May 16, 2013

AUDIT REPORT

U.S. EPR

DESIGN OF SEISMIC CATEGORY I CRITICAL SECTIONS

Dates of Audit: April 15 to 18, 2013

Audit Location: AREVA NP, 7207 IBM Drive, Charlotte, NC 28262

NRC Review Team: Jim Xu (NRC Technical Monitor) and Manuel Miranda (BNL)

Audit Scope

The scope of the audit was the review of a subset of calculations associated with the design of pre-stressed and reinforced concrete critical sections in the Nuclear Island (NI), as described in U.S. EPR Final Safety Evaluation Report (FSAR) Tier 2, Appendix 3E. See Table 1 for the complete list of calculations available for NRC review.

The day the audit started, AREVA identified an error in calculation 32-7012540-000 “U.S. EPR Standard Plant DC Fuel Building Design – Hardened Shell – Typical Material Lock Area Roof Slab & Support Walls (CS-21).” This calculation was then removed from the scope of the audit.

Audit Summary

Representatives from NRC, Brookhaven National Laboratory (BNL), and AREVA were present during the audit, including key technical personnel. A list of attendees is provided in Attachment 1.

After introductions and a review of the agenda, NRC staff made some introductory remarks regarding the audit background and objectives. It was indicated that the audit should be considered a continuation of the previous audit of critical sections held in February 25-27, 2013.

Following these remarks, a sequence of activities was followed in which AREVA presented brief overviews of the calculations prepared for pre-stressed and reinforced concrete critical sections in the NI, and the staff performed reviews of selected portions of these calculations.

As a result of the review, several technical issues were identified as requiring follow-up work by AREVA, which will be reviewed by the staff during the next audit of critical sections tentatively scheduled for July, 2013. These technical issues were discussed with AREVA. Details of the discussions are given in the following section.

The audit concluded with an exit meeting that summarized the discussions and the disposition of the issues raised during the audit.

Discussions

Update on Errors Identified with CivilFEM software

AREVA had previously identified an error with the CivilFEM software that is being used for the design of pre-stressed and reinforced concrete critical sections, in conjunction with ANSYS FEM results. This error is being addressed by the software vendor. AREVA indicated that this error does not affect the "symmetric" method of CivilFEM, which is the only method being implemented in all pre-stressed and reinforced concrete critical section calculations. "Symmetric" refers to the concrete sections being designed with equal and symmetric reinforcement arrangements (top and bottom).

Update on List of Critical Sections identified in FSAR Tier 2, Rev. 4, Appendix 3E

AREVA confirmed the list of critical sections in FSAR Tier 2, Rev. 4, Appendix 3E, is still valid.

Follow-Up from February 25-27, 2013, Audit of Critical Sections

The staff issued RAI 580 Questions 03.08.04-28, 03.08.04-29, and 03.08.04-30 that request AREVA to address the technical issues arising from the February 25-27, 2013, audit. AREVA indicated that work in support of the responses to this RAI is ongoing.

Two clarifications were also requested during the February 25-27, 2013, audit of critical sections:

> "AREVA will confirm whether ACI 349 Section 21.7 is applicable to concrete beams and columns in the NI."
>
> "AREVA will confirm whether loads induced by temperature effects should be considered for steel beams in the RBIS."

Regarding the first item, AREVA indicated that ACI 349-01 Section 21.7 does not appear to be strictly applicable to concrete beams and columns in the NI. The staff agreed that the code is not completely clear in this regard. Nevertheless, AREVA checked the ductile detailing requirements in ACI 349-01 Section 21.7 and the current design essentially complies. The staff also noted that inelastic demands on the concrete beams and columns of the NI are unlikely to require the full level of ductile detailing specified in ACI 349-01 Section 21.7 because the NI structure is designed to remain essentially elastic during an SSE event.

Regarding the second item, AREVA indicated that connection details necessary to allow for the thermal expansion of steel beams in the RBIS will be added to the scope of critical CS-24 "Typical Beams and Columns in the NI," thereby eliminating the need to consider additional loads induced by temperature effects. This will be documented in the response to RAI 580 Question 03.08.04-30.

General Methodology for Concrete Reinforcement

AREVA described the general methodology for calculating required steel reinforcement areas for the concrete critical sections, which relies heavily on automated computations using ANSYS, CivilFEM and the CivilFEM Interface Macro (CIM). This methodology has the following key steps:

(a) The ANSYS FEM of the NI (so-called "global static model") is used to compute internal forces and moments resulting from all loads and load cases. Only the loads and load cases that are directly applied to the global static model are accounted for. FSAR Tier 2, Appendix 3E, will describe the loads applied to the global static model.

(b) Automated computations identify a set of governing load combinations from the global static model analysis. This is an important step in reducing the computational effort since the total number of load combination permutations is in the order of several thousand.

(c) The engineer performs a systematic check of all potentially applicable loads that need to be considered in the design, but were not directly applied to the global static model (so-called “missing loads”). These include additional miscellaneous dead and live loads, moving equipment loads, localized piping loads, sub-compartment pressurization loads, and seismic torsion due to accidental eccentricity. FSAR Tier 2, Appendix 3E, will describe the missing loads considered for each critical section.

(d) Internal forces and moments resulting from the missing loads are evaluated using hand calculations or ANSYS sub models. These results are added to the results from the governing load combinations already identified from the global static model analysis. In some cases, it is necessary to include additional load combinations beyond those already identified as governing. This is to ensure that the effect of the missing loads is fully captured in the design.

(e) CivilFEM and the CIM utilize the internal force and moment results to compute the required steel reinforcement for all design conditions applicable to walls and slabs (i.e., combined membrane-bending, in-plane shear, and out-of-plane shear) and all applicable load combinations. This process is automated for each finite element within the scope of the critical section. Required design checks for punching shear are also performed if necessary.

(f) Additional steel reinforcement to account for aircraft hazard and explosion pressure wave loads is incorporated to the design if necessary. This is based on a separate calculation that is beyond the scope of the audit.

(g) Design sketches are prepared and required steel reinforcement is tabulated. FSAR Tier 2, Appendix 3E, will include this information for each critical section.

The staff noted that this automated design methodology is positive since it reduces the possibility of human error. In addition, a more robust design results because only the “symmetric” option of CivilFEM is being used.

Loads due to Construction Sequence and Differential Settlements

The staff identified that the construction sequence/differential settlement load case (described in FSAR Tier 2, Section 3.8.5, and response to RAI 354 Question 3.8.5-22) was not being considered in the design. In the calculations reviewed, this was stated as “an assumption requiring further verification.” The design is thus incomplete.

AREVA indicated that, during the implementation of the critical section design, unrealistically high forces and moments were obtained by applying the methodology and loads described in FSAR Tier 2, Section 3.8.5, and response to RAI 354 Question 3.8.5-22. Therefore, a modification to this methodology and loads was being considered. An outline of this revised methodology was presented to the staff, which considered it an acceptable approach.

AREVA indicated that once the revised construction sequence/differential settlement loads are evaluated, they will be incorporated into the design. This will be confirmed during the next critical sections audit.

AREVA will update FSAR Tier 2, Section 3.8.5, and supplement the response to RAI 354 Question 3.8.5-22 to describe the revised methodology and loads.

Scope of Critical Sections

The staff indicated its expectations regarding Tier 2* information in FSAR Tier 2, Appendix 3E. Tables listing required areas of steel reinforcement should be Tier 2*.

The staff could not identify design sketches that showed how perpendicular wall-wall and wall-slab connections were being implemented; particularly with regard to reinforcement development details at these junctions to ensure full moment capacity is maintained.

Furthermore, there seemed to be a systematic use of the adjective “typical,” as well as generic statements such as “non-typical portions of (…) within the bounds of the critical section (i.e. at penetrations or discontinuities) may require additional reinforcing and are outside the designated design scope.” These statements make the scope of the each critical section unclear.

AREVA indicated that the computed steel reinforcement is applicable to all the finite elements within the scope of the critical section, which is shown in each calculation and will also be included in each subsection of FSAR Tier 2, Appendix 3E. Additional detailing reinforcement in certain areas (e.g., around small openings and wall piers) may be necessary per code requirements; however, this cannot determined from the finite element calculations (the FE mesh would not be appropriate).

AREVA also indicated that FSAR Tier 2, Appendix 3E will include, for each critical section, a description of the critical section selection criteria that were used (i.e., qualitative, quantitative, or supplemental) and clearly define the scope of the structural elements included and excluded from the critical section. Notes will be added to clearly indicate locations where additional reinforcement is required but not calculated.

AREVA will include notes to clarify connection types between perpendicular wall-wall and wall-slab connections details if these were not provided in the design sketches. AREVA will also clarify the extent of applicability of the design sketches to include the structural elements of the corresponding critical sections.

The above information will be confirmed during the next critical sections audit.

CIM V&V

Since the CIM was developed in-house and is used extensively in the design calculations, the staff requested the Verification and Validation (V&V) package for this software. The staff briefly reviewed this V&V package (calculation 32-7013215-000).

Additional Seismic Analysis for Seven Critical Sections

AREVA indicated that, for 7 of the 36 critical sections (identified as CS-06, CS-08, CS-09, CS-10, CS-12, CS-17, CS-22), the equivalent-static seismic approach that has been implemented to date results in excessive stresses that cannot be resolved through the standard design process. Therefore, a time-history seismic analysis methodology is currently being considered as an alternative to the equivalent-static approach. An outline of this alternative methodology was presented to the staff.

The staff deferred from providing feedback until AREVA has a better understanding of how to implement this alternative methodology. AREVA indicated it will communicate to the staff once a decision has been made.

Containment Design – Typical Cylinder Wall and Buttress (CS-02)

AREVA performed a demonstration of the CIM to show how the design requirements in RG 1.90 Alternative B were being implemented for the typical cylinder wall and buttress; i.e., (a) limits on the reinforcement tensile stress, and (b) requirement that the cross-section remain in compression under peak test pressure. The CIM fully incorporates these design requirements as one of its options.

The staff also reviewed calculation 32-9011974-003 "U.S. EPR Standard Plant Structural Loads – Post Tensioning Loads," which confirms that the cross-section remains in compression under peak test pressure.

RAI 306, Supp. 6, Question 3.8.1-39, indicated that Figure 3.8.1-39-1 in the response (interaction diagram) would be updated with the final critical section design to ensure the RAI response remains valid. However, the staff could not identify whether this information had been included in the calculations or whether this would be provided to the staff.

AREVA indicated the updated interaction diagram will be provided with the final response to RAI 155. This will be confirmed during the next critical sections audit.

RAI 335 Supp. 18 Question 3.8.1-44 indicated a commitment that a 10% design margin would be maintained between the analysis demands and the section capacities. However, the staff could not identify whether this design margin had been incorporated in the calculations.

AREVA will re-evaluate the use of the 10% design margin. AREVA will submit a supplemental response to RAI 335 Question 3.8.1-44 if an alternative approach is implemented in the critical section design. This will be confirmed during the next critical sections audit.

The staff requested AREVA to explain how the thermal accident loads on the containment were applied to the global static model of the NI; in particular the induced thermal moments.

AREVA explained that a thermal analysis as performed using the global static model of the NI. Temperature was defined at all nodes of the containment building wall and dome at the four critical time instants identified in FSAR Tier 2, Section 3.8.1. The resulting four sets of induced internal forces and moments were utilized in the design in a similar manner as all other load cases.

Safeguard Building Design – Divisions 1 & 4 – Typical Main Steam/Feedwater Valve Room Walls & Slabs (CS-14)

The calculation has been performed for the MS/FW Valve Room in Safeguard Building 1; however, it is stated that the design is also applicable to Safeguard Building 4.

The staff requested AREVA to clarify to what extent the design is also applicable to Safeguard Building 4, since it is not necessarily the case that all internal forces and moments in Safeguard Building 4 are equal to or bounded by the corresponding forces and moments in Safeguard Building 1 (geometry and loads are not perfectly symmetrical).

AREVA indicated the calculation will be updated to limit the scope to Safeguard Building 1. This will be confirmed during the next critical sections audit.

Safeguard Building Design – Divisions 1 & 4 – Typical Exterior Walls from Top of Nuclear Island Basemat to Elevation +15'-5" (CS-15)

The staff noted that the wall reinforcement shown in calculation Figure 5-21 does not continue into the joint, thus reducing the moment capacity of the wall section adjacent to the joint.

AREVA indicated that the calculation will be updated to revise this Figure if needed. This will be confirmed during the next critical sections audit.

Fuel Building Design – Interior Structures – Typical Spent Fuel Pool Walls and Floor Slabs (CS-18)

RAI 335 Supp. 13 Question 3.8.4-10 identified a set of hydrodynamic pressures on the SFP walls and floor slab, which had been previously reconciled with pressures obtained from the coupled fluid-structure dynamic analysis performed as part of the fuel rack design. However, the staff could not identify whether these hydrodynamic pressures had been incorporated in the calculations.

RAI 335 Supp. 13 Question 3.8.4-10 also indicated that vertical fuel rack impact loads, obtained from the aforementioned coupled fluid-structure dynamic analysis, would be checked to ensure the punching shear resistance of the floor slab was adequate. However, the staff could not identify whether this check had been performed in the calculations.

The staff also requested AREVA to provide the status of an updated reconciliation between the hydrodynamic pressures considered in the design and pressures obtained from the aforementioned coupled fluid-structure dynamic analysis. The latter has been revised due to ongoing changes in the seismic SSI analysis (i.e., changes from SASSI SM to DM).

AREVA indicated that the issues raised by the staff will be addressed in a supplemental response to RAI 335 Question 3.8.4-10. This will be confirmed during next critical sections audit.

Table 1
List of AREVA Calculations Available for Review

Calculation Number	Revision	Date	Title
32-9029333-002	002	4/8/2013	U.S. EPR Standard Plant DC Containment Design – Typical Cylinder Wall and Buttress (CS-02)
32-7009391-000	000	4/3/2013	U.S. EPR Standard Plant DC Safeguard Building Design – Division 2/3 Interior Structures– Typical Floor Slab at Elevations -16'-5" & 0'-0" (CS-13)
32-9029336-001	001	4/4/2013	US EPR Standard Plant DC Safeguard Building Design – Divisions 1 & 4 – Typical Main Steam/Feedwater Valve Room Walls & Slabs (CS-14)
32-9029335-002	002	4/1/2013	U.S. EPR Standard Plant DC Safeguard Building Design – Divisions 1 & 4 – Typical Exterior Walls from Top of Nuclear Island Basemat to Elevation +15'-5" (CS-15)
32-9029346-002	002	4/4/2013	U.S. EPR Standard Plant DC Fuel Building Design – Interior Structures – Typical Spent Fuel Pool Walls and Floor Slabs (CS-18)
32-7012540-000	000	4/4/2013	U.S. EPR Standard Plant DC Fuel Building Design – Hardened Shell – Typical Material Lock Area Roof Slab & Support Walls (CS-21) (*)

(*) AREVA identified an error in this calculation the day the audit started. The staff removed this calculation from the scope of the audit.

Table 2
List of Additional AREVA Calculations Reviewed

Calculation Number	Revision	Date	Title
32-9011974-003	003	12/16/2010	U.S. EPR Standard Plant Structural Loads – Post Tensioning Loads
32-9056705-001	001	12/14/2011	U.S. EPR Standard Plant Structural Loads – Accidental Torsion Loads
32-7013215-000	000	3/11/2013	Validation for CivilFEM Interface Macro Version 1.2

ATTACHMENT 1

ATTENDANCE SHEET

Regulatory Audit of U.S. EPR
Structural Design Critical Sections

AREVA Office
Charlotte, NC

April 15 - 18, 2013

Name	Affiliation	Contact Information- Email/Phone
MICHAEL MIERNICKI	NRC	michael.miernicki@nrc.gov
Jim Xu	NRC	Jim.Xu@nrc.gov
MANUEL MIRANDA	BNL	mmiranda@bnl.gov
Brian Loseke	AREVA	Brian.Loseke@areva.com
JASON CROUSE	AREVA	Jason.Crouse@areva.com
VICTOR ABAYAN	AREVA	victor.abayan@areva.com
Joe Harrold	Areva	joseph.harrold@areva.com
Jenny Tsai	Areva	jenny.tsai@areva.com
Veronica Cornell	AREVA	veronica.cornell.ext@areva.com
TONI KOLEVA	AREVA	ANTOANETA.KOLEVA@AREVA.COM
BETH POORE	AREVA	LOIS.POORE@AREVA.COM
Tom Ryan	AREVA	Tom.Ryan@AREVA.com
Nawar Alchaar	"	John.Leighliter@AREVA.com
John Leighliter	"	Nawar.Alchaar@AREVA.com
TODD OSWALD	AREVA	TODD.OSWALD@AREVA.COM
SYED RAHMAN	AREVA	syed.rahman@areva.com
Tim Schmitt	AREVA	Timothy.Schmitt@areva.com
Len Gucwa	AREVA	Len.Gucwa@AREVA.com
Brian Vance	AREVA	Brian.Vance@AREVA.com
MIKE CARPENTER	AREVA	Mike.carpenter@areva.com
Dennis Williford	AREVA	Dennis.Williford@areva.com