U.S. NUCLEAR REGULATORY COMMISSION

January 2012
Revision 2

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE RG 1.115

(Draft was issued as DG-1217, November 2009 and April 2011)

PROTECTION AGAINST TURBINE MISSILES

A. INTRODUCTION

This guide describes methods acceptable to the U.S. Nuclear Regulatory Commission (NRC) staff for protecting important to safety structures, systems, and components (SSCs) against missiles resulting from turbine failure by the appropriate orientation and placement of the turbine-generator set, the management of the probability of turbine missile generation or the probability of SSC failure, and the use of missile barriers.

General Design Criterion 4, "Environmental and Dynamic Effects Design Bases," of Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10 of the *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities" (10 CFR Part 50) (Ref. 1), 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 to produce large high-energy missiles.

The NRC issues regulatory guides to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required.

This regulatory guide contains information collection requirements covered by 10 CFR Part 50 that the Office of Management and Budget (OMB) approved under OMB control number 3150-0011. The NRC may neither conduct nor sponsor, and a person is not required to respond to, an information collection request or requirement unless the requesting document displays a currently valid OMB control number. This regulatory guide is a rule as designated in the Congressional Review Act (5 U.S.C. 801–808). However, OMB has not found it to be a major rule as designated in the Congressional Review Act.

B. DISCUSSION

Failure Modes of Turbine Rotors

Although little information is available on failures of large turbines, cumulative failure data based on the operating history of conventional plants (Ref. 2) indicate that the protection of important to safety 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” (up to approximately 130 percent of the rated speed) failures and “destructive overspeed” (any speed above the design overspeed) failures. Design overspeed conditions are expected to occur one or more times per year of operation, but destructive overspeed conditions are expected to occur rarely. Missiles resulting from design overspeed failures are the result of the 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 malfunctioned and if the turbine speed increased to a point at which the low-pressure wheels or rotor would undergo ductile failure. Regardless of failure types, this guide addresses only large missiles that might be ejected in the event of a turbine failure that would have sufficient kinetic energy to damage even substantial reinforced concrete slabs and panels. Large turbine missiles therefore have the potential to damage important to safety SSCs of the plant.

Missiles from a turbine failure can be divided into the following two groups:

1. “high-trajectory” missiles, which are ejected upward through the turbine casing and may cause damage if the falling missile strikes an important to safety SSC, and
2. “low-trajectory” or “direct” missiles, which are ejected from the turbine casing directly toward an important to safety SSC.

This guide outlines acceptable methods of protection against both high-trajectory and low-trajectory turbine missiles.

Design Overspeed Failures

The probability of damage by turbine missiles is large enough to warrant design precautions in future plants. The historical failure data for conventional units indicate that an incidence rate of $1x10^{-4}$ per turbine year is appropriate for material failures at speeds up to design overspeed.

Although the turbine operating record has improved (Ref. 3), and advances in turbine design—particularly in the selection of materials—may reduce the design overspeed failure rate, turbine blade failures have occurred during operation at or below design overspeed conditions. An operating history long enough to permit estimates of very low failure rates, even in the absence of any failures, has not yet been accumulated. This factor, and the recurrence of disc or rotor degradation resulting from other causes, leads the staff to conclude that use of the failure rate of $1x10^{-4}$ per turbine year is still appropriate.

An inservice inspection program can enhance the assurance of low failure rates. Tradeoffs between frequency and level of testing and improvements in reliability can be assessed using the turbine missile probability analysis.

Destructive Overspeed Analysis

Runaway turbine failures that may result in turbine destructive overspeed before failure of the turbine wheels or shaft present a more difficult protection problem. Because the control systems of a typical turbine unit limit the maximum turbine overspeed to less than 130 percent of the rated speed, any speed over 130 percent of the rated speed resulting from failure of the overspeed control systems is considered a destructive overspeed event. In practice, the probability of turbine missiles resulting from destructive overspeed events should be considered, along with those resulting from turbine failures at a range of speed up to design overspeed.

Historical data indicate a destructive overspeed failure rate of about $1x10^{-4}$ per turbine year. However, the staff's view is that the application of improved overspeed protection systems, redundant turbine steam valving, improved valve design, and frequent valve testing may significantly reduce the rate of destructive overspeed failures. Prior to 1995, the reliability of turbine steam valving was considered the primary factor that limits the degree of credit for improved systems and procedures. Since then, attention has been expanded to include other critical hydraulic, mechanical, and electric subsystem components such as solenoid-operated valves, pressure switches, and relays.

In 1995, the NRC evaluated the incidence of turbine overspeed protection system failure events in the nuclear industry in NUREG-1275, "Operating Experience Feedback Report—Turbine-Generator Overspeed Protection Systems," Volume 11, issued April 1995 (Ref. 4). Currently, the turbine overspeed failure (160 percent of the turbine rated speed) that occurred at the Salem Generating Station, Unit 2 (Salem 2), in 1991 remains the only destructive turbine overspeed failure among U.S. nuclear plants. NUREG-1275 provides a point estimate of $1x10^{-3}$ per turbine year for the turbine overspeed failure rate based on the single event that occurred at Salem 2 and on the approximately 1,000 years of accumulated nuclear turbine operation as of 1995. Although the Salem 2 event did not produce the large turbine disk or rotor missiles that could have damaged important to safety SSCs, the study of the Salem 2 event and other overspeed events described in NUREG-1275 exposed deficiencies in testing, valve maintenance, control system fluid quality, and human factors. Operating experience since that time demonstrates that the industry's corrective actions to address the NUREG-1275 findings are effective in reducing the potential of such failures. Therefore, the NRC considers the overall turbine failure rate of $1x10^{-4}$ per turbine year to still be valid. The staff's review of the operating experience is currently limited to the turbines at nuclear power plants because it is unlikely that non-nuclear plants, that are not required to meet NRC regulations, have the same level of uniformity in operating practices, maintenance, testing, and inspections as have been implemented at nuclear plants after the Salem 2 event.

Scope of SSCs Required to be Protected Against Turbine Missiles

Consideration of turbine missile protection is relevant for SSCs, necessary to ensure the following:

1. the integrity of the reactor coolant pressure boundary,
2. the plant's capability to shut down the reactor and maintain it in a safe shutdown condition, or
3. the plant's capability to prevent accidents which could result in potential offsite exposures comparable to those referred to in 10 CFR 50.34(a)(1), 50.67(b)(2), or 100.11 (Ref. 5), as applicable.

Systems necessary only for the mitigation of limiting design-basis accidents need not be protected because the probability of turbine failure and a limiting design-basis accident occurring simultaneously is very low. Thus, the SSCs considered for protection from postulated turbine missiles may be limited to those listed in Appendix A of this Regulatory Guide, henceforth referred as "essential SSCs."

Protection against Turbine Missiles

The potential consequences of turbine missiles include direct effects (e.g., damage to the spent fuel storage pool) and indirect effects (e.g., impairment of vital control room functions). In either case, plants must 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. Protection measures based on these considerations are discussed below.

Protection Provided by Turbine Orientation

Evidence indicates that low-trajectory turbine missile strikes will be concentrated within an area bounded by lines that are inclined at 25 degrees to the turbine wheel planes and that pass through the end wheels of the low-pressure stages (see Figure 1). This evidence applies to the low-pressure-stage wheels of turbines with a rotational speed of 1,800 revolutions per minute (rpm) typically used with light-water-cooled reactors. Essential SSCs 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. High-energy, low-trajectory missiles do not endanger SSCs outside of this area. Plants designed with no essential SSCs within the low-trajectory hazard zone are considered to have a favorable turbine orientation.

The staff concludes that excluding essential SSCs from the low-trajectory hazard zone to protect them has less associated uncertainty than that of other methods and is therefore the preferred method of protection. However, plants with favorable turbine orientation should also protect these SSCs from high-trajectory missiles by controlling the turbine missile generation frequency or by using barriers.

The NRC has found plants with unfavorable turbine orientation to be acceptable through control of the frequency of turbine missile generation. The probability of turbine missiles is expressed as the product of the following three items:

1. the probability of turbine missile generation resulting in the ejection of turbine disk (or internal structure) fragments through the turbine casing, P_1,
2. the probability of ejected missiles perforating intervening barriers and striking essential SSCs, P_2, and
3. the probability of essential SSCs that are struck failing to perform their safety functions, P_3.

Mathematically, the probability of failure of an essential SSC because of turbine missiles, P_4, is $P_1 \times P_2 \times P_3$. P_4 is limited to less than 1×10^{-7} per year, which the NRC staff considers to be an acceptable risk rate for the loss of an essential SSC from a single event. Considering P_1, P_2, and P_3 in the placement of essential SSCs, detailed strike and damage analyses have shown that separation of redundant equipment and special attention to turbine valve reliability have accomplished the objective of ensuring a low risk of damage from turbine missiles.

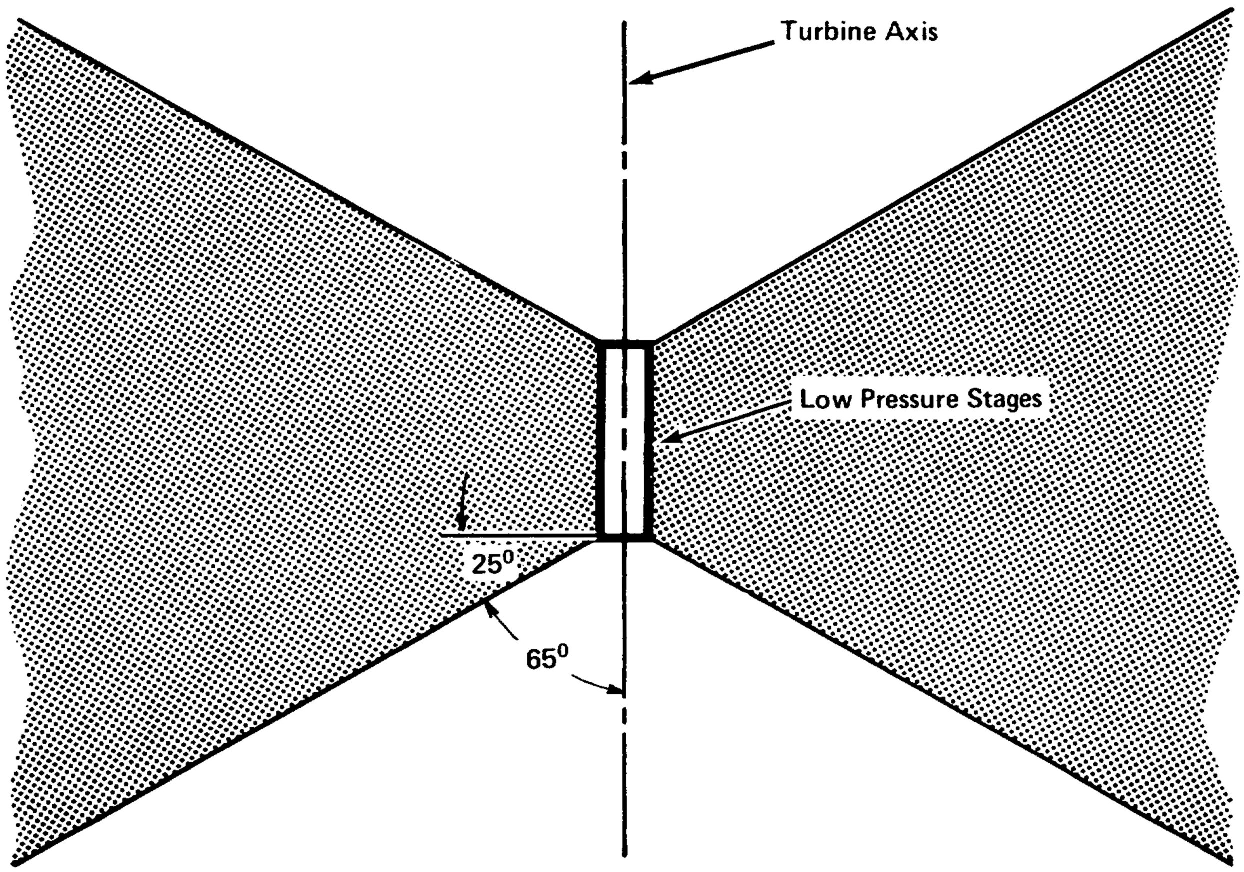

Figure 1 Low-trajectory turbine missile strike zone

Protection Provided by Control of Turbine Missile Generation Frequency

Over the years, the NRC staff has shifted its emphasis in the review of turbine missile issues from the strike and damage probability, $P_2 \times P_3$, to the missile generation probability, P_1. The minimum reliability requirement for loading the turbine and bringing the system online was established in 1986 and first used in an application documented in Appendix U to NUREG-1048, "Safety Evaluation Report Related to the Operation of Hope Creek Generating Station," Supplement 6, issued July 1986 (Ref. 6), as $P_1 < 1x10^{-4}$ for favorably oriented turbines, and $P_1 < 1x10^{-5}$ for unfavorably oriented turbines. These criteria are consistent with $P_1 < 1x10^{-4}$ based on turbine failure rate, which was used in applications where P_2 and P_3 were also considered. The P_1 criteria (without considering P_2 and P_3) were also incorporated into NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 3.5.1.3, "Turbine Missiles" (Ref. 7) in 2007.

Table 1 summarizes the NRC's criteria for low-trajectory and high-trajectory turbine missiles when barriers are not used to protect all essential SSCs. The frequency of turbine missile generation resulting in the ejection of turbine disk or rotor fragments through the turbine casing may be divided into separate frequencies for high-trajectory missiles and low-trajectory missiles based on a Monte Carlo analysis that considers turbine casing resistance. For unfavorably oriented turbines, evaluation of high-trajectory missiles is not required because the probability of a high-trajectory missile exiting the casing at a trajectory that results in striking and damaging an essential SSC ($P_2 \times P_3$) is much smaller than the equivalent probability for low-trajectory missiles. This is because high-trajectory, high-velocity missiles must exit the turbine casing through a much smaller arc (approximately one-tenth of the arc possible for a direct, low-trajectory missile) in order to strike essential SSCs than missiles exiting in a direct, low-trajectory path. High-trajectory, high-velocity missiles that exit the turbine casing more than a few degrees from vertical would travel too far over essential SSCs to strike them.

Table 1 Summary of the NRC Criteria for Turbine Missiles*

Probability Terms defined on page 4			P_1 *** (Yr^{-1})	P_2	P_3	P_4 (Yr^{-1})
Favorably oriented**	Preferred option	Low-trajectory	No turbine missile probability analysis is required.			
		High-trajectory	10^{-4}	N/A	N/A	10^{-7} ($P_2 \times P_3$ is credited by the NRC to be 10^{-3})
Unfavorably oriented**	Preferred option	Low-trajectory	10^{-5}	N/A	N/A	10^{-7} ($P_2 \times P_3$ is credited by the NRC to be 10^{-2})
		High-trajectory	Evaluation is not required.			
	Acceptable option	Both trajectories	P_1 (not greater than 10^{-4})	P_2	P_3	10^{-7}

* Table 1 is not applicable when barriers are used to protect all SSCs.
** See Figure 1 for the definition of turbine missile strike zone: The turbine is favorably oriented if essential SSCs are outside the strike zone; the turbine is unfavorably oriented if an essential SSC is inside the strike zone.
*** P_1 values presented in the table are the general, minimum reliability requirement for loading the turbine and bringing the system on line (see also Ref. 7)

Because protection of an essential SSC from low-trajectory turbine missiles is considered acceptable if the turbine is favorably oriented, industry has used the Table 1 criteria primarily for the low-trajectory turbine missile issues for unfavorably oriented turbines and for the high-trajectory turbine missile issues. The NRC has used the Table 1 criteria in evaluating the submittals related to these turbine missile issues since 1986. Currently, the maintenance and inspection of turbine rotors and valves are based on the P_1 calculation, the operating experience of similar equipment, and inspection results.

Recent industry reports (Ref. 8 and Ref. 9) proposed the management of turbine missiles by focusing on their contribution to core damage frequency in lieu of their probability of damaging essential SSCs. The NRC provided guidance for risk-informed approaches to licensing issues in Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," (Ref. 10) which specifies consideration of defense-in-depth attributes, safety margins, and uncertainties in addition to risk metrics such as core damage frequency. The NRC staff would consider applications conforming to the guidance of Regulatory Guide 1.174 on a case-by-case basis.

Protection Provided by Missile Barriers

Barriers can be constructed to protect all essential SSCs against low-trajectory turbine missiles, high-trajectory turbine missiles, or both. Barriers can also be constructed for certain essential SSCs in reducing P_2 and P_3. However, considerable uncertainty attends the current practice of using damage predictions based on ordnance data, particularly in the choice of an "effective impact area." Some data (Ref. 11) were generated during testing for protection from tornado missiles. For cases in which the impact was normal and the impact area was known, actual penetration distances into reinforced concrete correlated well with those predicted by the modified National Defense Research Council formula (Ref. 12). For metal structures, application of the U.S. Army Ballistic Research Laboratory formula (Ref. 13) should give conservative results for large missiles.

If plants count on multiple barriers to protect essential SSCs, the protection is deemed adequate if the last barrier will stop the missile without generating secondary missiles that could damage any essential SSC. 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, which is calculated by the conservative use of penetration data.

A paper published in 1997 (Ref. 14) reconfirmed the appropriateness of using this equation. The study described in the paper applied available damage assessment models for composite and multiple barriers to test data from 1977 to 1997. The paper recommended the best assessment model for analyzing each of these two types of barriers.

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 46 to 61 centimeters (1.5 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 SSCs.

Because turbine missile hazards may arise from nonnuclear and other nuclear units on the site, the placement of present and, to the extent possible, future units on the site should be considered. In addition, the placement of currently proposed plants may affect the future placement of additional units. Current plants should reevaluate their missile protection for the effects of any additional units built on the site. Future units should also evaluate their missile protection by considering the effects of turbine missiles from existing units.

Harmonization of Standards

The International Atomic Energy Agency (IAEA) has established a series of safety standards constituting a high level of safety for protecting people and the environment. Safety guides present international good practices and increasingly reflect best practices to help users striving to achieve high levels of safety. Relative to this regulatory guide, IAEA Safety Guide NS-G-1.11, "Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants," issued September 2004 (Ref. 15), addresses design considerations for high-speed rotating equipment (in Sections 3.11–3.32) as part of an overall review of the possible consequences of internal hazards in nuclear power plants. The NRC has an interest in facilitating the harmonization of standards used domestically and internationally. In this case, there are many similar elements between the regulatory guide and the rotating equipment section of the safety guide. This regulatory guide consistently implements and details the principles and basic safety aspects provided in IAEA Safety Guide NS-G-1.11.

C. STAFF REGULATORY GUIDANCE

1. Nuclear power plants should protect their essential SSCs against both high-trajectory and low-trajectory turbine missiles resulting from the failure of main turbine-generator sets. Consideration may be limited to the SSCs listed in Appendix A. The effect of physical separation of redundant or alternative systems may also be considered. Dimensioned plan and elevation layout drawings should identify each essential SSC and its location.

2. Plants can protect essential SSCs against turbine missiles by any one of the following approaches (the strike zones associated with the turbines of all present and future nuclear and nonnuclear units at the site should be considered):

a. As the preferred option for favorably oriented turbines, appropriately placing and orienting the turbine units such that essential SSCs are located outside the low-trajectory missile strike zone defined in Figure 1 and limiting the calculated turbine missile generation frequency for high-trajectory missiles to a value less than $1x10^{-4}$ per year.

b. As the preferred option for unfavorably oriented turbines, limiting the turbine missile generation frequency P_1 for low-trajectory missiles to a value less than $1x10^{-5}$ per year.

c. As an acceptable option for protection against both low-trajectory and high-trajectory turbine missiles, performing the P_2 and P_3 evaluation such that the frequency of damage to SSCs is less than$1x10^{-7}$ per year while the associated P_1 is less than $1x10^{-4}$ per year. Barriers may be constructed to protect some essential SSCs and, thereby, reduce the value for P_2.

d. Barriers can be constructed to protect all essential SSCs consistent with Regulatory Position 3 below. For unfavorably oriented turbines, barriers should protect all essential SSCs from both high-trajectory and low-trajectory missiles. For favorably oriented turbines, all essential SSCs should be protected against high-trajectory missiles.

3. When barriers are used to protect essential SSCs, 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 SSC. Steel barriers should be thick enough to prevent perforation. Concrete barriers should be thick enough to prevent backface scabbing.

4. In addition to material and fracture toughness properties, the P_1 calculation should consider initial crack depth, crack branching effects, and crack growth caused by degradation mechanisms of comparable significance such as high-cycle fatigue, low-cycle fatigue, and stress-corrosion cracking. Furthermore, the calculated P_1 values for normal (or rated) speed, design overspeed, and destructive overspeed failures should be considered. Selection of these parameters for the turbine missile analysis depends on the turbine rotor construction and should be justified and documented appropriately.

5. The NRC will review turbine designs that are significantly different from the current 1,800-rpm machines on a case-by-case basis to determine the applicability of the strike zones.

D. IMPLEMENTATION

The purpose of this section is to provide information on how applicants and licensees[1] may use this guide and information regarding the NRC's plans for using this regulatory guide. In addition, it describes how the NRC staff complies with the Backfit Rule (10 CFR 50.109) and any applicable finality provisions in 10 CFR Part 52.

Use by Applicants and Licensees

Applicants and licensees may voluntarily[2] use the guidance in this document to demonstrate compliance with the underlying NRC regulations. Methods or solutions that differ from those described in this regulatory guide may be deemed acceptable if they provide sufficient basis and information for the NRC staff to verify that the proposed alternative demonstrates compliance with the appropriate NRC regulations. Current licensees may continue to use guidance the NRC found acceptable for complying with the identified regulations as long as their current licensing basis remains unchanged. The acceptable guidance may be a previous version of this regulatory guide.

Licensees may use the information in this regulatory guide for actions which do not require NRC review and approval such as changes to a facility design under 10 CFR 50.59. Licensees may use the information in this regulatory guide or applicable parts to resolve regulatory or inspection issues.

Use by NRC Staff

The NRC staff does not intend or approve any imposition or backfitting of the guidance in this regulatory guide. The NRC staff does not expect any existing licensee to use or commit to using the guidance in this regulatory guide, unless the licensee makes a change to its licensing basis. The NRC staff does not expect or plan to request licensees to voluntarily adopt this regulatory guide to resolve a generic regulatory issue. The NRC staff does not expect or plan to initiate NRC regulatory action which would require the use of this regulatory guide. Examples of such unplanned NRC regulatory actions include: issuance of an order requiring the use of the regulatory guide, requests for information under 10 CFR 50.54(f) as to whether a licensee intends to commit to use of this regulatory guide, generic communication, or promulgation of a rule requiring the use of this regulatory guide without further backfit consideration.

During inspections of specific facilities, the staff may recommend that licensees consider various actions consistent with staff positions in this regulatory guide, as one acceptable means of meeting the underlying NRC regulatory requirement. Such recommendations would not ordinarily be considered backfitting even if prior versions of this regulatory guide are part of the licensing basis of the facility with respect to the subject matter of the inspection. However, unless this regulatory guide is part of the licensing basis for a plant, the staff may not represent to the licensee that the licensee's failure to comply with the positions in this regulatory guide constitutes a violation.

If an existing licensee voluntarily seeks a license amendment or change and (1) the NRC staff's consideration of the request involves a regulatory issue directly relevant to this new or revised regulatory

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1 In this section, "licensees" refers to licensees of nuclear power plants under 10 CFR Parts 50 and 52; and the term "applicants," refers to applicants for licenses and permits for (or relating to) nuclear power plants under 10 CFR Parts 50 and 52, and applicants for standard design approvals and standard design certifications under 10 CFR Part 52.

2 In this section, "voluntary" and "voluntarily" means that the licensee is seeking the action of its own accord, without the force of a legally binding requirement or an NRC representation of further licensing or enforcement action.

guide and (2) the specific subject matter of this regulatory guide is an essential consideration in the staff's determination of the acceptability of the licensee's request, then the staff may request that the licensee either follow the guidance in this regulatory guide or provide an equivalent alternative process that demonstrates compliance with the underlying NRC regulatory requirements. This is not considered backfitting as defined in 10 CFR 50.109(a)(1) or a violation of any of the issue finality provisions in 10 CFR Part 52.

Additionally, an existing applicant may be required to adhere to new rules, orders, or guidance if 10 CFR 50.109(a)(3) applies.

Conclusion

This regulatory guide is not being imposed upon current licensees and may be voluntarily used by existing licensees. In addition, this regulatory guide is issued in conformance with all applicable internal NRC policies and procedures governing backfitting. Accordingly, the NRC staff's issuance of this regulatory guide is not considered backfitting, as defined in 10 CFR 50.109(a)(1), nor is it deemed to be in conflict with any of the issue finality provisions in 10 CFR Part 52.

If a licensee believes that the NRC is either using this regulatory guide or requesting or requiring the licensee to implement the methods or processes in this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfit appeal with the NRC in accordance with the guidance in NUREG-1409 and NRC Management Directive 8.4.

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REFERENCES[3]

1. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," U.S. Nuclear Regulatory Commission, Washington, DC.

2. Twisdale, L.A. et.al., "Probabilistic Analysis of Turbine Missile Damage to Nuclear Power Plant Structures," Applied Research Associates, Raleigh, NC. (Available at: http://www.iasmirt.org/iasmirt-3/SMiRT7/M3-8.)

3. EPRI Report No. 1006451, "Technical Approach to Turbine Missile Probability Assessment," Electric Power Research Institute, Palo Alto, CA, December 2001.[4]

4. NUREG-1275, "Operating Experience Feedback Report—Turbine-Generator Overspeed Protection Systems," Volume 11, U.S. Nuclear Regulatory Commission, Washington, DC, April 1995.

5. 10 CFR Part 100, "Reactor Site Criteria," U.S. Nuclear Regulatory Commission, Washington, DC.

6. NUREG-1048, "Safety Evaluation Report Related to the Operation of Hope Creek Generating Station," Supplement 6, U.S. Nuclear Regulatory Commission, Washington, DC, July 1986.

7. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 3.5.1.3, "Turbine Missiles," U.S. Nuclear Regulatory Commission, Washington, DC, March 2009.

8. EPRI Report No. 1007637, "Risk-Informed Turbine Missile Analysis for a BWR 4," Electric Power Research Institute, Palo Alto, CA, February 2003.

9. EPRI Report No. 1009665, "Guidance for Performing a Simplified Risk-Informed Turbine Missile Analysis," Electric Power Research Institute, Palo Alto, CA, March 2005.

10. Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-specific Changes to the Licensing Basis," July 1998.

11. EPRI NP-148, "Full-Scale Tornado-Missile Impact Tests," Electric Power Research Institute, Palo Alto, CA, April 1976.

12. Kennedy, R.P., "A Review of Procedures for Analysis and Design of Concrete Structures to Resist Missile Impact Effects," *Nuclear Engineering and Design*, Volume 37, Issue 2, May 1976. (Available at http://www.sciencedirect.com/science/journal/00295493.)

[3] Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public Web site at: http://www.nrc.gov/reading-rm/doc-collections/. The documents can also be viewed on-line or printed for a fee in the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or (800) 397-4209; fax (301) 415-3548; and e-mail pdr.resource@nrc.gov.

[4] Copies of the listed Electric Power Research Institute (EPRI) standards and reports may be purchased from EPRI, 3420 Hillview Ave., Palo Alto, CA 94304; telephone (800) 313-3774; fax (925) 609-1310.

13. TM-5-855-1, "Fundamentals of Protective Design for Conventional Weapons," Department of the Army, November 1986. (NRC Agencywide Documents Access and Management System (ADAMS) Accession No. ML101970069).

14. Amde, A.M., et al., "Local Damage Assessment of Turbine Missile Impact on Composite and Multiple Barriers," *Nuclear Engineering and Design*, Volume 178, Issue 1, December 1997. (Available at http://www.sciencedirect.com/science/journal/00295493.)

15. IAEA Safety Guide NS-G-1.11, "Protection against Internal Hazards other than Fires and Explosions in the Design of Nuclear Power Plants," International Atomic Energy Agency, Vienna, Austria, September 2004. (Available at http://www.iaea.org/Publications/index.html.)

16. 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, Washington, DC.

APPENDIX A

STRUCTURES, SYSTEMS, AND COMPONENTS TO BE PROTECTED AGAINST TURBINE MISSILES

The structures, systems, and components considered for protection from postulated turbine missiles may be limited to the following:

1. The reactor coolant pressure boundary.[1]
2. Those portions of the main steam and main feedwater systems[2] in pressurized-water reactors (PWRs) up to and including the outermost containment isolation valves.
3. The reactor core.
4. Systems or portions of systems, considering a single failure, that are required for (1) attaining safe shutdown, (2) removing residual heat, (3) cooling the spent fuel storage pool, (4) mitigating the consequences of a credible missile induced high energy line break,[3] (5) supplying makeup water for the primary system, and (6) supporting the above systems (e.g., cooling water, ultimate heat sink, air supply, auxiliary feedwater, and ventilation).
5. The spent fuel storage pool, to the extent necessary to preclude significant loss of watertight integrity of the storage pool and to prevent missiles from contacting fuel within the pool.
6. The reactivity control systems (e.g., control rod drives and boron injection system).
7. The control room, including all equipment needed to maintain the control room within safe habitability limits for personnel and safe environmental limits for protected equipment.
8. Those portions of the gaseous radwaste treatment system whose failure due to missile effects could result in potential radioactive release resulting in calculated offsite exposures greater than 25 percent of the guideline exposures in 10 CFR 50.34(a)(1), 50.67(b)(2), or 100.11, as applicable, using appropriately conservative analytical methods and assumptions.
9. Systems or portions of systems that are required for monitoring, actuating, and operating protected portions of systems listed in items 4, 6, 7, and 13.
10. All electric and mechanical devices and circuitry between the process sensors and the input terminals of the actuator systems involved in generating signals that initiate protective actions by protected portions of systems listed in items 4, 6, 7, and 13.
11. When adjacent turbine units are present at the site, those portions of the long-term emergency core cooling system that would be required to maintain the plant in a safe condition for an extended time after a loss-of-coolant accident and individual fuel assemblies at all times.
12. Primary reactor containment and other safety-related structures, such as the control room building and auxiliary building, to the extent that they not collapse, allow perforation by missiles, or generate secondary missiles, any of which could cause unacceptable damage to protected items. However, the primary containment need not necessarily maintain its leaktight integrity.

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[1] The definition appears in 10 CFR 50.2, "Definitions."

[2] The system boundary includes those portions of the system required to accomplish the specified safety function and connecting piping up to and including the first valve (including a safety or relief valve). This valve is either normally closed or capable of automatic closure when the safe function is required.

[3] Alternatively, the main steam system, up to and including a second isolation valve, such as a redundant series main steam isolation valve or a turbine stop valve, may be protected.

13. The Class 1E electric systems, including the auxiliary systems for the onsite electric power supplies, that provide the emergency electric power needed for the functioning of plant features included in items 1 through 11 above.

14. Those portions of structures, systems, and components whose continued function is not required but whose failure could reduce to an unacceptable safety level the functional capability of any plant features included in items 1 through 13 above, or could result in incapacitating injury to occupants of the control room.