3 in determining the acceptability of the plant design with respect to turbine missile risk.

3. The reviewer may request technical assistance on an as needed basis in the following areas in order to complete the turbine missile evaluation:

   a. Where the design basis protection against turbine missiles is primarily by use of barriers, the adequacy of structural turbine barrier procedures are verified by the SEB in accordance with the criteria of SRP Section 3.5.3.

   b. The effect of fracture toughness properties on the failure probability of the low pressure turbine wheels is reviewed by the MTEB.

   c. The turbine overspeed protection system and its testing are evaluated by the MEB (turbine steam valve reliability) and the PSB (tripping and overspeed sensing systems).

   d. The identification of plant essential systems to be protected against turbine missiles is reviewed by the ASB.

4. For Construction Permit applications docketed prior to 11/15/76 and to all Operating License reviews, a summary should be prepared of the following items:

a. Identification of all safety-related targets vulnerable to turbine missiles.

b. MTEB findings regarding turbine disc and rotor integrity and inservice inspection program.

c. When appropriate, SEB evaluation of credit for missile barriers.

d. PSB findings regarding turbine overspeed protection system.

e. A general value impact assessment of localized missile shielding(CP's and OL's) and/or system relocation (CP's only).

f. Identification of additional plant requirements, if any.

5. High trajectory turbine missiles are characterized by their nearly vertical trajectories. Missiles ejected more than a few degrees from the vertical, either have sufficient speed such that they land offsite, or their speeds are low enough so that their impact on most plant structures is not a significant hazard. The probability of a high trajectory turbine missile landing within a few hundred feet from the turbine is on the order of 10^{-7} per square foot of horizontal target area. Consequently the risk from high trajectory turbine missiles is insignificant unless the vulnerable target area is on the order of 10^{4} square feet or more.[37]

2. Values calculated by the applicant for turbine missile generation probability are reviewed and compared with the acceptance criteria offered in subsection II. The applicant's methods and analyses are reviewed to determine that the probability of turbine missile generation is acceptable. The acceptance criteria describe inspection programs that are acceptable to the staff for defining turbine missile generation probability, and these criteria are compared with the applicant's program. The program is then reviewed to determine whether the applicant's level of commitment is acceptable.[38]

3. If the applicant proposes to install barriers or use existing structures or features as barriers against turbine missiles, the reasons for providing such barriers and their placement are reviewed. The structural capability of these barriers to withstand turbine missiles is reviewed by the ECGB in accordance with the procedures specified in SRP Section 3.5.3.[39]

For standard design certification reviews under 10 CFR Part 52, the procedures above should be followed, as modified by the procedures in SRP Section 14.3 (proposed), to verify that the design set forth in the standard safety analysis report, including inspections, tests, analysis, and acceptance criteria (ITAAC), site interface requirements and combined license action items, meet the acceptance criteria given in subsection II. SRP Section 14.3 (proposed) contains procedures for the review of certified design material (CDM) for the standard design, including the site parameters, interface criteria, and ITAAC.[40]

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and that the review and calculations support conclusions of the following types supports the following conclusion:[41]

1. The staff concludes that the turbine missile risk for the proposed plant design is acceptable and meets the requirements of General Design Criterion 4. This conclusion is based on the applicant having sufficiently demonstrated to the staff in accordance with Regulatory Guide 1.115[42] that the probability of turbine missile damage to safety-related structures, systems, and components important to safety (i.e., those listed in Regulatory Guide 1.117)[43] is acceptably low.

2. The staff concludes that the turbine missile risks for the proposed plant designs are too high and do not meet the requirements of General Design Criterion 4. Additional protection against turbine missiles is required in order to reduce the overall risk. The applicant should comply with Regulatory Guide 1.115 (turbine reorientation, vulnerable system relocation, missile barriers, overspeed protection, turbine disc integrity and inservice inspection, or other appropriate measures may be recommended).[44]

For design certification reviews, the findings will also summarize, to the extent that the review is not discussed in other safety evaluation report sections, the staff's ITAAC evaluation, including design acceptance criteria (DAC), site interface requirements, and COL action items that are relevant to this SRP section.[45]

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

This SRP section will be used by the staff when performing safety evaluations of license applications submitted by applicants pursuant to 10 CFR 50 or 10 CFR 52.[46] Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section.[47]

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

VI. REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Dynamic Effects[48] Design Bases."

2. Regulatory Guide 1.115, "Protection Against Low-Trajectory Turbine Missiles."

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

4. S. H. Bush, "Probability of Damage to Nuclear Components," Nuclear Safety, Vol. 14, No. 3, May-June 1973.[49]

54.[50] "Fundamentals of Protective Design," TM-5-855-1, Department of the Army, July 1965.

5. NUREG-1048, Supplement 6, "Safety Evaluation Report Related to the Operation of Hope Creek Generating Station," July 1986 (includes Appendix U, "Probability of Missile Generation in General Electric Nuclear Turbines").

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

7. J. J. Burns, Jr., "Reliability of Nuclear Power Plant Steam Turbine Overspeed Control Systems," ASME 1977 Failure Prevention and Reliability Conference, Chicago, Illinois, September 1977, page 27.

8. W. G. Clark, Jr., B. B. Seth, and D. H. Shaffer, "Procedures for Estimating the Probability of Steam Turbine Disc Rupture From Stress Corrosion Cracking," ASME/IEEE Power Generation Conference, October 4-8, 1981, St. Louis, Missouri.

9. D. Kalderon, "Steam Turbine Failure at Hinkley Point A," Proceedings of the Institute of Mechanical Engineers, 186, 31/72, 1972, page 341.

10. License Event Report No. 82-132, Docket No. 50-361, "Failure of Turbine Stop Valve 2UV-2200E to Close Fully," San Onofre Nuclear Generating Station, Unit 2, November 19, 1982.

11. Preliminary Notification of Event or Unusual Occurrence, PNO-111-81-104, "Circle in the Hub of the Eleventh Stage Wheel in the Main Turbine," Monticello Nuclear Power Station, November 24, 1981.

12. NRC Memorandum from E. Jordan to W. Russell (with enclosed report, AEOD/S94-02 by H. Ornstein), "AEOD Special Study, 'Turbine-Generator Overspeed Protection Systems at U.S. Light-Water Reactors,'" September 30, 1994.

13. Letter from C. Rossi (NRC) to J. Martin (Westinghouse Electric Corporation), "Approval for Referencing of Licensing Topical Reports WSTG-1-P, May 1981, 'Procedures for Estimating the Probability of Steam Turbine Disc Rupture From Stress Corrosion Cracking,' March 1974, 'Analysis of the Probability of the Generation and Strike of Missiles from a Nuclear Turbine,' WSTG-2-P, May 1981, 'Missile Energy Analysis Methods for Nuclear Steam Turbines,' and WSTG-3-P, July 1984, 'Analysis of the Probability of a Nuclear Turbine Reaching Destructive Overspeed,'" February 2, 1987.

14. NUREG-0887, Supplement No. 3, "Safety Evaluation Report Related to the Operation of Perry Nuclear Power Plant, Units 1 and 2," April 1983.[51]

SRP Draft Section 3.5.1.3

Attachment A - Proposed Changes in Order of Occurrence

Item numbers in the following table correspond to superscript numbers in the redline/strikeout copy of the draft SRP section.

Item	Source	Description
1.	Current primary review branch designation and abbreviation	Changed PRB to Materials and Chemical Engineering Branch (EMCB).
2.	Integrated Impact No. 230	Added an introductory sentence to indicate reason for the staff's concern with a nonsafety-related system. This sentence was adapted from Appendix U to NUREG-1048, "Probability of Missile Generation in General Electric Nuclear Turbines."
3.	Integrated Impact No. 230	Deleted one sentence and part of another to indicate the current scope of the staff's review regarding turbine missiles. The staff position since 1981 (NUREG-0887, Supplement 3, Perry SSER) is that strike and damage probabilities need not be calculated and that the industry should concentrate on lowering the probability of turbine missile generation.
4.	Editorial, SRP-UDP Format, PRB Comments	Based upon PRB comments on draft for SRP 10.2.3, PRB has changed and section scope is revised.
5.	SRP-UDP format item	Added "Review Interfaces" to AREAS OF REVIEW.
6.	Current primary review branch abbreviation	Changed PRB to EMCB.
7.	SRP-UDP format item	Divided the existing text into numbered subparagraphs in the new "Review Interfaces" subsection.
8.	Current review branch designation and abbreviation	Changed review interface branch to Civil Engineering and Geosciences Branch (ECGB).
9.	Editorial modification	Deleted "the."
10.	Editorial, SRP-UDP Format, PRB Comments	Based upon PRB comments on draft for SRP 10.2.3, PRB has changed and section scope is revised to cover rotor rather than disk analysis.
11.	Current review branch designation and abbreviation	Changed review interface branch to Plant Systems Branch (SPLB).
12.	Editorial modification	Added "The" at the beginning of the sentence to provide parallelism.
13.	Current review branch abbreviation	Changed review interface branch to EMEB.
14.	Current review branch abbreviation	Changed review interface branch to EMEB.

Item	Source	Description
15.	Editorial modification	Deleted "instrumentation and." Instrumentation is reviewed by HICB, and the review responsibilities are explained in new text added at the end of the paragraph.
16.	Editorial modification	Changed "its" to "their" to reflect the reference to two branches.
17.	Current review branch responsibility	Added "The Instrumentation and Control Systems Branch (HICB), in cooperation with the EMEB and SPLB, reviews seismic and environmental qualification of instrumentation as part of its secondary review branch responsibilities for SRP Sections 3.10 and 3.11." This change reflects current secondary review branch responsibilities.
18.	Current review branch responsibility	Changed review interface branch to SPLB.
19.	Editorial modification	Deleted "primary." Secondary review branch responsibilities are described in the subsection, so the word no longer applies.
20.	Editorial modification	Deleted redundant phrase "section of the corresponding primary branch" and replaced it with the word "sections."
21.	Integrated Impact No. 230	Deleted obsolete acceptance criteria. The staff's emphasis focuses on lowering the probability for generating turbine missiles rather than mitigating their effects. Accordingly, the obsolete text was deleted.
22.	Integrated Impact No. 230	Added items 1 and 2, which describe acceptance criteria that are in accordance with the staff's current position, as outlined in a number of documents. This text was adapted from Supplement 3 to NUREG-0887 (Perry SSER) and reflects the staff's emphasis on preventing turbine missile generation. Similar text can be found in Appendix U to Supplement 6 of NUREG-1048 (Hope Creek SSER). The Hope Creek SSER is cited in subsection 3.5.1.3 of the CE80+ FSER, NUREG-1462. Item 1 describes the regulatory bases for protecting equipment from turbine missiles. Item 2 describes the calculation of damage probabilities and the difficulties associated with calculating strike and damage probabilities.

Item	Source	Description
23.	Integrated Impact No. 230	Added item 3, which was adapted from Supplement 3 to NUREG-0887 (Perry SSER), Supplement 6 to NUREG-1048, Appendix U (Hope Creek SSER), and the Rossi-to-Martin Letter dated February 2, 1987 (Topical Report Reviews). These last two documents are cited in the CE80+ FSER. Item 3 describes the relationship between turbine inspection and maintenance and the potential for generating turbine missiles.
24.	Integrated Impact No. 230	Added item 4, which describes operating criteria for achieving acceptably low probabilities for generating turbine missiles. This text was adapted from Supplement 3 to NUREG-0887 (Perry SSER), Supplement 6 to NUREG-1048, Appendix U (Hope Creek SSER), and the Rossi-to-Martin Letter dated February 2, 1987 (Topical Report Reviews). The last two documents are cited in subsection 3.5.1.3 of the CE80+ FSER, NUREG-1462.
25.	Integrated Impact No. 230	Added Table 3.5.1.3-1, which describes operating criteria for achieving acceptably low probabilities for generating turbine missiles. This table was reproduced from Supplement 3 to NUREG-0887, Supplement 6 to NUREG-1048, Appendix U, and the Rossi-to-Martin Letter dated February 2, 1987. Similar tables can be found in the CE80+ FSER, NUREG-1462 (Table 3.1) and the ABWR FSER, NUREG-1503 (Table 3.1).
26.	Integrated Impact No. 230	Added item 5, which describes preparation of reports by turbine manufacturers on turbine missile generation probability. This text was adapted from subsection 3.5.1.3.1.4 of Supplement 3 to NUREG-0887 (Perry SSER).
27.	Integrated Impact No. 230	Added item 6, which describes an inspection and test program for the turbine and overspeed protection system, which ensures that turbine missile generation probability is maintained at an acceptably low level. This subsection pertains to applicants who obtain turbines from manufacturers that do not have approved reports. This text was adapted from subsection 3.5.1.3.1.5 of Supplement 3 to NUREG-0887 (Perry SSER).

Item	Source	Description
28.	Integrated Impact No. 230	Added item 7, which provides acceptance criteria for barriers if an applicant chooses to use barriers to protect specified equipment. The staff's position is that the use of barriers to resist the effects of turbine missiles is not required if the probability of damage is acceptably low, licensees have the option to provide such protection. Therefore acceptance criteria for barriers that resist turbine missiles is offered.
29.	SRP-UDP format item	Added "Technical Rationale" to ACCEPTANCE CRITERIA.
30.	SRP-UDP format item	Added a lead-in sentence to "Technical Rationale."
31.	SRP-UDP format item	Added technical rationale for GDC 4.
32.	Editorial modification	Changed the word "secondary" to "interface" to correct the description of the review branches.
33.	Editorial modification	Changed "assure" to "ensure" to correct usage.
34.	Integrated Impact No. 230	Deleted the words "drawings are" and substituted the word "is" in the sentence. It is no longer necessary for the staff to review drawings of the placement of equipment and barriers with regard to turbine missile protection. The staff's emphasis on prevention of the generation of turbine missiles makes it necessary to determine the general orientation and placement of main turbines. This can be done using general information normally provided in an FSAR.
35.	Integrated Impact No. 230	Added the phrase "the containment and other" in the sentence to determine whether the turbine is favorably or unfavorably oriented.
36.	Integrated Impact No. 230	Added text to define review responsibilities to determine favorable or unfavorable turbine orientation.
37.	Integrated Impact No. 230	Deleted the review procedures that refer to mitigation of strike and damage probabilities from turbine missiles. The acceptance criteria was changed to allow standardized numbers for these quantities based on the general orientation of the turbine with respect to the containment and other safety-related equipment. Accordingly, review procedures related to strike and damage probability of turbine missiles are no longer needed.

Item	Source	Description
38.	Integrated Impact No. 230	Added new item III.2 referring to review procedures to matching the acceptance criteria provided in subsection II of this SRP section.
39.	Integrated Impact No. 230	Added new item III.3 to cover situations in which the applicant may propose to use barriers to mitigate or prevent damage from turbine missiles.
40.	SRP-UDP format item	Added standard paragraph to cover design certification reviews.
41.	Integrated Impact No. 230	Deleted reference to calculations at the end of the sentence. The preparation of calculations to verify that barriers are competent will no longer be emphasized by the staff in its review of turbine missile hazards.
42.	Integrated Impact No. 230	Deleted phrase that referred to the staff's review, in accordance with Regulatory Guide 1.115, for strike and damage probability. The staff's emphasis will now be focused on minimizing the probability of generation of turbine missiles.
43.	Editorial modification	Revised wording to conform to definition of equipment covered that were offered in subsection I of the SRP section.
44.	Integrated Impact No. 230	Deleted existing paragraph II.2 referring to designs that do not meet the staff's criteria. The criteria cited are obsolete considering the staff's emphasis on minimizing the probability of turbine missile generation. Further, the paragraph is not needed because the SRP section provides criteria for use in determining whether applicants are in compliance with the Commission's rules.
45.	SRP-UDP format item	Added standard paragraph to cover design certification reviews.
46.	SRP-UDP Guidance, Implementation of 10 CFR 52	Added standard sentence to address application of the SRP section to reviews of applications filed under 10 CFR Part 52, as well as Part 50.
47.	SRP-UDP Guidance	Added standard paragraph to indicate applicability of this section to reviews of future applications.
48.	Editorial modification	Updated title for GDC 4.
49.	Integrated Impact No. 230	Deleted obsolete reference cited in text that was deleted.

Item	Source	Description
50.	SRP-UDP format item	Revised reference numbers.
51.	Integrated Impact No. 230	Added References 5 through 14 to support text added to the SRP section.

SRP Draft Section 3.5.1.3

Attachment B - Cross Reference of Integrated Impacts

Integrated Impact No.	Issue	SRP Subsections Affected
230	Revise SRP Section 3.5.1.3 to reflect the staff's current approach toward the review of the protection against turbine missiles. The staff's current approach focuses on minimizing the probability of generation of turbine missiles. The previous approach focused primarily on providing mitigating features for the plant.	AREAS OF REVIEW ACCEPTANCE CRITERIA REVIEW PROCEDURES EVALUATION FINDINGS REFERENCES