SEB Issue List Regarding APR 1400, FSAR 3.5.3 “Barrier Design Procedures”

Issue #1 (AI 3-80.1)

In FSAR Section 3.5.3.1.1.1, the applicant used the modified National Defense Research Council (NDRC) approach to calculate the depth of missile penetration. The symbol “**W**” is used to represent missile weight in the Modified NDRC formula; however, the same symbol “**W**” was also used in the steel section Stanford Research Institute (SRI) Formula to represent the length of square sides. In order to prevent this confusion, it is recommended to replace “**W**” in the concrete section with “$\mathbf{W_m}$” to represent missile weight.

Response

DCD Tier 2 subsection 3.5.3.1.1.1 will be revised to replace “**W**” with “$\mathbf{W_m}$”.

Impact on DCD

DCD Tier 2, subsection 3.5.3.1.1.1 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

hurricane-generated missiles. The minimum barrier thicknesses for local damage due to tornado- and hurricane-generated missiles are provided in Table 3.5-3. The equations used to evaluate local structural effects are described as follows.

3.5.3.1.1.1 Penetration

The depth of missile penetration, x, is calculated using the modified NDRC formulas:

$$x = KNW\left(\frac{V_o}{1{,}000d}\right)^{1.80} + d, \quad for\ \frac{x}{d} > 2.0,$$

$$x = \sqrt{4KNWd\left(\frac{V_o}{1{,}000d}\right)^{1.80}}, \quad for\ \frac{x}{d} \le 2.0$$

W_m

Where:

x = penetration depth (inch)

K = concrete penetrability factor, based on experimental data

= $\frac{180}{\sqrt{f'_c}}$, (with f'_c in psi)

N = missile shape factor and is taken as follows:

= 0.72 for flat-nosed bodies

= 0.84 for blunt-nosed bodies

= 1.00 for spherical end

= 1.14 for very sharp nose

W = missile weight (lb)

V_o = missile impact velocity (ft/sec)

d = effective missile diameter ; for non-solid cylindrical missiles or solid missiles with non-circular cross section, d is the diameter of an equivalent solid cylindrical shaped missile with the same contact surface area as the actual missile (inch)

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Issue #2 (AI 3-80.2)

SRP Section 3.5.3.II.1.B provides the acceptance criteria for the use of the SRI equations developed from the test data prescribed in ORNL/NSIC-5, Vol. 1, Chapter 6, by Cottrell and Savolainen for designing steel penetration thickness. The Ballistic Research Laboratory (BRL) equations may be used provided that the results are comparable to those obtained by using the SRI equation or validated by penetration tests. FSAR Section 3.5.3.1.2 permits the use of both formulas. If the BRL equation is used to calculate steel penetration thicknesses, staff requests the applicant to provide the test data verifying its application, and to confirm that the larger thickness requirement resulting from the use of either the BRL or the SRI equation will be used in the design of the steel penetration thickness.

Response

The penetration thickness will be calculated using both formulas. Design thickness will be determined by comparing the results.

Impact on DCD

DCD Tier 2, subsection 3.5.3.1.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

3.5.3.1.2 Steel Barriers

Both of the Ballistic Research Laboratory (BRL) formulas available in "Reactor Safeguards" (Reference 17) and the Stanford Research Institute (SRI) equation are used as the basis for the design and analysis of steel barriers.

The larger value is used as the perforation thickness by comparing results from the BRL Formula and the SRI Formula.

BRL Formula

$$T = \frac{(E_k)^{\frac{2}{3}}}{672 D_e}$$

Where:

T = steel plate thickness for which perforation is possible (inch)

D_e = effective diameter of missile (inch)

E_k = missile kinetic energy, $MV^2/2$ (ft-lb)

V = impact velocity (ft/sec)

M = mass of missile (lb-sec^2/ft)

SRI Formula

$$\frac{E}{D} = \frac{S}{46{,}500}\left(16{,}000T^2 + 1{,}500\frac{W}{W_S}T\right)$$

Where:

E = critical kinetic energy required for perforation (ft-lb)

D = effective diameter of missile (inch)

S = ultimate tensile strength of the target (steel plate) (lb/in^2)

T = target plate thickness (inch)

W = length of a square side between rigid supports (inch)

W_s = length of a standard width (4 inch)

The SRI formula is applicable within the following ranges:

$0.1 < T/D < 0.8$

$0.002 < T/L < 0.05$

SEB Issue List Regarding APR 1400,
FSAR 3.5.3 “Barrier Design Procedures”

Issue #3 (AI 3-80.3)

In FSAR Section 3.5.3.1.1, the case of concrete barriers, the design thickness is 20 percent greater than what calculated by the SRI formula. The staff requests the applicant to describe in Section 3.5.3.1.2 the percentage increased used in the minimum design thickness steel barriers to prevent perforation.

Response

The steel barrier design thickness will be 25 percent greater than the minimum design thickness to prevent perforation.

Impact on DCD

DCD Tier 2, subsection 3.5.3.1.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

3.5.3.1.2 Steel Barriers

Both of the Ballistic Research Laboratory (BRL) formulas available in "Reactor Safeguards" (Reference 17) and the Stanford Research Institute (SRI) equation are used as the basis for the design and analysis of steel barriers.

The perforation thickness will be 25 percent greater than the minimum design thickness to prevent perforation.

BRL Formula

$$T = \frac{(E_k)^{\frac{2}{3}}}{672 D_e}$$

Where:

T	=	steel plate thickness for which perforation is possible (inch)
D_e	=	effective diameter of missile (inch)
E_k	=	missile kinetic energy, $MV^2/2$ (ft-lb)
V	=	impact velocity (ft/sec)
M	=	mass of missile (lb-sec^2/ft)

SRI Formula

$$\frac{E}{D} = \frac{S}{46{,}500}\left(16{,}000T^2 + 1{,}500\frac{W}{W_S}T\right)$$

Where:

E	=	critical kinetic energy required for perforation (ft-lb)
D	=	effective diameter of missile (inch)
S	=	ultimate tensile strength of the target (steel plate) (lb/in^2)
T	=	target plate thickness (inch)
W	=	length of a square side between rigid supports (inch)
W_s	=	length of a standard width (4 inch)

The SRI formula is applicable within the following ranges:

$0.1 < T/D < 0.8$

$0.002 < T/L < 0.05$

SEB Issue List Regarding APR 1400, FSAR 3.5.3 "Barrier Design Procedures"

Issue #4 (AI 3-80.4)

In FSAR section 3.5.3.1.2, the SRI Formula is missing one applicable range, 0.2 < W/L < 1.0. The staff requests the applicant to explain why this particular range is not listed.

Response

The range of 0.2 < W/L < 1.0 should have been included and will be added to section 3.5.3.1.2.

Impact on DCD

DCD Tier 2, subsection 3.5.3.1.2 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

10 < L/D < 50

5 < W/D < 8

8 < W/T < 100 ← 0.2 < W/L < 1.0

70 < ν < 400

Where:

L = missile length (inch)

ν = impact velocity (ft/sec)

3.5.3.2 Overall Damage Prediction

Overall evaluation of structures/barriers under impact or impulsive loads is focused on providing reasonable assurance that the structures or barriers will not collapse and have excessive deformations to affect the function of safe shutdown equipment. For the evaluation of overall response of reinforced concrete and steel structures or barriers under impact and impulse loads, nonlinear and elasto-plastic response of structures is used.

Evaluations of the overall damage due to missile impact are performed by either considering missile impact in the elastic range of the structural element with other loadings applied and accounting for rebound effects of the impact, or by assuming that the inelastic capacity of the structural element resists missile impact loads. Inelastic impact analyses are performed by assuming that the full elastic capacity of the structural element is used to accommodate other loading conditions, and that the missile impact loads are accommodated in-elastically based on the ductility of the structural element. Code requirements for ductility shall be satisfied for the structural response evaluations under the missile impact.

Excessive deformation is limited by the allowable ductility ratios, which is defined as the ratio of maximum displacement to the yield displacement of structural element, where the maximum displacement will not result in the loss and damage of structural elements and components. The ductility limits for concrete and steel structures or barriers for various loading categories are defined in Table 3.5-5 which is based on NRC RG 1.142 (Reference 18) and AISC N690.

SEB Issue List Regarding APR 1400, FSAR 3.5.3 “Barrier Design Procedures”

Issue #5 (AI 3-80.5)

SRP Section 3.5.3.II.1.C provides the acceptance criteria for Composite Sections. The staff reviewed Section 3.5.3 and noted that the applicant did not provide information related to the protection of the composite barriers. The staff requests the applicant to provide a technical basis for not including composite barrier protection in the APR-1400 design.

Response

There are no composite sections designed as a missile barrier in the APR1400. The containment liner plate is not designed as a missile barrier nor is it part of a composite barrier. DCD Tier 2 subsection 3.5.3 will be revised to make it clear that composite sections are not used as missile barriers.

Impact on DCD

DCD Tier 2, section 3.5.3 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

Openings and penetrations through the exterior walls and roofs of seismic Category I structures and the location of equipment in the vicinity of such openings are arranged so that a missile passing through the opening would not prevent the safe shutdown of the plant and would not result in an offsite release of nuclides exceeding the limits defined in 10 CFR Part 100 (Reference 15). Otherwise, structural barriers composed of enclosures, missiles-resistant doors and covers, and physical protection features are designed to resist tornado missiles in accordance with the design procedures described in Subsection 3.5.3. Tornado and hurricane missiles are not postulated to strike more than once at a target location. Because of the robustness of the exterior wall, all seismic Category I structures are capable of withstanding the impact of each identified missile.

3.5.3 Barrier Design Procedures

Missile barriers, whether steel or concrete, are designed with sufficient strength and thickness to prevent local damage including perforation, spalling and scabbing, and overall damage. The procedures by which structures and barriers are designed to perform this function are presented in this subsection.

3.5.3.1 Evaluation of Local Structural Effects

The prediction of local damage in the immediate vicinity of an affected area depends on the basic material of construction of the barrier itself. Corresponding procedures are described below.

There are no composite sections designed as missile barrier in APR1400. Containment liner plate is not designed as missile barriers nor composite sections.

3.5.3.1.1 Concrete Barriers

Local damage prediction for concrete structures includes the estimation of the depth of missile penetration and an assessment of whether secondary missiles could be generated by spalling. Design criteria for concrete barriers are consistent with the National Defense Research Council (NDRC), "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects" (Reference 16). The modified NDRC formula is used to estimate the missile penetration depth, and barrier thickness to prevent perforation, spalling, and scabbing effects. The design thicknesses of missile barriers are 20 percent greater than the threshold values for the phenomenon being prevented. The design thicknesses also satisfy the minimum acceptable barrier thickness requirements for local damage prediction against tornado-generated missiles as well as

SEB Issue List Regarding APR 1400, FSAR 3.5.3 “Barrier Design Procedures”

Issue #6 (AI 3-80.6)

SRP acceptance criteria 3.5.3.II.2 states that 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 global structural response, in conjunction with other design loads, can be evaluated using conventional design methods. In FSAR Section 3.5.3.2 “Overall Damage Prediction,” additional information is needed in order for the staff to complete its safety review of Section 3.5.3.2 per 10 CFR 52.47 requirements, which states, in part, that the FSAR must include sufficient information to allow the staff to make a final safety finding. Therefore, the applicant is requested to provide a description of the methodology used to assess the flexural, shear and the buckling effects on the overall damage predictions for the barriers in Section 3.5.3.2 of the DCD.

Response

KHNP received a formal RAI, 215-8231, pertaining to this issue on September 15, 2015. The methodology used to assess concrete barriers will be submitted in the response to this RAI. For steel barriers, there are no steel barriers used in the APR1400 design. Therefore, the design requirements for steel barriers in subsections 3.5.3.1.2, 3.5.3.2 and Table 3.5-5 will be deleted to avoid confusion.

Impact on DCD

DCD Tier 2, subsections 3.5.3.1.2, 3.5.3.2 and Table 3.5-5 will be revised as indicated in the attached markup.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specification.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Reports.

3.5.3.1.2 Steel Barriers

Both of the Ballistic Research Laboratory (BRL) formulas available in "Reactor Safeguards" (Reference 17) and the Stanford Research Institute (SRI) equation are used as the basis for the design and analysis of steel barriers.

BRL Formula

$$T = \frac{(E_k)^{\frac{2}{3}}}{672D_e}$$

Where:

T = steel plate thickness for which perforation is possible (inch)

D_e = effective diameter of missile (inch)

E_K = missile kinetic energy, $MV^2/2$ (ft-lb)

V = impact velocity (ft/sec)

M = mass of missile ($lb\text{-}sec^2/ft$)

SRI Formula

$$\frac{E}{D} = \frac{S}{46{,}500}\left(16{,}000T^2 + 1{,}500\frac{W}{W_S}T\right)$$

Where:

E = critical kinetic energy required for perforation (ft-lb)

D = effective diameter of missile (inch)

S = ultimate tensile strength of the target (steel plate) (lb/in^2)

T = target plate thickness (inch)

W = length of a square side between rigid supports (inch)

W_s = length of a standard width (4 inch)

The SRI formula is applicable within the following ranges:

$0.1 < T/D < 0.8$

$0.002 < T/L < 0.05$

Steel barriers are not used in the APR1400 design to protect the safety related equipment or systems from missile impact.

10 < L/D < 50

5 < W/D < 8

8 < W/T < 100

70 < v < 400

Where:

L = missile length (inch)

v = impact velocity (ft/sec)

3.5.3.2 Overall Damage Prediction

Overall evaluation of structures/barriers under impact or impulsive loads is focused on providing reasonable assurance that the structures or barriers will not collapse and have excessive deformations to affect the function of safe shutdown equipment. For the evaluation of overall response of reinforced concrete and steel structures or barriers under impact and impulse loads, nonlinear and elasto-plastic response of structures is used.

Evaluations of the overall damage due to missile impact are performed by either considering missile impact in the elastic range of the structural element with other loadings applied and accounting for rebound effects of the impact, or by assuming that the inelastic capacity of the structural element resists missile impact loads. Inelastic impact analyses are performed by assuming that the full elastic capacity of the structural element is used to accommodate other loading conditions, and that the missile impact loads are accommodated in-elastically based on the ductility of the structural element. Code requirements for ductility shall be satisfied for the structural response evaluations under the missile impact.

Excessive deformation is limited by the allowable ductility ratios, which is defined as the ratio of maximum displacement to the yield displacement of structural element, where the maximum displacement will not result in the loss and damage of structural elements and components. The ductility limits for concrete and steel structures or barriers for various loading categories are defined in Table 3.5-5 which is based on NRC RG 1.142 (Reference 18) and AISC N690.

Table 3.5-5 (2 of 2)

Component	Loading Categories	Ductility Ratio	Remarks
	Axial Compression + Flexure (beam-column, walls, and slabs)		
Reinforced Concrete (continued)	When compression load $>0.1f'_cA_g$ or $1/3F_{bc}$	1.0	F_{bc}: Force which would produce balanced condition
	When compression load $\leq 0.1f'_cA_g$ or $1/3F_{bc}$	Follow remarks	Ductility ratio for flexure is used
	Combined compression + Flexure	Follow remarks	Ductility ratio is calculated linearly between 1.0 (Compression controls) and ductility ratio for flexure (Flexure controls)
Steel	Axial Tension members	$\mu_d \leq 0.25\frac{\varepsilon_u}{\varepsilon_y} < \frac{0.1}{\varepsilon_y}$	ε_u: strain at ultimate strength ε_y: strain at yield strength
	Flexural members		
	Tension controls	$\mu_d \leq 10$ $\mu_d \leq 20$	For open sections For closed section
	Shear controls	$\mu_d \leq 5$	
	Columns	$\mu_d = \frac{0.225}{\left(F_y/F_e e\right)} \leq \frac{\varepsilon_{st}}{\varepsilon_y} < 10$	$F_e = \frac{\pi^2 E}{(KL/r)^2}$ ε_{st}: strain corresponding to the onset of strain hardening