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PROTECTION AGAINST LOW-TRAJECTORY TURBINE MISSILES

A. INTRODUCTION

General Design Criterion 4, "Environmental and Missile Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50, "Licensing of Production and Utilization Facilities," requires, in part, that structures, systems, and components important to safety be appropriately protected against the effects of missiles that might result from equipment failures. Failures that could occur in the large steam turbines of the main turbine-generator sets have the potential for producing large high-energy missiles. This guide describes methods acceptable to the NRC staff for protecting safety-related structures, systems, and components against low-trajectory missiles resulting from turbine failure by appropriate orientation and placement of the turbine-generator set. The Advisory Committee on Reactor Safeguards has been consulted concerning this guide and has concurred in the regulatory position.

B. DISCUSSION

Although there is little information available on failures of large turbines, cumulative failure data based on operating history for conventional plants[1] indicate that the protection of safety-related portions of nuclear power plants from turbine missiles is an appropriate safety consideration. The two broad categories of turbine failures are usually referred to as design overspeed failures and destructive overspeed failures. Missiles resulting from design overspeed failures are the result of brittle fracture of turbine blade wheels or portions of the turbine rotor itself. Failures of this type can occur during startup or normal operation. Missiles resulting from destructive overspeed failures would be generated if the overspeed protection system malfunctions and the turbine speed increases to a point at which the low-pressure wheels or rotor will undergo ductile failure. The kinetic energy of ejected missiles can be sufficient to damage even substantial reinforced concrete slabs and panels. Thus turbine missiles have the potential for damaging safety-related structures, systems, and components of the plant.

Missiles from a turbine failure can be divided into two groups: "high-trajectory" missiles, which are ejected upward through the turbine casing and may cause damage if the falling missile strikes an essential system and "low-trajectory" or "direct" missiles, which are ejected from the turbine casing directly toward an essential system. This guide outlines acceptable methods of protection against low-trajectory turbine missiles.

Consideration of turbine missile protection is relevant for essential systems, i.e., those structures, systems, and components necessary to ensure:

1. The integrity of the reactor coolant pressure boundary,

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

3. 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."

The potential consequences of turbine missiles include direct effects (e.g., damage to the spent fuel storage pool) as well as indirect effects (e.g., impairment of vital control room functions). In either case, it is necessary to show that the risk from turbine mis-

*Lines indicate substantive changes from previous issue.

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

siles is acceptably small, either because design features are provided to prevent damage or because the probability of a strike by a turbine missile is sufficiently low. Turbine orientation and placement, shielding, quality assurance in design and fabrication, inspection and testing programs, and overspeed protection systems are the principal means of safeguarding against turbine missiles. The first of these, turbine orientation and placement, provides a high degree of confidence that low-trajectory missiles resulting from turbine failures will not damage essential systems.

The probability of damage by low-trajectory turbine missiles is large enough to warrant design precautions in future plants. The historical failure data on conventional units indicate that an incidence rate of 10^{-4} per turbine year is appropriate for material failures at speeds up to design overspeed (120% to 130% of turbine operating speed). There is reason to believe that improvements in turbine design, particularly in materials selection, will reduce the design overspeed failure rate. However, an operating history of the length required to permit estimates of very low failure rates, even in the absence of any failures, has not been accumulated. This, and the recurrence of disc or rotor degradation due to other causes, leads the staff to conclude that without additional evidence, use of the historical failure rate is appropriate. Assurance of low failure rates can be enhanced by an inservice inspection program. Tradeoffs between frequency and level of testing and improvements in reliability are currently under study by the NRC staff.

A more difficult protection problem is presented by runaway turbine failures that may result in turbine speeds of 180% to 190% prior to destructive failure of the turbine wheels or shaft. Again, historical data indicate a destructive overspeed failure rate of about 10^{-4} per turbine year. The staff's view is, however, that significant reduction in the rate of destructive overspeed failures may be obtained by the application of improved overspeed protection systems, redundant turbine steam valving, improved valve design, and frequent valve testing. The degree of credit for improved systems and procedures appears to be limited primarily by the reliability of turbine steam valving. Many of the destructive overspeed failures of recent years were caused by the failure of turbine steam valves to close and stop the flow of steam even though a trip signal was generated. A definitive study of turbine valve failure modes is not available in the published literature, but the subject is currently being investigated by the NRC staff.

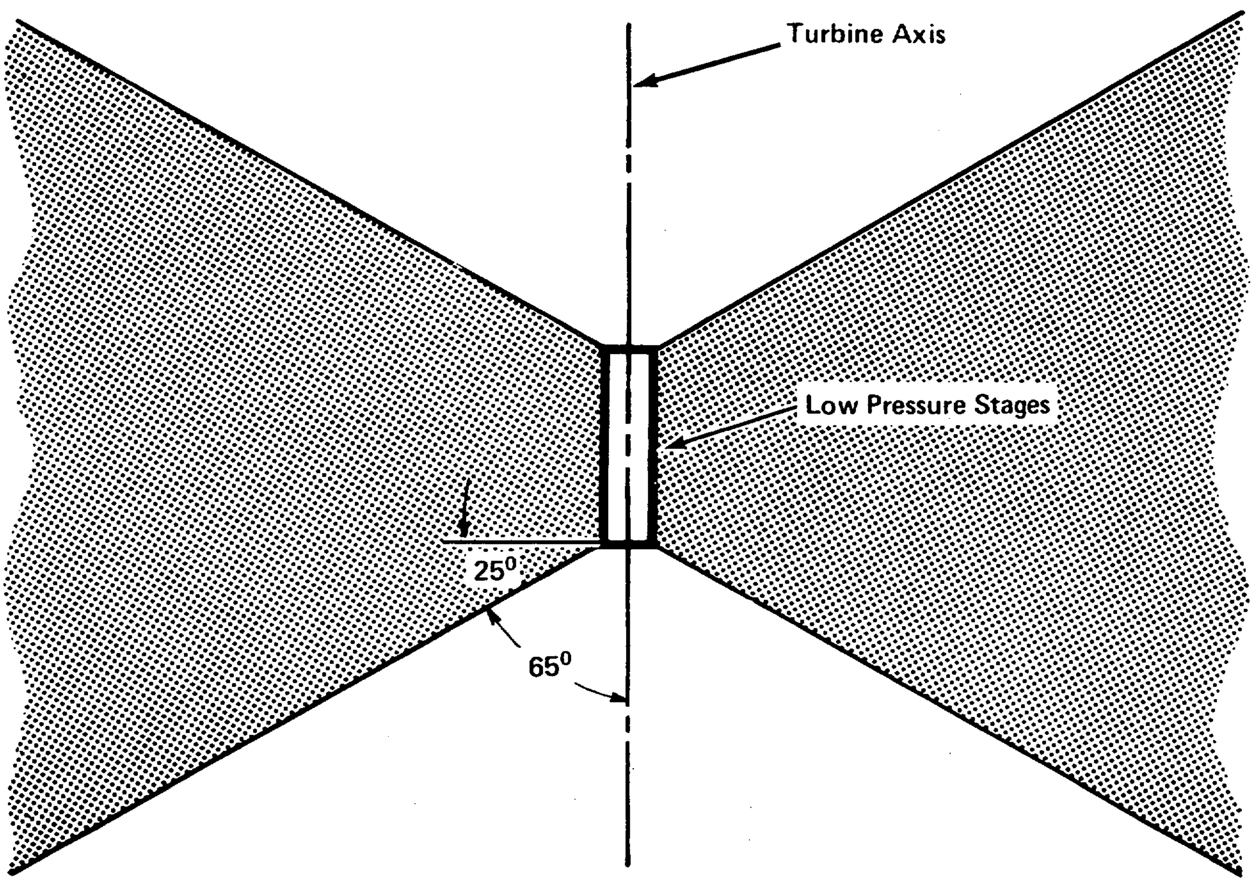

Figure 1 Low-Trajectory Turbine Missile Strike Zone

Evidence currently available[2] indicates that low-trajectory turbine missile strikes will be concentrated within an area bounded by lines inclined at 25 degrees to the turbine wheel planes and passing through the end wheels of the low-pressure stages (see Figure 1). This applies to the low-pressure stage shrunk-on wheels of the 1800-rpm turbines generally used with light-water-cooled reactors. Essential systems within this area and close to the turbine axis are most vulnerable; those further removed from the turbine axis are less likely to be hit by a missile. Systems outside this area are not endangered by high-energy low-trajectory missiles.

The staff has concluded that protecting essential systems by excluding them from the low-trajectory hazard zone has less associated uncertainty than other methods and thus is the preferred method of protection. However, plants with less favorable turbine orientation have been found acceptable. The protection of an essential system within the low-trajectory missile strike zone is considered adequate against low-trajectory turbine missiles if the system is either small enough or far enough removed from the turbine that the probability of its being struck by a turbine missile is less than 10^{-3}. If more than one essential system is so located, the sum of the probabilities of their being struck should be less than 10^{-3}. This criterion is a conservative way to ensure that the hazard rate due to low-trajectory turbine missiles is less than 10^{-7} per year, which the NRC staff considers an acceptable risk rate for the loss of an essential system from a single event. Combinations of such measures as care in the placement of essential systems, separation of redundant equipment, and special attention to turbine valve reliability have been shown, through detailed strike and damage analyses, to have accomplished the objective of ensuring a low risk of damage from turbine missiles.

Some degree of protection against low-trajectory turbine missiles may be provided by barriers. There is no body of experimental evidence on the impact effects of large irregularly shaped missiles similar to those observed in turbine failures on either steel or reinforced concrete structures. Considerable uncertainty attends the current practice of using damage predictions based on ordnance data, particularly in the choice of an "effective impact area." However, conservative damage predictions can be made by using results of similar tests and conservative assumptions. Some recent data[3] were motivated by protection against tornado missiles. For cases in which the impact was normal and the impact area known, there was good correlation[3] between actual penetration distances into reinforced concrete and those predicted by the Modified National Defense Research Council (NDRC) formula.[4] Predictions of backface scabbing due to missile impact were not as good. For metal structures, application of the Ballistic Research Laboratory (BRL) formula[5] should give conservative results for large missiles.

If multiple barriers are counted on to protect essential systems, the protection is deemed adequate if the last barrier will stop the missile without generating secondary missiles that could damage any essential system. For calculating residual velocities after the missile has perforated a barrier, the following relationship is conservative:

$$v_r = (v_i^2 - v_p^2)^{1/2}$$

where v_r = residual missile velocity after perforation,

v_i = incident missile velocity, and

v_p = incident missile velocity required to just perforate the barrier, calculated by conservative use of penetration data.

This guide addresses only large missiles that might be ejected in the event of a turbine failure. The inherent protection provided in most plants (generally 1½ to 2 feet of reinforced concrete) ensures that minor missiles, which could be ejected in significant numbers and in widely scattered directions once the casing is breached, would not result in damage to essential systems.

Since turbine missile hazards may arise from nonnuclear as well as other nuclear units on the site, consideration should be given to the placement of present and, to the extent possible, future units on the site. It should be recognized that the placement of currently proposed plants may affect the future placement of additional units.

C. REGULATORY POSITION

1. Essential systems of a nuclear power plant should be protected against low-trajectory turbine missiles due to failure of main turbine-generator sets. Consideration may be limited to the structures, systems, and components listed in the Appendix to Regulatory Guide 1.117, "Tornado Design Classification." The effect of physical separation of redundant or alternative systems may also be considered. Each essential system and its location should be identified on dimensioned plan and elevation layout drawings.

[2]Ibid.

[3]"Full-Scale Tornado-Missile Impact Tests," EPRI NP-148, Electric Power Research Institute, April 1976.

[4]Kennedy, R. P., "A Review of Procedures for Analysis and Design of Concrete Structures to Resist Missile Impact Effects," *Nuclear Engineering and Design*, 1976.

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

2. Protection of essential systems or structures against direct strikes by low-trajectory turbine missiles can be provided by appropriate placement and orientation of the turbine units. The protection of an essential system is acceptable if the system and any protecting structure are located outside the low-trajectory missile strike zones, which are defined by ±25-degree lines emanating from the centers of the first and last low-pressure turbine wheels as measured from the plane of the wheels (see Figure 1). The strike zones associated with the turbines of all present and future nuclear and nonnuclear units at the site should be considered.

3. When protection of essential systems is provided by barriers, dimensioned plan and elevation layout drawings should include information on wall or slab thicknesses and materials of pertinent structures. The protection is considered acceptable if no missile can compromise the final barrier protecting an essential system. Steel barriers should be thick enough to prevent perforation. Concrete barriers should be thick enough to prevent backface scabbing.

4. The protection of essential systems located within the low-trajectory missile strike zone is acceptable if, in the event of a turbine failure, the probability of damage summed over all such systems is less than 10^{-3}

5. Turbine designs significantly different from current 1800-rpm machines will be reviewed on a case-by-case basis to determine the applicability of the strike zone.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plans for using this regulatory guide.

This guide reflects current NRC staff practice. Therefore, 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 is being and will continue to be used in the evaluation of submittals in connection with operating license or construction permit applications until this guide is revised as a result of suggestions from the public or additional staff review.

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