U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

3.5.3 BARRIER DESIGN PROCEDURES

REVIEW RESPONSIBILITIES

Primary - ~~Structural Engineering Branch (SEB)~~ Civil Engineering and Geosciences Branch (ECGB)[1]

Secondary - None

I. AREAS OF REVIEW

The following areas relating to procedures utilized in the design of seismic Category I structures, shields, and barriers to withstand the effects of missile impact are reviewed:

1. Procedures utilized for the prediction of local damage in the impacted area. This includes estimation of the depth of penetration and, in case of concrete barriers, the potential for generation of secondary missiles by spalling or scabbing effects.

2. Procedures utilized for the prediction of the overall response of the barrier or portions thereof due to the missile impact. This includes assumptions on acceptable ductility ratios where elasto-plastic behavior is relied upon, and procedures for estimation of forces, moments, and shears induced in the barrier by the impact force of the missile.

Review Interfaces[2]

~~3~~1.[3] ~~Accident Evaluation Branch (AEB)~~ The Plant Systems Branch (SPLB)[4] reviews the adequacy of ~~missiles'~~ missile[5] parameters cited in support of the applicant's conclusions concerning their suitability for the plant as part of its primary review responsibility for ~~SRP~~ Standard Review Plan (SRP) ~~Section 3.5.1~~ Sections 3.5.1.1, 3.5.1.2, 3.5.1.4,

3.5.1.5, and 3.5.1.6.[6] ~~Structural Engineering Branch reviews the parameters reviewed by the (AEB) for consideration as an integral part of structural analysis.~~[7]

2. The Materials and Chemical Engineering Branch (EMCB) reviews the adequacy of turbine missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant as part of its primary review responsibility for SRP Section 3.5.1.3.[8]

II. ACCEPTANCE CRITERIA

~~SEB~~ The ECGB[9] accepts the design of structures, shields, and barriers that must withstand the effects of environmental and natural phenomena if the relevant requirements of General Design Criteria 2 ~~(Ref. 1)~~[10] and 4 ~~(Ref. 2)~~[11] are met. The relevant requirements of General Design Criteria 2 and 4 are as follows:

A. General Design Criterion 2 (GDC 2)[12] as it relates to structures, systems, and components; capability to withstand, without loss of safety functions, the effects of tornadoes; and the appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena.

B. General Design Criterion 4 (GDC 4)[13] as it relates to structures, systems, and components being appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.

Specific criteria necessary to meet the relevant requirements of General Design Criteria 2 and 4 are as follows:

1. For Local Damage Prediction

   a. In Concrete

      Sufficient thickness of concrete should be provided to prevent perforation, spalling, or scabbing of the barriers in the event of missile impact.

      Several empirical equations, such as the modified National Defense Research Council (NDRC)[14] formula (Ref. 3) are available to estimate missile penetration into concrete. These equations should be used to determine the required barrier thicknesses. Thicknesses resulting from such calculations should ~~in no case~~ not[15] be less than those listed in Table 1, which specifies the minimum thicknesses ~~are~~[16] necessary to protect against tornado missiles.

      The tornado missile spectrum for which Table 1 concrete barrier thickness[17] requirements are adequate is shown in Table 2. Tornado missiles and other types of missiles are specified in accordance with SRP ~~Section 3.5.1~~ Sections 3.5.1.1 through 3.5.1.6.[18]

Barrier thicknesses less than those listed in Table 1 may be used, provided that sufficient justification (including test data) ~~are~~ is[19] presented to support them, in which case they will be reviewed on a case-by-case basis.

For turbine missile barriers, penetration and scabbing predictions should be based on empirical equations such as the modified NDRC formula (Ref. 3) or the results of a valid test program.

b. In Steel

The results of tests[20] conducted by the Stanford Research Institute on the penetration of missiles into steel plates are summarized by W. B. Cottrell and A. W. Savolainen in "U.S. Reactor Containment Technology" (Ref. 4). The equations presented in Reference 4 are acceptable. Other equations such as the Ballistic Research Laboratory formula described in Reference 5 may be used, provided the results are either comparable to those referenced above or are validated by penetration tests.

c. In Composite Sections

For composite or multi-element missile barriers, procedures for prediction of local damage are acceptable if the residual velocity of the missile perforating the first element is considered as the striking velocity for the next element. For determining this residual velocity, the equations presented by Recht and Ipson (Ref. 6) are acceptable when the first barrier of a multi-element missile barrier is steel. When the first barrier is concrete, procedures are reviewed on a case-by-case basis.

2. <u>For Overall Damage Prediction</u>

The response of a structure or barrier to missile impact depends largely on the location of impact (e.g., midspan of a slab or near a support), on the dynamic properties of the target and missile, and on the kinetic energy of the missile. In general, the assumption of plastic collisions is acceptable, where all of the missile's[21] initial momentum is transferred to the target and only a portion of its kinetic energy is absorbed as strain energy within the target. However, where elastic impacts are expected, the additional momentum transferred to the target by missile rebound should be ~~included~~ considered in the analyses.[22]

After it has been demonstrated that the missile will not penetrate the barrier, an equivalent static load concentrated at the impact area should then be determined, from which the structural response, in conjunction with other design loads, can be evaluated using conventional design methods. An acceptable procedure for such an analysis, where the impact is assumed to be plastic, is presented in a paper by Williamson and Alvy (Ref. ~~6~~ 7[23]). Other procedures may be used, provided the results obtained are comparable to those referenced above.

Maximum allowable ductility ratios for steel and reinforced concrete barriers and other structural elements ~~if used, in the above analysis,~~[24] are given in Appendix A to this SRP section.

Technical Rationale

The technical rationale for application of acceptance criteria regarding the provision and design of barriers is discussed in the following paragraphs:[25]

1. Compliance with GDC 2, "Design Bases for Protection Against Natural Phenomena," requires that structures, systems, and components important to safety be designed to withstand (or be protected against) the effects of natural phenomena without loss of capability to perform their safety functions. The design bases for such structures, systems, and components must include considering the effects of accident conditions, plus the importance of the safety function to be performed and the effects of natural phenomena.

   The staff's criteria for the design of missile barriers provide for protecting structures, systems, and components from missiles generated by natural phenomena and other events. The criteria are based on sound engineering principles, experience, and testing and provide for protecting structures, systems, and components against natural phenomena that occur concurrently with accident conditions.

   Meeting the requirements of GDC 2 provides a level of assurance that equipment important to safety will be protected against missile and accident effects caused by natural phenomena and will thus be capable of performing its intended safety function.[26]

2. 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. Ensuring the adequacy of such components includes protecting against the effects of missiles, pipe whipping, and discharging fluids that may result from equipment failures and from events and conditions outside the nuclear power unit.

   SRP Section 3.5.3 includes descriptions of the staff's criteria for providing adequate barriers to resist missiles, pipe whipping, and the effects of discharging fluids in order to protect structures, systems, and components important to safety. These criteria are based on sound engineering principles, experience, and test results.

   Meeting the requirements of GDC 4 to protect equipment against the effects of missiles, pipe whipping, and discharging fluids provides a level of assurance that equipment important to safety will be capable of performing its intended safety function.[27]

III. REVIEW PROCEDURES

The reviewer selects and emphasizes material from the review procedures described below as may be appropriate for a particular case.

1. For the prediction of local damage, the equations proposed by the applicant for estimation of missile penetration are reviewed in the following manner:

   a. For missile penetration in concrete, the reviewer verifies that the applicant has made a commitment to utilize empirical formulas such as the modified NDRC formula (Ref. 3)[28] or valid test results. The reviewer also verifies that the applicant has made a commitment to provide sufficient barrier thickness to prevent perforation and to prevent spalling or scabbing when protection from spalling or scabbing is considered necessary.

   b. For missile penetration in steel, the reviewer verifies that the applicant has made a commitment to utilize the more conservative of the ~~BRL formula~~ Ballistics Research Laboratory formula (Ref. 5)[29] or the Stanford equations (Ref. 4).[30] If other equations are selected, the applicability and validity of such equations are reviewed to ~~assure~~ ensure[31] that the results are comparable to those obtained from the Stanford equations. If sufficient justification for the use of alternate equations is not provided, additional information is requested from the applicant at the first stage of the review.

   c. For missile penetration in composite or multi-element barriers, the reviewer verifies that the applicant has made a commitment to utilize the criteria delineated in subsection II.1.c of this plan. If other criteria are proposed, the justification provided is reviewed to ~~assure~~ ensure[32] that such equations give results which are comparable to those referenced above.

2. For the prediction of overall damage and response of the barrier, the reviewer verifies that the applicant has made a commitment to utilize the criteria delineated in subsection II.2 of this SRP section. If other criteria are selected, the applicant's justification is reviewed to ~~assure~~ ensure[33] that the results obtained are at least as conservative as those delineated in subsection II.2. If sufficient justification is not provided, additional information is requested from the applicant at the first stage of the review.

3. Refer to SRP Section 3.5.1.3 for additional information regarding the protection of structures, systems, and components from the effects of turbine missiles.[34]

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.[35]

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided to satisfy the requirements of this SRP section and concludes that ~~his~~ the[36] evaluation is sufficiently complete and adequate to support the following type of conclusive statement to be included in the staff's safety evaluation report:

> The staff concludes that the barrier design is acceptable and meets the requirements of General Design Criteria 2 and 4 with respect to the capabilities of the structures, shields, and barriers to provide sufficient protection to equipment that must withstand the effects of natural phenomena (tornado missiles) and environmental effects including the effects of missiles, pipe whipping, and discharging fluids. This conclusion is based on the following:
>
> [37] The procedures utilized to determine the effects and loadings on seismic Category I structures and missile shields and barriers induced by design basis missiles selected for the plant are acceptable since these procedures provide a conservative basis for engineering design to ~~assure~~ ensure[38] that the structures or barriers are adequately resistant to and will withstand the effects of such forces.
>
> The use of these procedures provides reasonable assurance that in the event of design basis missiles striking seismic Category I structures or other missile shields and barriers, the structural integrity of the structures, shields, and barriers will not be impaired or degraded to an extent that will result in a loss of required protection. Seismic Category I systems and components protected by these structures are, therefore, adequately protected against the effects of missiles and will perform their intended safety function, if needed. Conformance with these procedures is an acceptable basis for satisfying in part the requirements of General Design Criteria 2 and 4.

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 evaluation of inspections, tests, analyses, and acceptance criteria (ITAAC), including design acceptance criteria (DAC), site interface requirements, and combined license action items that are relevant to this SRP section.[39]

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.[40] 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.[41]

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.[42]

VI.[43] REFERENCES

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and ~~Missile~~ Dynamic Effects[44] Design Bases."

3. R. P. Kennedy, "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects," Holmes and Narver, Inc., September 1975.

4. W. B. Cottrell and A. W. Savolainen, "U.S. Reactor Containment Technology." ORNL-NSIC-5, Vol. 1, Chapter 6, Oak Ridge National Laboratory.

5. C. R. Russell, "Reactor Safeguards," MacMillan, New York, 1962.

6. R. F. Recht and T. W. Ipson, "Ballistic Perforation Dynamics," Journal of Applied Mechanics, Transactions of the ASME, Vol. 30, Series E, No. 3, September 1963.

7. R. A. Williamson and R. R. Alvy, "Impact Effect of Fragments Striking Structural Elements," Holmes and Narver, Inc., Revised November 1973.

8. Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants."

TABLE 1

Minimum Acceptable Barrier Thickness Requirements
For Local Damage Prediction Against Tornado
Generated Missiles

Regions*	Concrete Strength MPa (psi)	Wall Thickness cm (inches)	Roof Thickness cm (inches)
Region I	20.7 (3000)	59 (23)	46 (18)
	27.6 (4000)	51 (20)	41 (16)
	34.5 (5000)	46 (18)	36 (14)
Region II	20.7 (3000)	41 (16)	33 (13)
	27.6 (4000)	36 (14)	28 (11)
	34.5 (5000)	33 (13)	26 (10)
Region III	20.7 (3000)	≮[45] 16 (6)	≮ 16 (6)
	27.6 (4000)	≮ 16 (6)	≮ 16 (6)
	34.5 (5000)	≮ 16 (6)	≮ 16 (6)[46]

*For definition of Regions I, II, and III, refer to Regulatory Guide 1.76 (Ref. 8).

Table 2

Revised Tornado Missile Spectrum

Missile Description	Dimensions (meters)	~~Mass~~ Weight (kilograms)	Velocity[a] (meters per sec.)
Wood Plank	0.092 x 0.289 x 3.66	52	83
6-inch Schedule 40 Pipe	0.168 Diameter x 4.58	130	52
1-inch Steel Rod	0.0254 Diameter x 0.915	4	51
Utility Pole	0.343 Diameter x 10.68	510	55
12-inch Schedule 40 Pipe	0.32 Diameter x 4.58	340	47
Automobile	5 x 2 x 1.3	1810	59[47]

[a] Velocities are horizontal velocities. For vertical velocities, 70 percent of the horizontal velocities ~~are~~ is[48] acceptable. For missile velocities in tornado regions other than Region I, see SRP Section 3.5.1.4.

APPENDIX A

STANDARD REVIEW PLAN SECTION 3.5.3

PERMISSIBLE DUCTILITY RATIO
FOR OVERALL DAMAGE PREDICTION

I. INTRODUCTION

In the evaluation of overall response of reinforced concrete and steel structural elements (e.g., missile barriers, columns, slabs~~, etc.~~[49]) subjected to impactive or impulsive loads, such as impacts due to missiles, assumption of nonlinear response (i.e., ductility ratios greater than unity) of the structural elements is generally acceptable, provided that the intended safety functions of the structural elements and those of safety-related systems and components supported or protected by the elements are maintained. The following summarizes specific positions for review and acceptance of ductility ratios for reinforced concrete and steel structural elements subjected to impactive and impulsive loads.

II. SPECIFIC POSITIONS

1. Reinforced Concrete Members

The technical position of the regulatory staff with regard to permissible ductility ratios is stated in Regulatory Guide 1.142. ~~Prior to publication of Revision 1 of Regulatory Guide 1.142, the staff position regarding ductility will be provided to applicants on a case-by-case basis.~~[50]

2. Structural Steel Members

a. For tension due to flexure

$$\mu_d \leq 10.0$$

b. For columns with slenderness ratio (l/r) equal to or less than 20

$$\mu_d \leq 1.3$$

Where l = effective length of the member

r = the least radius of gyration

For columns with slenderness ratio greater than 20

$$\mu_d \leq 1.0$$

c. For members subjected to tension

$$\mu_d \leq 0.5 \frac{e_u}{e_y}$$

Where e_u = Ultimate strain
e_y = Yield strain

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SRP Draft Section 3.5.3
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 Civil Engineering and Geosciences Branch (ECGB).
2.	SRP-UDP format item	Added "Review Interfaces" to REVIEW PROCEDURES.
3.	Editorial modification	Renumbered paragraph to conform to updated format of SRP sections.
4.	Current review branch designation and abbreviation	Changed review interface branch to Plant Systems Branch (SPLB).
5.	Editorial modification	Substituted "missile" for "missiles'."
6.	SRP-UDP format item	Deleted "Section 3.5.1" and substituted "Sections 3.5.1.1, 3.5.1.2, 3.5.1.4, 3.5.1.5, and 3.5.1.6," and defined "SRP" as "Standard Review Plan." There is no SRP Section 3.5.1, and Section 3.5.1.3 is under a different primary review branch than the other sections.
7.	Editorial modification	Deleted "Structural Engineering Branch reviews the parameters reviewed by the (AEB) for consideration as an integral part of structural analysis." The sentence is vague and confusing.
8.	SRP-UDP format item	Added subsection I.2 as follows: "The Materials and Chemical Engineering Branch (EMCB) reviews the adequacy of turbine missile parameters cited in support of the applicant's conclusions concerning their suitability for the plant as part of its primary review responsibility for SRP Section 3.5.1.3." This information reflects the responsibilities of the current review interface branch.
9.	Current primary review branch abbreviation	Changed PRB to ECGB.
10.	SRP-UDP format item	Deleted unnecessary reference citation.
11.	SRP-UDP format item	Deleted unnecessary reference citation.
12.	Editorial modification	Provided initialism for General Design Criterion 2.
13.	Editorial modification	Provided initialism for General Design Criterion 4.
14.	Editorial modification	Defined "NDRC" as "National Defense Research Council."
15.	Editorial modification	Substituted "not" for "in no case"; the wording was not consistent with the second paragraph below that refers to barrier thicknesses allowed to be less in some cases.

Item	Source	Description
16.	Editorial modification	Changed wording slightly to improve clarity.
17.	Editorial modification	Added "barrier thickness" to improve clarity.
18.	Editorial modification	Deleted "Section 3.5.1" and substituted "Sections 3.5.1.1 through 3.5.1.6" to cite the SRP accurately.
19.	Editorial modification	Added punctuation and changed "are" to "is" to improve clarity and to provide noun/verb agreement.
20.	Editorial modification	Changed "test" to "tests" to fit context.
21.	Editorial modification	Added "'s" to "missile" to accommodate possessive context.
22.	Editorial modification	Deleted the word "included" and substituted the phrase "considered in the analyses" for clarity.
23.	Editorial modification	Corrected reference callout from "6" to "7."
24.	Editorial modification	Deleted the redundant phrase "if used, in the above analysis."
25.	SRP-UDP format item	Added "Technical Rationale" and lead-in sentence to ACCEPTANCE CRITERIA.
26.	SRP-UDP format item	Added technical rationale for GDC 2.
27.	SRP-UDP format item	Added technical rationale for GDC 4.
28.	Editorial modification	Added "(Ref. 3)" to the sentence to identify the source of the formula.
29.	Editorial modification	Deleted the unidentified acronym "BRL" and substituted "Ballistics Research Laboratory (Ref. 5)."
30.	Editorial modification	Added "(Ref. 4)" to identify the source of the formula.
31.	Editorial modification	Changed "assure" to "ensure" to correct usage.
32.	Editorial modification	Changed "assure" to "ensure" to correct usage.
33.	Editorial modification	Changed "assure" to "ensure" to correct usage.
34.	Integrated Impact No. 515	Added subsection III.3 to REVIEW PROCEDURES as follows: "Refer to SRP Section 3.5.1.3 for additional information regarding the protection of structures, systems, and components from the effects of turbine missiles." This information reflects the staff's position regarding the protection of equipment against turbine missiles.
35.	SRP-UDP Guidance, Implementation of 10 CFR 52	Added standard paragraph to address application of Review Procedures in design certification reviews.
36.	Editorial modification	Changed "his" to "the" to eliminate gender-specific terminology.

Item	Source	Description
37.	Editorial modification	Indented paragraphs for clarification.
38.	Editorial modification	Changed "assure" to "ensure" to correct usage.
39.	SRP-UDP format item	Added paragraph to indicate evaluation findings appropriate to design certification reviews.
40.	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.
41.	SRP-UDP format item	Added IMPLEMENTATION to conform to standard format for the SRP.
42.	SRP-UDP Guidance	Added standard paragraph to indicate applicability of this section to reviews of future applications.
43.	SRP-UDP format item	Renumbered REFERENCES to conform to standard format for the SRP.
44.	SRP-UDP format item	Updated title for GDC 4.
45.	Editorial modification	Deleted less-than (<) symbol in the table. The existing notation is inconsistent with the title of the table. The minimum barrier thickness is now clearly designated as 6 inches.
46.	SRP-UDP format item	Added metric equivalents to table for all values.
47.	Place holder	No change was made to the table. The table already exists in metric units.
48.	Editorial modification	Changed "are" to "is" to provide noun/verb agreement ("70 percent...is").
49.	Editorial modification	Deleted unnecessary "etc." from list of parenthetical examples of structural elements.
50.	Editorial modification	Deleted the obsolete sentence that refers to the "future" publication of Revision 1 of Regulatory Guide 1.142. Revision 1 of Regulatory Guide 1.142 was published in October 1981 and contains the staff's position on ductility ratios as described in the previous sentence.

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SRP Draft Section 3.5.3

Attachment B - Cross Reference of Integrated Impacts

Integrated Impact No.	Issue	SRP Subsections Affected
515	Add Regulatory Guide 1.115, "Protection Against Low-Trajectory Turbine Missiles," to REVIEW PROCEDURES in SRP Section 3.5.3 concerning guidance for the design of missile barriers.	Added subsection III.3 to REVIEW PROCEDURES to refer to SRP Section 3.5.1.3 concerning protection against turbine missiles.