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)

Secondary - None

I. AREAS OF REVIEW

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. The review requires input from the Auxiliary Systems Branch (ASB) on target identification and from the Structural Engineering Branch (SEB) on barrier quality.

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.

In addition, MTEB will coordinate other branches' evaluations that interface with the overall review of turbine missiles. These interfaces are as follows: SEB, upon request, reviews the 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. Power Systems Branch (PSB) reviews the turbine overspeed protection including overspeed sensing and tripping as part of its primary review responsibility for SRP Section 10.2. Mechanical Engineering Branch (MEB) 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. Equipment Qualification Branch (EQB) reviews the seismic qualification of instrumentation and electrical system components and the environmental qualification of mechanical and electrical system components as part of its primary review responsibility for SRP Sections 3.10 and 3.11, respectively. ASB 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 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.

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. Exclusions 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.

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 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 that this review procedure is complete.

The review procedure involves the following:

1. The plant layout drawings are reviewed to determine the relative placement of safety-related structures, systems, and components with respect to the turbine-generator unit(s). 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

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

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 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_{2ij} 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

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

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° for inner wheels

= 25° 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, $\phi_{max} = 360°$).

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

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

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. Consequenty 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.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and that the review and calculations support conclusions of the following types:

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 that the probability of turbine missile damage to structures, systems, and components important to safety (i.e., those listed in Regulatory Guide 1.117) 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).

V. IMPLEMENTATION

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

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.

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 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.

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