MITSUBISHI HEAVY INDUSTRIES, LTD.
16-5, KONAN 2-CHOME, MINATO-KU
TOKYO, JAPAN

April 8, 2009

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Mr. Jeffery A. Ciocco

Docket No. 52-021
MHI Ref: UAP-HF-09153

Subject: MHI's Response to US-APWR DCD RAI No. 221-1909

Reference: 1) "Request for Additional Information No. 221-1909 Revision 0, SRP Section: 03.05.03 – Barrier Design Procedures, Application Section: 03.05.03," dated 2/26/2009.

With this letter, Mitsubishi Heavy Industries, Ltd. ("MHI") transmits to the U.S. Nuclear Regulatory Commission ("NRC") a document entitled "Responses to Request for Additional Information No. 221-1909, Revision 0."

Enclosed are the responses to 6 RAIs contained within Reference 1.

Please contact Dr. C. Keith Paulson, Senior Technical Manager, Mitsubishi Nuclear Energy Systems, Inc. if the NRC has questions concerning any aspect of this submittal. His contact information is provided below.

Sincerely,

Y. Ogata

Yoshiki Ogata,
General Manager- APWR Promoting Department
Mitsubishi Heavy Industries, LTD.

Enclosure:

1. Responses to Request for Additional Information No. 221-1909, Revision 0

CC: J. A. Ciocco
C. K. Paulson

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NRO

Contact Information

C. Keith Paulson, Senior Technical Manager
Mitsubishi Nuclear Energy Systems, Inc.
300 Oxford Drive, Suite 301
Monroeville, PA 15146
E-mail: ck_paulson@mnes-us.com
Telephone: (412) 373-6466

Enclosure 1

UAP-HF-09153
Docket No. 52-021

Responses to Request for Additional Information No. 221-1909,
Revision 0

April, 2009

4/8/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 221-1909 REVISION 1**
SRP SECTION:	**03.05.03 – Barrier Design Procedures**
APPLICATION SECTION:	**03.05.03**
DATE OF RAI ISSUE:	**02/26/09**

QUESTION NO. RAI 3.5.3-01:

1. RAI Text

The F-Scale and EF-Scale are based on structural damage due to tornado wind effect near or at the ground level. Thus it is obvious that the distribution of the maximum tornado wind speed above the ground level cannot be readily related to F-Scale or EF-Scale. Furthermore, in light of maximum wind speed of ~300 mph recorded by DOW during May 3rd, 1999 Oklahoma City tornado, this wind speed is greater than the maximum speed provided in EF-scale and used in RG 1.76 (2007 March version) of 230 mph. Thus, Table 1, "Design-Basis Tornado Characteristics, provided in the older version of RG 1.76 (before 2007) seems to be more appropriate, due to higher maximum wind speed provided.

Therefore, from the conservative considerations, the applicant's DCD may want to preserve the option of using the maximum tornado wind speed higher than the current RG 1.76's specification (either from historical data or the update scientific measurements) for safety design purposes and the requirements of GDC 2.

The staff requests the applicant to affirm whether the above mentioned issue regarding the maximum tornado wind speed will be considered and implemented into the USAWPR DCD.

2. Concern:

To meet the requirements of 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.

GDC 2 also requires that design bases for SSCs reflect appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding region, <u>with sufficient margin</u> for the limited accuracy and quantity of the historical data and the period of time in which the data have been accumulated.

Enhanced Fujita (EF)-scale approach has been used to replace Fujita (F)-scale approach to project and update the Design-basis Tornado Characteristic in RG 1.76; which has resulted in a significant reduction of Region I maximum tornado wind speed from 360 MPH to 230 MPH. (It is noted here that the recommended EF-scale has not assigned an upper bound, or the maximum wind speed for the most intense tornado.) The Chronological changes of regulatory uses on the maximum tornado wind speeds are also shown a trend of decreasing maximum speeds used for design.

However, the maximum tornado missile speed is strictly associated with the maximum tornado wind speed and is not directly related to the structural damage induced by tornado, as that associated with the F-Scale or EF-Scale approaches. Furthermore, no upper bound was provided in current EF-scale approach. Thus, the consequence of what is the true safe design basis for the "maximum tornado wind speed" may deserve special attention. A good example of recent maximum tornado event is the Bridge Creek/OKC area tornado that happened on May 3, 1999. "Doppler on Wheels" (DOW) researchers from the University of Oklahoma announced that their radar measured 318- mph winds in the tornado while it was near Bridge Creek. The data obtained by the DOW team were also gone through scientific peer review, and results of this review suggest that the maximum speed actually may be less than 318 mph, but still in 300 mph range. This yields **DOWs measured record high wind speeds of 301 +/- 20 mph (135 +/- 10 m/s) in 03 May 1999 Oklahoma City tornado**. The May 3 tornado likely does have the highest recorded tornado wind speeds. But since typical wind measuring equipment does not survive a strong tornado, there are about three dozen tornadoes on record from which wind speeds have been obtained. Those measurements usually have been obtained from special research projects, such as the Doppler on Wheels (DOW) project, and have been obtained from only a dozen or so tornadoes (less than 0.1 percent of all tornadoes). So while the DOW data indicate the highest **recorded** tornado wind speed, there have been tens of thousands of tornadoes throughout history for which no wind speeds were ever obtained. Some of them easily could have had stronger winds than the May 3, 1999 tornado.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5 and Section 3.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue of PMF. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Chapter 3.0, Section 3.3, and Section 3.5.

External – There are no external dependencies.

ANSWER:

NRC Staff published a document dated January 2006 that is available through the NRC Electronic Reading Room, and which contains the NRC Comment Resolution to public comments on DG-1143. DG-1143 is the draft regulatory guide that preceded Revision 1 of RG 1.76 in March, 2007.

Public general comment 7 noted the old Fujita (F) scale is being replaced by the Enhanced Fujita (EF) scale. In the NRC Resolution to Comment 7, the revision to RG 1.76 implements the new EF scale. As stated in the resolution, the change from F scale to EF scale reduced the 10^{-7} tornado wind speeds in DG-1143 for each of the three regions. The net result of this conversion of measurement scale correctly reflects the reduction of maximum tornado wind speed from 300 mph to 230 mph. Because of this reduction in the wind speeds, the analysis also recalculated the resulting missile speeds presented in DG-1143. Therefore, the key site parameter of 230 mph for maximum tornado wind speed considers data presented in DG-1143 as well as RG 1.76, Revision 1, and no change to the DCD is applicable.

In addition, DCD Section 2.0 states the site-specific parameters for the US-APWR bound an estimated 75% to 80% of the United States landmass. COL Applicant Item COL 2.3(1) as stated in DCD Section 2.3 is to verify the site-specific regional climatology and local meteorology are bounded by the site parameters for the standard US-APWR design, or to demonstrate by some other means that the proposed facility and associated site-specific characteristics are acceptable at the proposed site. Therefore, the COL Applicant is to address any site-specific tornado wind speeds that are determined to exceed the key site parameters for the standard US-APWR.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

4/8/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 221-1909 REVISION 1**
SRP SECTION:	**03.05.03 – Barrier Design Procedures**
APPLICATION SECTION:	**03.05.03**
DATE OF RAI ISSUE:	**02/26/09**

QUESTION NO. RAI 3.5.3-02:

1. RAI Text

The DCD specified predictive formula regarding the missile induced damage to concrete material was based on Modified NDRC formula. However, there are several other predictive models available for such purpose; e.g., Modified Petry formula, Ballistic Research Laboratory (BRL) formula, and Army corps of Engineers (ACE) formula. Therefore, in order to satisfy GDC 4 criteria, use of these formulas and to choose the most critical outcome for design purpose need to be considered in the DCD.

Furthermore, the missile shape factor was assigned to a value of unity for the Modified NDRC formula in DCD. However, the N parameter of the missile shape factor is not a constant and is dependent on the projectile nose shape as described below.

N=0.72 for flat nosed body

N= 0.84 for blunt nose body,

N=1.0 for average bullet nose (spherical end), and

N=1.14 for very sharp nose.

Thus, it is recommended to add these descriptions into the DCD text for completeness.

A typo was also found in the limit specification for t_p/d equation in section 3.5.3.1.1. The correct limit term for tp/d prediction evaluation is stated below.

$tp / d = 3.19 (x / d) - 0.718 (x / d)^2$ for $x / d \leq 1.35$

Furthermore, W = missile weight was used in the Modified NDRC formula; however, the W term was also used in the steel section for the length of square sides. In order to prevent the confusion, it is recommended to replace W in concrete section with Wm to represent missile weight.

The staff requests the applicant to provide corrections on the above subjects.

2. Concern:

In SRP 3.5.3., Barrier Design Procedures," the Accept Criteria Section specifies the criteria necessary to meet the relevant requirements of GDC 2 and GDC-4. Several prediction models are available for estimating the missile impact damages for concrete materials. From the safety design view point, the most critical prediction should be used as a design basis. Furthermore, the missile impact penetrations are strongly dependent on the shape of the missile projectile. However, no specific shape factors were identified in the DCD.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 and GDC-4 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue of flood load design. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Section 3.5.

External – There are no external dependencies.

ANSWER:

SRP 3.5.3 indicates several empirical equations are available to estimate the missile penetration into concrete. The American Society of Civil Engineers (ASCE) Guideline for Design and Analysis of Nuclear Safety Related Earth Structures (ASCE 1-82 N-725) Subsection 6.4.1.2, Concrete Targets, notes only the modified National Defense Research Council (NDRC) formula adequately fits the test data within the range of interest for nuclear power facilities, and the other empirical formulas suffer from limitations in the range of available test data. Since the modified NDRC is identified within SRP 3.5.3 and is acceptable as confirmed by the above information, the modified National Defense Research Council (NDRC) formula was selected for the US-APWR as acceptable to the NRC for analysis of a concrete surface.

The Ballistic Research Laboratory (BRL) formula, which is available in "Reactor Safeguards" (DCD Reference 3.5-12), is provided as an alternative method to the Stanford Research Institute formula, which is available in "US Reactor Containment Technology" (DCD Reference 3.5-11), for analyzing steel plate thicknesses. Both formulas are provided within the DCD, and the greatest calculated value used for the design of steel targets, provided the minimum design thickness maintains a minimum factor of 1.25 over the perforation thickness.

The selection of "N" equal to 1.0 is applicable for an average bullet nose, or spherical objects, which are within the missile spectrum defined by RG 1.76. However, it is agreed that other missile sources may be of other nose shapes, and therefore the presentation of missile shape factor "N" will be revised in the DCD to be dependent on projectile nose shape. It should be noted that any blunt or flat nose objects may be conservatively analyzed using N equal to 1.0, without requiring the basis for selection of a lower value of N.

MHI agrees with the correction to typographical error on the limit specification, where $x / d \geq 13.5$ should be $x / d \leq 1.35$.

MHI agrees to change the variable W to W_m in the Modified NDRC Formula to prevent misinterpretation with W in the Stanford Formula.

Impact on DCD

See Attachment 1 for the mark-up of DCD Tier 2, Section 3.5, Revision 2, changes to be incorporated.

- Change the formulas under **Modified NDRC Formula** in first paragraph of Subsection 3.5.3.1.1 to the following:

  "$x = [4\ KNW_m\, d\ (V/1000d\ )^{1.8}\ ]^{0.5}$ $\quad$ *for* $x/d \leq 2.0$

  $x = KNW_m\ (V/1000d\ )^{1.8} + d$ $\quad$ *for* $x/d > 2.0$"

- Change the second parameter of the formulas under **Modified NDRC Formula** in first paragraph of Subsection 3.5.3.1.1 to the following:

  "W_m = missile weight, pounds"

- Change the fourth parameter of the formulas under **Modified NDRC Formula** in first paragraph of Subsection 3.5.3.1.1 to the following:

  "N = missile shape factor: N = 0.72 for flat nose body; N = 0.84 for blunt nose body; N = 1.0 for average bullet nose (spherical end); N = 1.14 for very sharp nose"

- Change the fourth formula in second paragraph of Subsection 3.5.3.1.1 to the following:

  "$t_p / d\ =\ 3.19\ (\ x / d\ ) - 0.718\ (x / d\ )^2$ $\quad$ for $x / d \leq 1.35$"

Impact on COLA

There is no impact on COLA.

Impact on PRA

There is no impact on PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

4/8/2009

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 221-1909 REVISION 1**
SRP SECTION:	**03.05.03 – Barrier Design Procedures**
APPLICATION SECTION:	**03.05.03**
DATE OF RAI ISSUE:	**02/26/09**

QUESTION NO. RAI 3.5.3-03:

1. RAI Text

With regard to the predictive equations stated in the DCD for steel, the first formula was referred to as "Stanford Formula;" and this is incorrect; the correct term should be called "SRI" formula. SRI stands for Stanford Research Institute which is different from "Stanford" or "Stanford University". Thus, all the term Stanford appears in the DCD should be replaced with SRI.

Further, this formula was expressed in critical kinetic energy parameter, rather than the parameter of penetration depth commonly used in the DCD Section 3.5.3. Therefore, it is recommended to add the expression for the penetration-depth-into the DCD as described below.

$$T_p = \sqrt{2.906\frac{E_k}{DS} + 0.0022\left(\frac{W}{W_S}\right)^2} - 0.047\left(\frac{W}{W_S}\right)$$

where, the symbol E for critical kinetic energy was replaced with E_k to bring consistency to the BRL formula used for steel evaluation. Furthermore, one of the limit criteria was omitted from the DCD; and this limit should be added back to the DCD as described below.

0.2 < W/L < 1.0, where, L is the projectile length.

The definition of the velocity unit was added to the limit specification, "70<V<400;" where, V is the striking velocity normal to the barrier surface, unit in ft/s.

In general, SRI and BRL formula agree only for the case of short span. However, for long spans the SRI equation is less conservative. Furthermore, the SRI formula is based on empirical data derived from parameter-dependent tests thus is not recommended for general use.

The staff requests the applicant to respond to the above questions related to steel materials.

2. Concern:

In order to be consistent with the formula used in the DCD for steel material for the prediction of local impact effects, additional equations are recommended for adequacy.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 and GDC-4 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Chapter 3.0, Section 3.5.

External – There are no external dependencies.

ANSWER:

The parenthetical abbreviation of "Stanford Formula" in DCD Subsection 3.5.3.1.2 is not intended to be a reference to any institution other than Stanford Research Institute as referenced within the DCD. Nevertheless, a search of acronyms defined within the DCD has not noted any previous use of "SRI," and therefore "SRI" will be added as the acronym for "Stanford Research Institute."

The use of the SRI formula is defined within the DCD Subsection 3.5.3.1.2 as valid within specified ranges. However, the introductory paragraph in DCD Subsection 3.5.3.1.2 also indicates the BRL formula as an alternate method that provides comparable results to the SRI formula. Since the SRI formula is based on empirical data derived from parameter-dependent tests, DCD Subsection 3.5.3.1.2 will be re-structured to use the BRL Formula in determining the required plate thickness; however the plate thickness is not to be less than that calculated using the SRI Formula.

Impact on DCD

See Attachment 1 for the mark-up of DCD Tier 2, Section 3.5, Revision 2, changes to be incorporated.

- Change Subsection 3.5.3.1.2 to the following:

  "**3.5.3.1.2 Steel**

  The formula by the Ballistic Research Laboratory (BRL Formula) available in "Reactor Safeguards" (Reference 3.5-12) is utilized to determine the steel plate thickness for threshold of perforation. In addition, the results of tests by Stanford Research Institute (SRI) summarized in "US Reactor Containment Technology"

(Reference 3.5-11) also establishes an equation (SRI Formula) for the steel plate thickness for threshold of perforation. The steel plate thickness for perforation threshold is to satisfy both BRL and SRI formulas.

BRL Formula

$$T_p = (E_k)^{2/3} / (672\,D)$$

where

T_p = steel plate thickness for threshold of perforation, inches

D = equivalent missile diameter, inches

E_k = missile kinetic energy, foot pounds = $M\,V^2/2$

M = mass of the missile, lb-sec^2/ft

V = impact velocity, ft/s

SRI Formula

$$E / D = (S / 46{,}500)\,[\,16{,}000\,T^2 + 1{,}500\,(W / W_s)\,T\,],$$

which can be re-written as:

$$T_p = \sqrt{2.906\frac{E_k}{DS} + 0.0022\left(\frac{W}{W_S}\right)^2} - 0.047\left(\frac{W}{W_S}\right)$$

where:

E = critical kinetic energy required for perforation, foot pounds

E_k = missile kinetic energy, foot pounds = $M\,V^2/2$

D = effective missile diameter, inches

L = length of projectile, inches

M = mass of the missile, lb-sec^2/ft

S = ultimate tensile strength of the target (steel plate), pounds per square inch

T = target plate thickness, inches

T_p = steel plate thickness for threshold of perforation, inches

V = impact velocity, ft/s

V_c = critical penetration velocity, ft/s

W = length of a square side between rigid supports, inches

W_s = length of a standard window, 4 inches

The ultimate tensile strength is directly reduced by the amount of bilateral tension stress already in the target. The SRI formula is valid within the following ranges of parameters, which are defined above:

$0.1 < T/D < 0.8$

$0.002 < T/L < 0.05$

$10 < L/D < 50$

$5 < W/D < 8$

$8 < W/T < 100$

$0.2 < W/L < 1.0$

$70 < V_c < 400$

For the design of steel targets, the minimum design thickness (t_d) is given below where the perforation thickness, T_p, is obtained from the BRL Formula or SRI Formula as applicable:

$t_d = 1.25\ T_p$"

Impact on COLA

There is no impact on COLA.

Impact on PRA

There is no impact on PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

4/8/2009

US-APWR Design Certification
Mitsubishi Heavy Industries
Docket No. 52-021

RAI NO.:	**NO. 221-1909 REVISION 1**
SRP SECTION:	**03.05.03 – Barrier Design Procedures**
APPLICATION SECTION:	**03.05.03**
DATE OF RAI ISSUE:	**02/26/09**

QUESTION NO. RAI 3.5.3-04:

1. RAI Text

As stated in DCD Section 3.5.3.1.3 Composite (Modular) Sections, "*Composite or multi-element barriers consider the residual velocity of the missile perforating the first element as the striking velocity for the next element.*" In order to further clarify the residual velocity, it is recommended to add the following equation into the DCD:

$$V_r = \sqrt{V^2 - V_B{}^2}$$

where, V_r is the residual velocity after missile penetration of the first layer (or the first shield), V is the impact velocity or striking velocity, and V_B is the perforation velocity associated with the proper absorbed energy to just perforate an element, according to Recht's and Ipson's method. The staff requests the applicant to consider inclusion of such information in the DCD.

2. Concern:

In order to further clarify the term of the "residual velocity" used in DCD Section for composite (modular) material of the local impact effect, the additional equation was recommended for clarification.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 and GDC-4 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Chapter 3.0, Sections 3.5.

External – There are no external dependencies.

ANSWER:

MHI agrees to provide within the DCD an equation for the calculation of residual velocity after missile penetration of the first layer in a composite section.

Impact on DCD

See Attachment 1 for the mark-up of DCD Tier 2, Section 3.5, Revision 2, changes to be incorporated.

- Add the following as the last paragraph in Subsection 3.5.3.1.3:

  "The residual velocity after missile penetration of the first layer (or outer shield) is determined by the formula:

$$V_r = \sqrt{V^2 - V_B{}^2}$$

where

V_r = residual velocity after missile penetration of the first layer (or outer shield)

V = impact (or striking) velocity of the missile object

V_B = perforation velocity associated with the energy absorbed up to the threshold of perforation."

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

4/8/2009

US-APWR Design Certification

Mitsubishi Heavy Industries

Docket No. 52-021

RAI NO.:	**NO. 221-1909 REVISION 1**
SRP SECTION:	**03.05.03 – Barrier Design Procedures**
APPLICATION SECTION:	**03.05.03**
DATE OF RAI ISSUE:	**02/26/09**

QUESTION NO. RAI 3.5.3-05:

1. RAI Text

In Section 3.5.1.6, Aircraft Hazards, the DCD states that, "The US-APWR standard plant design basis is that the plant is located such that an aircraft crash and air transportation accidents are not required to be considered as part of the design basis." However, in light of the 911 terrorist attack to the WTC in New York, consideration of such scenario is needed, including the consequence of jet fuel leakage into the interior of the R/B, due to initial impact induced partial/or small perforation. Moreover, such fire hazards, associated with the aircraft fuel, can significantly degrade the concrete property and impact the overall concrete barrier's structure integrity. Thus, the staff requests the applicant to provide more considerations on this subject.

2. Concern:

The request was made here: (1) to further clarify the statement, "the plant is located such that an aircraft crash and air transportation accidents are not required to be considered as part of the design basis," provided in the DCD, and (2) to further explore the consequence of the potential terrorist attack of airplane missiles.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 and GDC-4 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Chapter 3.0, Sections 3.5.

External – There are no external dependencies.

ANSWER:

DCD Subsection 3.5.1.6 identifies the US-APWR standard plant design is based on the plant being located such that an aircraft crash and air transportation accidents are not considered as part of the design basis. It is the COL Applicant's responsibility to verify the site interface parameters with respect to aircraft crashes and air transportation accidents.

Evaluations of malevolent threats, such as terrorist attack using airplane missiles, are of beyond-design basis events. Aircraft impact assessment has been conducted to meet NRC proposed rule 10 CFR 52.500, using NEI 07-13 methodology and NRC specified aircraft threat. The technical report for the beyond-design basis aircraft impact is being prepared now, and is scheduled to be submitted to the NRC this year. Content of the assessment and the results will be safeguards information. After the release of the technical report, DCD Chapter 19 will be updated to provide non-safeguards information applicable to the DCD, or to reference the technical report.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

4/8/2009

US-APWR Design Certification

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RAI NO.:	**NO. 221-1909 REVISION 1**
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QUESTION NO. RAI 3.5.3-06:

1. RAI Text

No specific guideline of the subject related to the "massive missile", such as automobile missile that may puncture or perforate barriers, was provided in the DCD. The "massive" missiles normally are very soft missiles subjected to large deformations upon the impact. Thus, for large structures, the dynamic response of the overall structure to this missile strike is negligible, and the dynamic effects are limited to local impact effects. The staff requests the applicant to provide more detailed information on this subject.

2. Concern:

The massive missile is one of the potential missile threats to the barrier design, and no specific guidelines were provided in the DCD in this area associated with such event.

3. Applicant References:

DCD Tier 2, Revision 1, Section 3.5.3.

4. Context

Structural integrity of Seismic Category I structures, which assures that SSCs important to safety are protected, and not compromised according to GDC-2 and GDC-4 in the Appendix A to Part 50 of 10 CFR.

5. Priority/Impact

Medium – information is essential to completing a technical review and resolving a safety issue. The review can continue, but cannot be completed without the requested additional information.

6. Dependencies

Internal – There are interfaces with SRP Chapter 3.0, Sections 3.5.

External – There are no external dependencies.

ANSWER:

The discussion in the first paragraph of DCD Subsection 3.5.1.4 recognizes the spectrum of missiles includes a massive high-kinetic-energy missile that deforms on impact. By the position provided by RG 1.76, the NRC staff considers an automobile to be acceptable as the massive missile for use in the design of the nuclear power plant.

DCD Subsection 3.5.3.1 provides the formulas to predict the penetration depth (x), scabbing thickness (t_s) and the perforation thickness (t_p) potential created by the missile impact. As noted by the NRC Reviewer in Question No. RAI 3.5.3-02, the Modified NDRC formula that is applicable for the design of concrete surfaces includes a missile shape factor N that is dependent on the projectile nose shape. The impact of very soft missiles subjected to large deformations upon the impact may be considered as caused by a blunt or flat nose object. Therefore, a reduced value for the missile shape factor N is applicable; however massive high-kinetic-energy missiles may be conservatively analyzed using N equal to 1.0 to limit the justification of the basis for selection of any lower value of N.

Impact on DCD

There is no impact on the DCD.

Impact on COLA

There is no impact on the COLA.

Impact on PRA

There is no impact on the PRA.

This completes MHI's responses to the NRC's questions.

ATTACHMENT 1
to RAI 221-1909

3.5.3.1 Evaluation of Local Structural Effects

The following subsections address the design of structures to withstand and absorb missile impact loads. Formulas are provided to predict the penetration depth (x), scabbing thickness (t_s) and perforation thickness (t_p) potential created by the missile impact. Safety factors are then applied to determine required barrier thicknesses to restrict missile penetration, scabbing and/or perforation. It is assumed that the missile impacts normal to the plane of the wall on a minimum impact area and, in the case of reinforced concrete, its resistance does not credit capacity of struck reinforcing.

3.5.3.1.1 Concrete

The National Defense Research Council (NDRC) provides "A Review of Procedures for the Analysis and Design of Concrete Structures to Resist Missile Impact Effects", by R. P. Kennedy (Reference 3.5-9). Selected wall thicknesses also satisfy minimum barrier thicknesses provided in Table 1 of NUREG-0800, SRP 3.5.3 (Reference 3.5-10) to prevent local damage against tornado generated missiles.

Modified NDRC Formula

$$x = [4\,KN\cancel{W}\,W_{\underline{m}}\,d\,(V/1000d)^{1.8}]^{0.5} \quad \text{for } x/d \le 2.0$$

$$x = KN\cancel{W}\,W_{\underline{m}}\,(V/1000d)^{1.8} + d \quad \text{for } x/d > 2.0$$

where

x	=	penetration depth, inches
$W_{\underline{m}}$	=	missile weight, pounds
d	=	missile diameter, inches
N	=	missile shape factor<ins>; N = 0.72 for flat nose body; N = 0.84 for blunt nose body; N</ins> = 1.0 <ins>for average bullet nose (spherical end); N = 1.14 for very sharp nose</ins>
V	=	impact velocity, ft/s
K	=	experimentally obtained material coefficient for penetration = $180/(f_c')^{0.5}$
f_c'	=	concrete compressive strength

Scabbing thickness, t_s, and perforation thickness, t_p is given by

$$t_s / d = 2.12 + 1.36\, x / d \quad \text{for } 0.65 \le x / d \le 11.75$$

$$t_s / d = 7.91\,(x / d) - 5.06\,(x / d)^2 \quad \text{for } x / d \le 0.65$$

$$t_p / d = 1.32 + 1.24\,(x / d) \quad \text{for } 1.35 \le x / d \le 13.5$$

$$t_p / d = 3.19\,(x / d) - 0.718\,(x / d)^2 \quad \text{for } x / d\ \cancel{\ge 13.5}\ \underline{\le 1.35}$$

In order to provide a sufficient safety margin, the design thickness (t_d) is 20% greater than the threshold value for the phenomenon being prevented as follows:

To prevent perforation, the design thickness, $t_d = 1.2\, t_p$

To prevent scabbing, the design thickness, $t_d = 1.2\ t_s$

3.5.3.1.2 Steel

~~The results of tests by Stanford Research Institute summarized in "US Reactor Containment Technology" (Reference 3.5-11) are used to establish equations (Stanford Formula) to determine required plate thickness. Alternately,~~ The formulas by the Ballistic Research Laboratory (BRL Formula) available in "Reactor Safeguards" (Reference 3.5-12) ~~are~~ is utilized ~~and provide comparable results to the US Reactor Containment Technology method~~ to determine the steel plate thickness for threshold of perforation. In addition, the results of tests by Stanford Research Institute (SRI) summarized in "US Reactor Containment Technology" (Reference 3.5-11) also establishes an equation (SRI Formula) for the steel plate thickness for threshold of perforation. The steel plate thickness for perforation threshold is to satisfy both BRL and SRI formulas.

BRL Formula

$$T_p = (E_k)^{2/3} / (672\ D)$$

where

T_p = steel plate thickness for threshold of perforation, inches

D = equivalent missile diameter, inches

E_k = missile kinetic energy, foot pounds = $M\ V^2/2$

M = mass of the missile, lb-sec²/ft

V = impact velocity, ft/s

~~Stanford~~ SRI Formula

$$E / D = (S / 46{,}500)\ [\ 16{,}000\ T^2 + 1{,}500\ (\ W / W_s\ ) \cdot T\ ]$$

which can be re-written as:

$$T_p = \sqrt{2.906 \frac{E_k}{DS} + 0.0022 \left(\frac{W}{W_S} \right)^2} - 0.047 \left(\frac{W}{W_S} \right)$$

where:

E = critical kinetic energy required for perforation, foot pounds

E_k = missile kinetic energy, foot pounds = $M\ V^2/2$

D = effective missile diameter, inches

L = length of projectile, inches

M = mass of the missile, lb-sec^2/ft

S = ultimate tensile strength of the target (steel plate), pounds per square inch

T = target plate thickness, inches

T_p = steel plate thickness for threshold of perforation, inches

V = impact velocity, ft/s

V_c = critical penetration velocity, ft/s

W = length of a square side between rigid supports, inches

W_s = length of a standard window, 4 inches

The ultimate tensile strength is directly reduced by the amount of bilateral tension stress already in the target. The SRI ~~equation~~ formula is valid within the following ranges of parameters, which are defined above:

$0.1 < T/D < 0.8$

$0.002 < T/L < 0.05$

$10 < L/D < 50$

$5 < W/D < 8$

$8 < W/T < 100$

$0.2 < W/L < 1.0$

$70 < V_c < 400$

~~**BRL Formula**~~

$\cancel{T_p = (E_k)^{2/3} / (672\ D)}$

~~where~~

~~T_p = steel plate thickness for threshold of perforation, inches~~

~~D = equivalent missile diameter, inches~~

~~E_k = missile kinetic energy, foot pounds = $M\ V^2/2$~~

~~M = mass of the missile, lb-sec^2/ft~~

~~V = impact velocity, ft/s~~

For the design of steel targets, the minimum design thickness (t_d) is given below where the perforation thickness, T_p, is obtained from the ~~Stanford~~ BRL Formula or ~~BRL~~ SRI Formula as ~~follows~~ applicable:

$t_d = 1.25\ T_p$

3.5.3.1.3 Composite (Modular) Sections

Composite or multi-element barriers consider the residual velocity of the missile perforating the first element as the striking velocity for the next element. For steel-concrete modular sections, the outer steel plates satisfy minimum thicknesses as determined in Subsection 3.5.3.1. In cases of extreme missile impact, steel plate thicknesses may be limited and the residual velocity of the missiles is to be absorbed by concrete determined by equations presented in “Ballistic Perforation Dynamics” (Reference 3.5-13).

The residual velocity after missile penetration of the first layer (or outer shield) is determined by the formula:

$$V_r = \sqrt{V^2 - V_B^{\ 2}}$$

where

V_r = residual velocity after missile penetration of the first layer (or outer shield)

V = impact (or striking) velocity of the missile object

V_B = perforation velocity associated with the energy absorbed up to the threshold of perforation.

3.5.3.2 Evaluation of Overall Structural Effects

Elements required to remain elastic are evaluated to assure that the usable strength capacity exceeds the demand. For structures allowed to displace beyond yield (elasto-plastic response), an evaluation confirms that acceptable deformation limits to demonstrate ductile behavior are not exceeded by comparing computed demand ductility ratios with capacity values.

After it is determined that a missile will not penetrate the barrier, an equivalent static load concentrated at the impact area is applied in conjunction with other design loads. Refer to Subsection 3.3.2.2 for determination of tornado forces on structures, including equivalent static loads for tornado missile impact. In determining an appropriate equivalent static load for other missiles sources (as defined in Subsection 3.8.4), elasto-plastic behavior may be assumed with permissible ductility ratios as long as deflections will not result in loss of function of any safety-related system.

The flexural, shear, and buckling effects on structural members are determined using the equivalent static load obtained from the evaluation of missile impact on structural response. Stress and strain limits for the equivalent static load comply with "Safety-Related Concrete Structures for Nuclear Power Plants (Other than Reactor Vessels and Containments)", RG 1.142, Rev.2 (Reference 3.5-14), and "Specification for the Design, Fabrication and Erection of Steel Safety-Related Structures for Nuclear Facilities", including Supplement 2 (2004) American Institute of Steel Construction (AISC) N690-1994 & 2004. (Reference 3.5-15). The consequences of scabbing are evaluated if the thickness is less than the minimum thickness to preclude scabbing.

The overall qualification of concrete barriers is discussed in RG 1.142 (Reference 3.5-14). Regulatory position 10 of RG 1.142 accepts evaluations completed in accordance with Appendix C of American Concrete Institute (ACI) Code ACI-349 (Reference 3.5-16), with provisions made for maximum permissible ductility ratios (μ) and dynamic increase factor (DIF) as stated in the RG 1.142:

1. In ACI-349, Section C.3.5, where flexure controls design, μ = 1.0 for the structure as a whole, except as noted in conjunction with Section C3.8 below, and μ = 3.0 for a localized area in the structure.