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REGULATORY GUIDE

OFFICE OF STANDARDS DEVELOPMENT

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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 of nuclear power plants important to safety be appropriately protected against the effects of missiles that might result from equipment failures. This guide describes a method acceptable to the NRC staff for protecting such components against low-trajectory missiles resulting from turbine failure by appropriate orientation and placement of the turbine. Another guide is under preparation with regard to protection against high-trajectory (lob shot) missiles resulting from turbine failures.

B. DISCUSSION

Cumulative failure data based on turbine 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, although there is little information available on failures of large turbines. 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. Usually they are characterized conservatively as occurring at about 120 to 130 percent of normal speed. Missiles resulting from destructive overspeed failures would be generated if the overspeed protection system malfunctions and the turbine speed increases to about 180 percent of normal speed, at which point the low-pressure wheels or rotor will undergo ductile failure. The kinetic energy of ejected missiles can be sufficient to cause penetration of several feet of reinforced concrete. 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 by falling back down on an essential system (see regulatory position C.1) 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 those plant systems and components necessary to shut down a plant safely. 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 missiles 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 cause damage that would prevent a safe shutdown of the reactors on a site.

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

The overall 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 about 10^{-4} per turbine year is appropriate for material failures at speeds up to design overspeed (120% to 130% of turbine operating speed). Although turbine manufacturers feel that improved technology will reduce failure rates below those historically observed, the staff believes that these improvements are offset by factors associated with increased turbine power output and the increased number of wheels (as many as 42 on some machines) in current turbines. Careful attention to turbine disk and rotor properties is therefore warranted to ensure that failure rates do not increase above historical levels.

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 failure rates indicate that destructive overspeed failures could occur at the 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.

Past experience with turbine failures, as well as the laws of mechanics, indicates that turbine missiles are ejected primarily in a direction perpendicular to the turbine axis, i.e., within the plane of rotation of the failed turbine wheel. Thus targets aligned with the turbine shaft have a much reduced probability of being struck directly by turbine missiles. On the basis of present information, the staff concludes that, in future nuclear power plants, all essential systems should be located outside the area most likely to sustain direct hits in the event of a turbine failure at destructive overspeed.

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

[2] Ibid.

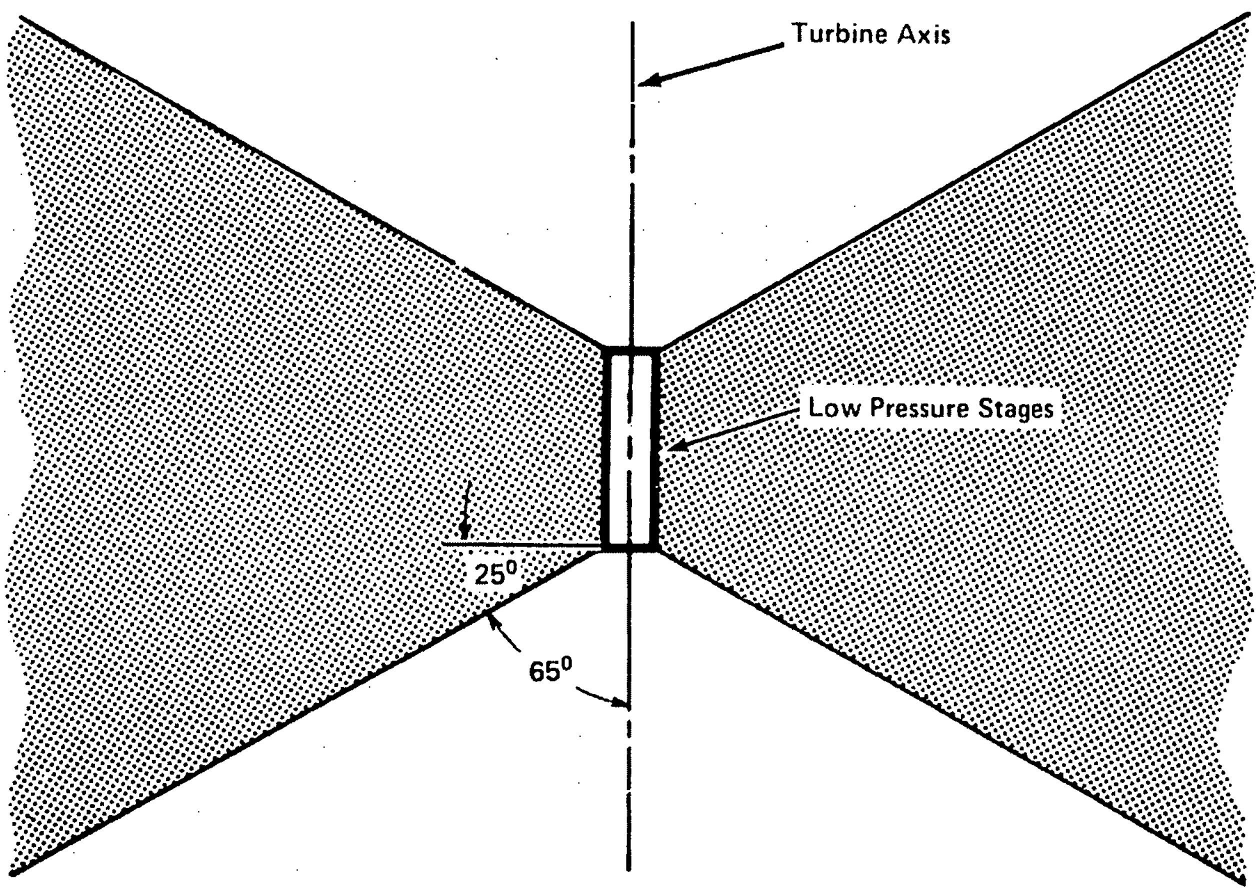

Figure 1 Low-Trajectory Turbine Missile Strike Zone

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.

For essential systems within the low-trajectory missile strike zone, an acceptable basis for determining adequate safety against low-trajectory turbine missiles is that the system is either small enough or far enough removed from the turbine that its probability of being struck by a turbine missile is 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. Computational methods reflecting the reduction in risk provided by intermediate barriers and the fact that a missile strike will not always lead to an event with radiological consequences are still in the development stage.

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 1-1/2 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. Some attention should be directed to this problem, however, when turbine buildings themselves are relied on as barriers to missiles (e.g., for control room areas).

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. For the purposes of this guide, essential systems are defined as all plant structures and equipment for which damage by turbine missiles could lead to significant radiological consequences either by the direct release of radioactivity from the damaged system itself, e.g., spent fuel pools, or by failing in a manner that could lead to unacceptable conditions for other systems, e.g., emergency diesel generators. The control room should be included as an essential system.

2. Each essential system and its location should be identified, and a physical description should be provided. Dimensioned plan and elevation layout drawings and wall thicknesses and materials of pertinent structures should be included.

3. 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 is 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.

4. The protection of an essential system located within the low-trajectory missile strike zone is acceptable if, in the event of a turbine failure, the probability of its being hit by such a missile 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.

Except in those cases in which the applicant proposes an alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used in the evaluation of submittals for construction permit applications docketed after November 15, 1976.

If an applicant wishes to use this regulatory guide in developing submittals for applications docketed on or prior to November 15, 1976, the pertinent portions of the application will be evaluated on the basis of this guide.