August 31, 2017

Dr. Han-Gon Kim, Project Manager
APR1400 Design Certification
Advanced Reactors Development Laboratory
Korea Hydro and Nuclear Power Co., Ltd.
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305-343 Korea (Republic of)

SUBJECT: THE KOREA HYDRO AND NUCLEAR POWER CO. LTD ADVANCED POWER REACTOR 1400 DESIGN AIRCRAFT IMPACT ASSESSMENT INSPECTION, NUCLEAR REGULATORY COMMISSION INSPECTION REPORT NO. 05200046/2016-202

Dr. Han-Gon Kim,

From July 17, 2017, through July 20, 2017, the U.S. Nuclear Regulatory Commission (NRC) conducted an inspection of the Korea Hydro and Nuclear Power Co., Ltd. (KHNP) Advanced Power Reactor 1400 (APR1400) Aircraft Impact Assessment (AIA). The NRC staff performed this inspection at the Structural Integrity Associates Inc. office located in San Diego, CA. The purpose of the inspection was to assess KHNP's compliance with the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.150, "Aircraft impact assessment." The enclosed report presents the results of this inspection.

Based on the inspection samples, the NRC inspection team determined that a Severity Level IV violation of NRC requirements occurred. The violation was evaluated in accordance with the enforcement policy. The violation is cited in the enclosed Notice of Violation (Notice), and the circumstances surrounding the violation are described in detail in the subject inspection report. The violation cites three examples that include KHNP's failure to: (1) identify and incorporate into the design control document (DCD) those design features and functional capabilities credited in the AIA to show the reactor core remains cooled and spent fuel pool integrity is maintained; (2) perform a design specific assessment in portions of the AIA; and (3) use realistic analyses in portions of the AIA.

It is important to note that the NRC inspection team performed a limited review of the APR1400 AIA. Many of the deficiencies identified may also affect other portions of the AIA that the NRC inspection team did not review. Therefore, KHNP should extend its review, where applicable, beyond the specific examples identified by the inspection team and apply corrective actions as appropriate. In its response to this violation, KHNP should document the areas for which it extended its review beyond the specific examples of the deficiencies identified by the inspection team, the extent of its review, the additional findings, and the corrective actions implemented.

In accordance with 10 CFR 2.390 "Public inspections, exemptions, requests for withholding," of the NRC's "Rules of Practice," a copy of this letter, its enclosures, and your response will be made available electronically for public inspection in the NRC Public Document Room or from the NRC's Agencywide Document Access and Management System (ADAMS), accessible from the NRC Web site at http://www.nrc.gov/reading-rm/adams.html. To the extent

possible, your response, if applicable, should not include any personal privacy, proprietary, or safeguards information so that it can be made available to the public without redaction. If personal privacy or proprietary information is necessary to provide an acceptable response, then please provide a bracketed copy of your response that identifies the information that should be protected and a redacted copy of your response that deletes such information. If you request that such material is withheld from public disclosure, you must specifically identify the portions of your response that you seek to have withheld and provide in detail the bases for your claim (e.g., explain why the disclosure of information will create an unwarranted invasion of personal privacy or provide the information required by 10 CFR 2.390(b) to support a request for withholding confidential commercial or financial information). If safeguards information is necessary to provide an acceptable response, please provide the level of protection described in 10 CFR 73.21, "Protection of Safeguards Information: Performance Requirements."

Sincerely,

/RA/

Terry W. Jackson, Chief
Quality Assurance Vendor Inspection Branch-1
Division of Construction Inspection
and Operational Programs
Office of New Reactors

Docket No.: 05200046

Enclosures:
1. Notice of Violation
2. Inspection Report No. 05200046/2016-202
   and Attachment

SUBJECT: THE KOREA HYDRO AND NUCLEAR POWER CO. LTD ADVANCED POWER REACTOR 1400 DESIGN AIRCRAFT IMPACT ASSESSMENT INSPECTION, NUCLEAR REGULATORY COMMISSION INSPECTION REPORT NO. 05200046/2016-202

Dated: August 31, 2017

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NAME	AIstar*	SSmith	MMcCoppin*	
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NAME	SSamaddar*	MHayes*	ADias*	
DATE	08/17/17*	08/17/17	08/10/17	
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NOTICE OF VIOLATION

Korea Hydro and Nuclear Power Co., Ltd. Docket No.: 05200046
305-343 Korea (Republic of) Inspection Report No.: 05200046/2016-202

During a U.S. Nuclear Regulatory Commission (NRC) inspection of the Korea Hydro and Nuclear Power Co., Ltd. (KHNP) Advanced Power Reactor 1400 (APR1400) aircraft impact assessment (AIA) conducted in San Diego, CA, on July 17-20, 2017, NRC staff identified one violation of NRC requirements with three examples. In accordance with the NRC Enforcement Policy, the violation is listed below:

A. Title 10 of the *Code of Federal Regulations* (10 CFR), Section 50.150, "Aircraft impact assessment," Paragraph (a)(1) requires that each applicant listed in 10 CFR 50.150(a)(3) shall perform a design-specific assessment of the effects on the facility of the impact of a large, commercial aircraft. Using realistic analyses, the applicant shall identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions:

   i. the reactor core remains cooled, or the containment remains intact; and

   ii. spent fuel cooling or spent fuel pool integrity is maintained.

   KHNP chose to meet 10 CFR 50.150 by showing that the reactor core remains cooled and spent fuel pool integrity is maintained.

      a. Contrary to the above, as of July 17, 2017, KHNP failed to identify and incorporate into the APR1400 design control document (DCD) those design features and functional capabilities credited in the AIA to show the reactor core remains cooled and spent fuel pool integrity is maintained.

         Specifically, the AIA relied upon the following design features and functional capabilities to show how the reactor core remains cooled. However, the DCD failed to identify or incorporate the following design features and functional capabilities:

         - ultimate heat sink;
         - cabling for the safety-related instrumentation and control in the A and B equipment rooms;
         - design and configuration of viewing areas in the A and B diesel generator control rooms;
         - design of the wall and the size of rebar used in the exterior walls of the main steam valve rooms;
         - design and configuration of the polar crane support bracers and girders; and,
         - design and configuration of auxiliary building interior and exterior walls.

         In addition, the AIA relied upon the design and configuration of the auxiliary building exterior walls to show how spent fuel pool integrity is maintained. However, the DCD does not identify or describe the design and configuration of

the auxiliary building exterior walls, which contribute to the protection of the spent fuel pool.

This is the first example of Violation 05200046/2016-202-01

b. In addition, KHNP failed to perform a design specific assessment in certain portions of the AIA. Specially, the AIA credits component cooling water to provide room cooling for systems relied upon to support core cooling (such as the motor driven auxiliary feed water pumps and safety injection pumps). However, the essential chilled water system is the system designed to provide room cooling. The essential chilled water system was not identified nor considered as a key design feature in the assessment; and, as a result, it was not analyzed in the assessment nor identified or described in the DCD. In addition, the AIA incorrectly credits the remote shutdown room for controlling core cooling equipment for a number of aircraft impact scenarios.

   This is the second example of Violation 05200046/2016-202-01.

c. Furthermore, KHNP did not use realistic analyses in certain portions of the AIA. Specifically, KHNP used a non-realistic value of concrete strength gain to analyze aircraft impacts. Specifically KHNP utilized 91-day test strength values for concrete and NEI 07-13 aging factors, but the NEI 07-13 aging factors are intended for use with 28-day test strengths. The resulted in non-realistic values for the aging strength gain of the concrete.

   This is the third example of Violation 05200046/2016-202-01.

This is a Severity Level IV Violation (Enforcement Policy, Section 6.5).

Pursuant to the provisions of 10 CFR 2.201, “Notice of Violation,” KHNP is hereby required to submit a written statement or explanation to the U.S. Nuclear Regulatory Commission, ATTN: Document Control Desk, Washington, DC 20555-0001, with a copy to the Chief, Quality Vendor Inspection Branch-1, Division of Construction Inspection and Operational Programs, Office of New Reactors, within 30 days of the date of the letter transmitting this Notice of Violation. This reply should be clearly marked as a “Reply to a Notice of Violation” and should include: (1) the reason for the violation, or, if contested, the basis for disputing the violation or severity level, (2) the corrective steps that have been taken and the results achieved, (3) the corrective steps that will be taken to avoid further violations, and (4) the date when full compliance will be achieved. Your response may reference or include previous docketed correspondence, if the correspondence adequately addresses the required response.

Where good cause is shown, the NRC will consider extending the response time. Because your response will be made available electronically for public inspection in the NRC Public Document Room or from the NRC’s Agencywide Documents Access and Management System, accessible at http://www.nrc.gov/reading-rm/adams.html, to the extent possible, it should not include any personal privacy, proprietary, or Safeguards Information so that it can be made available to the public without redaction. If personal privacy or proprietary information is necessary to provide an acceptable response, then please provide a bracketed copy of your response that identifies the information that should be protected and a redacted copy of your response that deletes such information. If you request withholding of such material, you must specifically identify the portions of your response that you seek to have withheld and provide in detail the bases for your

claim of withholding (e.g., explain why the disclosure of information will create an unwarranted invasion of personal privacy or provide the information required by 10 CFR 2.390(b) to support a request for withholding confidential commercial or financial information). If safeguards information is necessary to provide an acceptable response, please provide the level of protection described in 10 CFR 73.21, "Protection of Safeguards Information: Performance Requirements."

Dated this the 31st day of August 2017.

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NEW REACTORS
DIVISION OF CONSTRUCTION INSPECTION AND OPERATIONAL PROGRAMS
VENDOR INSPECTION REPORT

Docket No.:	05200046
Report No.:	05200046/2016-202
Inspection Location:	5435 Oberlin Dr. San Diego, CA 92121
Contact:	Dr. Kapsun Kim
Nuclear Industry Activities:	Korea Hydro and Nuclear Power Co., Ltd. (KHNP) has completed their aircraft impact assessment of the advanced power reactor 1400 (APR1400) design certification to comply with the U.S. Nuclear Regulatory Commission requirements in Title 10 of the Code of Federal Regulations Section 50.150, "Aircraft Impact Assessment."
Inspection Dates:	July 17-20, 2017
Inspectors:	Stacy Smith, Team Leader, NRO/DCIP/QVIB-1 Dennis Andrukat, NRO/DSRA/SPSB Odunayo Ayegbusi, NRO/DSRA/SPRA Ata Istar, NRO/DEI/SEB Ryan Nolan, NRO/DSRA/SPSB George Wang, NRO/DEI/SEB Dr. Alexander L. Brown, Sandia National Laboratory Dr. Chris Jones, Sandia National Laboratory Dr. Allen Ricks, Sandia National Laboratory
Approved by:	Terry W. Jackson, Chief Quality Assurance Vendor Inspection Branch-1 Division of Construction Inspection and Operational Programs Office of New Reactors

EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) conducted this inspection to verify that Korea Hydro and Nuclear Power Co., Ltd. (KHNP) had implemented the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.150, "Aircraft Impact Assessment," and performed a design-specific assessment of the effects on the facility of the impact of a large commercial aircraft.

The NRC conducted the inspection at the Structural Integrity office in San Diego, CA, on July 17-20, 2017.

The following served as the bases for the NRC inspection:

- 10 CFR 50.150

During this inspection, the NRC inspection team implemented Inspection Procedure (IP) 37804, "Aircraft Impact Assessment," dated February 9, 2012.

This inspection was performed to verify that KHNP's aircraft impact assessment (AIA) of the Advanced Power Reactor (APR1400) design complies with the requirements of 10 CFR 50.150. Revision 8 of Nuclear Energy Institute (NEI) 07-13, "Methodology for Performing Aircraft Impact Assessments for New Plant Designs," dated April 2011, has been endorsed by the NRC in Regulatory Guide (RG) 1.217, "Guidance for the Assessment of Beyond-Design-Basis Aircraft Impacts," as one means of performing an AIA acceptable to the NRC. KHNP utilized NEI 07-13, Revision 8, with no exceptions, to perform their AIA.

For the implementation of this inspection, the NRC team used Revision 1 of KHNP's design control document (DCD). The results of the inspection are summarized below.

Systems-Loss Assessment

Due to the examples of Violation 05200046/2016-202-01, the NRC inspection team could not conclude that the system's assessment performed by KHNP is consistent with the regulatory requirements of 10 CFR 50.150. Specifically, KHNP's APR1400 AIA relied upon incorrect assumptions, as described in Section 1.b.1 of this report to credit success paths for core cooling. Therefore, the NRC inspection team could not verify the conclusions of the assessment stated in Table 7-1, "Summary of Results," in Section 7.1 of the AIA, "Results for Strikes While the Plant is At-Power."

Fire Damage Assessment

The NRC inspection team concluded the fire damage assessment performed by KHNP for the APR1400 AIA is consistent with the regulatory requirements of 10 CFR 50.150.

Structural Damage Assessment

The NRC inspection team found that, with the exception of the examples of Violation 05200046/2016-202-01, the structural damage assessment performed by KHNP for the APR1400 AIA is consistent with the regulatory requirements of 10 CFR 50.150.

Documentation and Quality Assessment

The NRC inspection team concluded that with the exception of the examples of Violation 05200046/2016-202-01, documented in Sections 1.b and 3.b of this inspection report, the documentation and quality assessment performed by KHNP for the APR1400 AIA is acceptable.

REPORT DETAILS

1. Systems-Loss Assessment

   a. Inspection Scope

   The NRC inspection team reviewed the following activities for KHNP's APR1400 AIA systems-loss assessment:

   - Verification of the location of those structures, systems, and components (SSC) that provide core cooling, and spent fuel pool (SFP) integrity to determine the potential for damage by aircraft impact;
   - Verification that those SSCs would be capable of performing their intended function given the established structural, shock, and fire damage footprints and the rule sets and assumptions provided in NEI 07-13;
   - Verification that KHNP addressed accident initiators, such as a breach of the reactor coolant system (RCS) or the failure of the reactor to trip, that could result from damage caused by an aircraft impact; and
   - Verification that success paths for core cooling exist.

   Specifically, the NRC inspection team reviewed the following documents:

   - APR1400-E-P-NR-14002-P-SGI, "Aircraft Impact Assessment Report Volume II: Heat Removal," Revision 1, April 2017,
   - APR1400-E-P-NR-14001-P, "Probabilistic Risk Assessment Summary Report," Revision 0, January 2015, and
   - ARP1400-K-X-FS-14002-NP, "APR1400 Design Control Document Tier 2," Revision 1, March 2017.

   b. Observations and Findings

   b.1 Determination of the location of credited SSCs

   The NRC inspection team reviewed KHNP's selection of SSCs needed to prevent fuel damage in the core and maintain SFP integrity, and the documented spatial configuration of those SSCs. SSCs needed to maintain containment intact and to provide for SFP cooling were not reviewed because KHNP indicated that its objective in adding key design features to address the AIA rule was to maintain core cooling and SFP integrity.

   The NRC inspection team compared the descriptions of SSCs in the AIA to those in the APR1400 DCD and probabilistic risk analysis (PRA) and reviewed whether the scope of SSCs treated in the assessment was complete and consistent with those needed to satisfy the core cooling success criteria in the PRA. The inspection team used equipment location data and drawings in Section 9.5A, "Fire Hazard Analysis,"

of the DCD and the general arrangement drawings to confirm that the locations of equipment documented in the AIA were accurate.

During the review, the NRC inspection team identified features credited in the AIA to keep the core cooled that were not identified or incorporated into the DCD. Specifically, the APR1400 AIA identified that the size of the viewing areas in the A and B diesel generator (EDG) control rooms in Figure 1.2-21, "General Arrangement EDG Building El 100'-0" and El. 121'-6"," of DCD Revision 0, was inadequate to stop physical damage of an aircraft on analyzed Strikes 8 and 12. To stop physical damage, KHNP made a design change to limit the size of this opening to a specific square footage. As a result of the design change KHNP updated Figure 1.2-21, "General Arrangement EDG Building El 100'-0" and El 121'-6"," of DCD Revision 1, to depict smaller viewing areas. However, KHNP failed to identify a specific dimension of the viewing areas that would ensure the viewing panel square footage key assumption in the assessment is not exceeded. The NRC inspection team also noted the APR1400 AIA relies on the ultimate heat sink for transferring decay heat to the atmosphere and for the protection of cabling for the safety-related instrumentation and control in the A and B equipment rooms. However, the DCD failed to identify and incorporate these two design features. These three deficiencies are instances of the first example of Violation 05200046/2016-202-01, in which KHNP failed to identify and incorporate into the APR1400 DCD those design features and functional capabilities credited in the AIA to show the reactor core remains cooled.

The NRC inspection team also observed that the APR1400 AIA incorrectly credits component cooling water to provide room cooling for systems relied upon to support core cooling (such as the motor driven auxiliary feed water pumps and safety injection pumps). Although, the APR1400 DCD correctly identifies the essential chilled water system as the system designed to provide room cooling; the essential chilled water system was not identified or considered as a key design feature in the assessment. As a result, it was not analyzed in the assessment or described as a key design feature in the APR1400 DCD. Therefore, the NRC inspection team could not verify the conclusions of the assessment stated in Table 7-1, "Summary of Results," in Section 7.1 of the AIA, "Results for Strikes While the Plant is At-Power." In addition, the APR1400 AIA incorrectly credits the remote shutdown room for controlling core cooling equipment for a number of aircraft impact scenarios. These two deficiencies are instances of the second example of Violation 05200046/2016-202-01, in which KHNP failed to perform a design-specific assessment in certain parts of the APR1400 AIA.

b.2 Determination of the state of SSCs in the aircraft impact scenarios

The NRC inspection team reviewed the APR1400 AIA to determine whether KHNP correctly applied the rules and assumptions given in NEI 07-13 for the loss of SSCs. Specifically, the team selected a sample of SSCs that KHNP identified as remaining functional in one or more scenarios. Then, the team verified that the basis used to conclude that these SSCs will survive the conditions created by an aircraft impact are consistent with the rules and assumptions given in NEI 07-13.

The NRC inspection team reviewed those portions of KHNP's AIA that discussed the approach used for identifying which SSCs will remain capable of performing their

intended function following an aircraft impact. The inspection team determined that KHNP considered the potential effect of structural, shock, or fire damage on core cooling equipment.

b.3 Determination of accident conditions

The NRC inspection team verified that KHNP used appropriate assumptions and scenarios to determine accident conditions. These assumptions were consistent with NEI 07-13 and include:

- KHNP's success criteria and the scenario analysis that addresses initial plant states of 100 percent power and cold shutdown;
- The analysis takes no credit for the availability of offsite power;
- The assumption, as part of its shutdown cooling scenarios, that the reactor vessel is vented, and the water level is at or near the reactor vessel head flange;
- The consideration of the possibility of an anticipated transient without scram (ATWS); and
- KHNP has considered the influence of containment status on the operability of other equipment.

Specifically, the NRC inspection team reviewed KHNP's treatment of the following potential accident conditions:

LOCA inside containment

The NRC inspection team reviewed KHNP's assessment of a loss of coolant accident (LOCA) inside the containment to determine if the containment adequately protects the reactor coolant system such that it could not be impacted by an aircraft. The NRC inspection team determined that the assessment adequately demonstrated that neither shock damage to the containment nor structural damage inside the containment would occur and, as such, verified that a LOCA inside the containment will not occur.

LOCA outside containment

The NRC inspection team reviewed KHNP's assessment of a LOCA outside containment to determine if piping outside of primary containment that is connected to the reactor coolant pressure boundary, above grade level, is protected from structural damage. The inspection team used plan and elevation drawings of the auxiliary building to confirm that KHNP's assessment effectively determined that the applicable piping was adequately protected from structural damage.

ATWS

The NRC inspection team reviewed the APR1400 AIA to determine if KHNP adequately assessed the potential for any damage scenarios that could affect the ability to trip the reactor. The NRC inspection team verified that an ATWS was not a viable outcome from an aircraft impact because the equipment necessary to maintain the reactor shutdown is outside the damage footprint areas.

Flooding

The NRC inspection team reviewed the APR1400 AIA to determine if KHNP adequately assessed the potential for flooding from a large water source as described in NEI 07-13. The assessment stated the DCD layouts indicated there are no open loop cooling systems in the physical damage impact zones. Therefore, expansion of the damage footprints due to flooding is not required. The NRC inspection team verified that any potential large water source was either not vulnerable or was bounded by the internal flooding analysis.

Loss of Decay Heat Removal – Shutdown

The NRC inspection team reviewed the APR1400 AIA to determine if KHNP adequately assessed the potential for a loss of decay heat removal event when the reactor is shutdown. The NRC inspection team reviewed the assumptions used in the analysis and verified that they were consistent with guidance in NEI 07-13. Specifically, the reactor vessel is vented, and water level is at or near the reactor vessel head flange. The NRC inspection team noted the DCD has administrative controls to ensure that, for shutdown conditions, no trains of the safety injection and shutdown cooling system and necessary support systems are out of service when the reactor vessel head is removed and the reactor vessel water level is at or near the reactor vessel head flange. This ensures that adequate water for core cooling is available for at least 24 hours.

b.4 Identification of Success Paths

The NRC inspection team reviewed the APR1400 AIA to determine if KHNP had a success path for core cooling. The inspection team reviewed the PRA Summary Report (Report No. APR1400-E-P-NR-14001-P, Revision 0), which serves as the basis for information documented in Chapter 19 of the DCD, and verified the normal decay heat removal methods identified by KHNP are shown as success paths for avoiding core damage.

c. Conclusions

Due to the examples of Violation 05200046/2016-202-01, the NRC inspection team could not conclude that the system's assessment performed by KHNP is consistent with the regulatory requirements of 10 CFR 50.150. Specifically, KHNP's APR1400 AIA relied upon incorrect assumptions, as described in Section 1.b.1 of this report to credit success paths for core cooling. Therefore, the NRC inspection team could not verify the conclusions of the assessment stated in Table 7-1, "Summary of Results," in Section 7.1 of the AIA, "Results for Strikes While the Plant is At-Power."

2. Fire Damage Assessment

a. Inspection Scope

The NRC inspection team conducted the following fire damage assessment inspection activities:

- Verification that the fire damage assessment identifies and incorporates the necessary design features and functional capabilities;
- Verification that the fire damage assessment is realistic and design-specific;
- Verification that damage footprints include the effects from the spread of fire damage through existing connected compartments and through new compartment connections due to overpressure; and
- Verification of the SSCs determined to be damaged and no longer credited.

Specifically, the NRC inspection team reviewed the following documents:

- Jensen Hughes Report, "Aircraft Impact Assessment - Volume II: Heat Removal", APR1400-E-P-NR-14002-P-SGI, Revision 1; and
- APR1400 DCD Quadrant Color Code (tool aid showing safety divisions).

b. Observations and Findings

b.1 Damage Footprint Assessment

The APR1400 AIA evaluated a total of 133 impact scenarios throughout the reactor building in accordance with NEI 07-13, Revision 8. The NRC inspection team reviewed a sample of nine impact scenarios out of the 133 impact scenarios that KHNP evaluated, including: 7, 46, 51, 58, 65, 70, 73, 88, 90, 92, and 102. These scenarios included one or more of the following criteria: large fire damage footprints, fire damage footprints resulting in damage to two or more safety quadrants/trains, fire damage footprints in between the main control room and core cooling equipment, and fire damage footprints with impact strikes to floors elevations 100', 120', 137', 156', and 174'. The NRC inspection team reviewed the fire damage assessment contained in the Jensen-Hughes report, "Aircraft Impact Assessment - Volume II: Heat Removal", APR1400-E-P-NR-14002-P-SGI, Revision 1. The NRC inspection team verified the developed fire damage footprints developed by KHNP were consistent with the rules and assumptions given in NEI 07-13, Revision 8. The team also verified that the key design features used in the assessment for these impact scenarios were consistent with those features credited in KHNP's APR1400 DCD.

b.2 Fire Damage Effects on SSCs

The NRC inspection team reviewed a sample of fire damage footprints to determine if KHNP properly identified all SSCs within the footprints. The NRC inspection team verified that the KHNP properly identified the SSCs within the fire damage footprint

and correctly considered the identified SSCs as failing within five minutes of the start of the fire consistent with the guidance provided in NEI 07-13, Revision 8. Further review of damage to the SSCs was conducted and documented as part of the systems-loss assessment.

c. Conclusions

The NRC inspection team concluded the fire damage assessment performed by KHNP for the APR1400 AIA is consistent with the regulatory requirements of 10 CFR 50.150.

3. Structural Damage Assessment

a. Inspection Scope

The NRC inspection team verified the following elements of the structural damage assessment:

- Adequacy of information found in plant documentation including plant arrangement drawings displaying locations of major equipment and plant elevation drawings documenting the relative heights of various buildings;
- Civil-structural drawings that provide wall thicknesses, reinforcement details, and material specifications;
- General structural analysis considerations such as design inputs, analysis parameters and assumptions, computer codes, methods used for structural analyses and results to evaluate whether KHNP adequately analyzed the effects of, and damage to structures resulting from, global and local aircraft impact loads;
- SFP impact analyses to evaluate whether KHNP addressed the criteria in Section 2.5 of NEI 07-13; and
- Structural damage footprint assessments to evaluate whether KHNP adequately assessed the containment and other reinforced concrete buildings containing essential SSCs for maintaining reactor core cooling using the damage rule sets in Section 3.3 of NEI 07-13.

b. Observations and Findings

b.1 Structural Assessment Document Review

The NRC inspection team reviewed KHNP's structural assessment design inputs, including plant arrangement drawings, plant elevation drawings, civil-structural drawings, and material specifications. The inspection team verified the plant arrangement drawings display the locations of major equipment (e.g., trolley), and the plant elevation drawings identified the relative heights of various buildings.

The NRC inspection team found that KHNP failed to identify some key design features and functional capabilities in the DCD that were credited in the assessment. These include the following:

- Design of the wall and the size of rebar used in the exterior walls of the main steam valve rooms;
- Design and configuration of the polar crane support bracers and girders;
- Design and configuration of auxiliary building interior and exterior walls; and
- Vertical reinforcing bars in the wall of the main steam valve rooms.

These deficiencies are additional instances of the first example of Violation 05200046/2016-202-01, because KHNP failed to identify and incorporate into the DCD those design features and functional capabilities credited in the APR1400 AIA to show the reactor core remains cooled and SFP is integrity maintained.

b.2 General Structural Analysis

KHNP's APR1400 AIA evaluated 16 structural analysis cases in accordance with NEI 07-13, Revision 8. Analyses performed for the SFP and Reactor Containment Building (RCB) predicted that the SFP liner would remain intact and that the RCB would not be perforated. The NRC inspection team reviewed a sample of structural analysis cases.

The NRC inspection team verified that KHNP used appropriate design inputs including the structural analysis parameters and assumptions, type of finite elements used in each analysis, material models considered, boundary conditions and extent of model, initial conditions, and time duration of the analysis. In addition, the NRC inspection team verified that KHNP adequately documented and justified the structural design input for a sampling of analysis and adequately analyzed the effects of, and damage to structures resulting from, local and global loading arising from an aircraft impact.

The NRC inspection team verified that KHNP properly modeled the reinforcing bars as sub-elements embedded within the concrete elements at the appropriate locations and steel liners in the SFP as plate bending elements attached to the surface of the adjacent concrete elements.

The NRC inspection team verified that all potential aircraft impact scenarios were considered in the structural analyses. The NRC inspection team reviewed a sample of the structural damage impact scenario analyses and verified that KHNP properly applied the NRC-supplied forcing function and missile-target interaction to the appropriate structural damage impact scenarios. In addition, the NRC inspection team reviewed the assumptions used in the structural damage analyses and verified that KHNP adequately documented the technical basis in the APR1400 AIA for the assumptions used in the analyses.

The NRC inspection team reviewed a sample of structural damage analyses and verified that KHNP used the correct failure criteria. As part of the review, the NRC inspection team reviewed the various material properties used in the structural analyses, and found that KHNP failed to perform realistic analyses by incorrectly applying NEI 07-13 aging factors described in Section 2.3.1, "Material Properties." Specifically, the concrete aging factors are intended for use with a 28 day test strength; however, KHNP provided an incompatible value from 91 day test-based average compressive strength. In addition, if KHNP used the 28 day test-based average compressive strength with the aging factor as described in NEI-07-13, the resulting aged compressive strength would be less than the aged compressive strength used in KHNP's APR1400 AIA. This situation resulted in non-realistic values for the aging strength gain of the concrete.

This deficiency is the third example of Violation 05200046/2016-202-01 in which KHNP failed to use realistic analyses in certain portions of the APR1400 AIA.

b.3 Containment Structure and SFP Specific Impact Assessment

The NRC inspection team reviewed the containment and SFP impact analyses to evaluate whether KHNP met the sufficiency criteria in NEI 07-13, Section 2.5.

The NRC inspection team reviewed the structural damage assessment as it relates to local loading on the containment and SFP structure and verified that KHNP conducted the following activities in accordance with NEI 07-13, Section 2.1:

- Documented and cross-checked the aircraft engine parameters used in the analysis against NRC-specified parameters;
- Properly applied the various local loading formulas referenced in NEI 07-13, Subsection 2.1.2, to arrive at the degree of local damage and the wall thickness required to prevent perforation of the target; and
- Used the formulas cited in NEI 07-13 and approved by the NRC.

The NRC inspection team reviewed the structural damage assessment as it relates to global loading effects on the containment and SFP structure. The inspection team verified that the following activities were conducted in accordance with NEI 07-13, Section 2.2:

- Documentation and use of the application of the force time-history analysis method and cross-checking it for its equivalency to the NRC-specified force time-history;
- Documentation of the application of the missile-target interaction analysis method and cross-checking it for its equivalency to the NRC-specified force-time history;
- The missile-target interaction analysis method reasonably captured the mass distribution of the missile when a "reverse-engineering" approach was used to determine the missile-target interaction from the force-time history; and

- For the application of the force time-history analysis method, KHNP properly used and adequately documented the NRC-specified spatial distribution of the impact force in the analyses.

The NRC inspection team reviewed a sample of documents for material characterization and failure criteria related to the structural damage assessment and verified that the following analysis activities were conducted in accordance with NEI 07-13, Section 2.3:

- Application of the ANACAP-U concrete constitutive model consisting of material properties and the equations used to model the nonlinear behavior of both steel and reinforced concrete materials in the analyses. The model parameters used are adequately documented and consistent with the material properties and equations documented in NEI 07-13, Section 2.3;

- Application of the ductile failure strain limits specified in NEI 07-13, Subsection 2.3.2, for the various materials used in the analyses;

- The concrete structural failure criteria used in the analyses are appropriately documented and consistent with the criteria specified in NEI 07-13, Subsection 2.3.3;

- Application and documentation of the material models specified in NEI 07-13, Subsection 2.3.4; and

- Application and documentation of the structural integrity failure criteria specified in NEI 07-13, Subsection 2.3.5.

The NRC inspection team reviewed the major assumptions applied to the containment and SFP related structural analyses and verified that the following activities were conducted in accordance with NEI 07-13, Section 2.4:

- Missile-target interaction analysis model properly assumed that the aircraft impact was perpendicular to the centerline of the containment;

- Missile-target interaction analysis model properly assumed takeoff weight such that the missile-target interaction model is equivalent to the NRC-specified force time-history;

- Containment regions containing critical penetrations received an appropriate level of special consideration;

- SFP analyses properly assumed that both the engine and the aircraft fuselage strike were perpendicular to and at the mid-point of the SFP wall;

- Assessment of potential aircraft impact at other locations that could result in greater consequences; and

- No credit was taken for SFP water inventory in its SFP analyses.

The NRC inspection team reviewed the SFP related structural analyses and verified KHNP's conclusion, that the damage imparted to the SFP wall would not result in leakage of the SFP water. Thus the integrity of the SFP is maintained, consistent with the sufficiency criteria of NEI 07-13, Subsection 2.5.2.

b.4 Structural damage footprint assessment

The APR1400 AIA evaluated a total of 133 different impact scenarios in accordance with NEI 07-13, Revision 8. The NRC inspection team reviewed a sample of impact scenarios, including scenarios 29, 30, 53, 54, 63, 65, 73, 77, 78, and 90.

The NRC inspection team reviewed the structural damage footprint analyses to evaluate whether or not the following items of interest related to the damage rule sets identified in NEI 07-13, Chapter 3, "Heat Removal Capability," have been met.

- Structures of concern that contain SSCs have been identified.
- A systematic evaluation of susceptible damage was conducted and adequately documented.
- Assumptions used to determine elevations of concern have been addressed and adequately documented.
- Each external face of each building exposed to a direct hit has been divided into two categories, containment structures and other reinforced concrete buildings, and each external face has been analyzed and adequately documented.

The NRC inspection team verified that the structural damage rule sets for containment structures were appropriately assessed consistent with the guidance in NEI 07-13, Subsection 3.3.1. In addition, the NRC inspection team verified that the structural damage rule sets for reinforced concrete buildings were appropriately assessed consistent with the guidance in NEI 07-13, Subsection 3.3.2. The NRC inspection team verified that the following activities were conducted in the analyses:

- Various impact points have been investigated and documented in order to define the damage footprint;
- Structural damage rule sets regarding perforations were appropriately developed;
- Shock damage was evaluated in the structural damage footprints and these evaluations have been adequately documented;
- The guidance in NEI 07-13, Table 3-3, was used to define the shock damage footprints and was adequately documented; and

- Shock effects impacting seismic separation between buildings has been adequately assessed and documented.

c. Conclusions

The NRC inspection team found that, with the exception of the two examples of Violation 05200046/2016-202-01, the structural damage assessment performed by KHNP for the AIA is consistent with the regulatory requirements of 10 CFR 50.150.

4. AIA Documentation and Quality Assessment

a. Inspection Scope

The NRC inspection team verified the following activities for KHNP APR1400 AIA quality assurance assessment:

- KHNP adequately documented the assessment in a quality manner consistent with NEI 07-13, Section 5.1; and

- KHNP adequately established standards and measures to establish the validity of the assessment and supporting calculations.

b. Observations and Findings

The NRC inspection team reviewed TeraGrande, a software used for final analyses implementing the ANACAP-U concrete material constitutive modeling software. The NRC inspection team verified that KHNP had validated and benchmarked the codes for the applications assessed, consistent with Appendix C of NEI 07-13, and KHNP had adequately documented the validation.

The NRC inspection team noted that KHNP did not perform a sensitivity study of mesh refinement in any APR1400 AIA finite element analyses. Since the accuracy obtained from finite element analysis results is related to the finite element mesh that is used, the NRC inspection team considers mesh refinement a generally accepted practice for this application. NEI 07-13 states that, the analytical methodologies used in the assessment should be adequately described, including adequacy of the geometric characterization (i.e. mesh). Although KHNP did not perform a sensitivity study of mesh refinement, the NRC inspection team performed a qualitative review of the analyses results and did not identify any conditions where a different or more refined mesh might lead to results that could affect the APR1400 AIA conclusions. The NRC inspection team determined that KHNP performed a realistic analysis as described in the final AIA rule (see 74 FR 28130; June 12, 2009).

c. Conclusions

The NRC inspection team concluded that with the exception of the examples of Violation 05200046/2016-202-01, documented in Sections 1.b and 3.b of this inspection report, the documentation and quality assessment performed by KHNP for the APR1400 AIA is acceptable.

5. Entrance and Exit Meetings

On July 17, 2017, the NRC inspection team discussed the scope of the inspection with representatives from KHNP. On July 20, 2017, the NRC inspection team presented the inspection results and observations during an exit meeting with representatives from KHNP.

ATTACHMENT

1. PERSONS CONTACTED

Name	Affiliation	Entrance	Exit	Interviewed
Stacy Smith	NRC	X	X	
Ryan Nolan	NRC	X	X	
Dennis Andrukat	NRC	X	X	
George Wang	NRC	X	X	
Ata Istar	NRC	X	X	
Odunayo Ayegbusi	NRC	X	X	
Dr. Alex Brown	SNL			
Dr. Christopher Jones	SNL	X		
Dr. Allen Ricks	SNL	X	X	
Paul Krohn	NRC		X	
Randy James	ANATECH/SI	X	X	X
Gary Hayner	Jensen Hughes	X	X	X
Dr. Kapsun Kim	KHNP	X	X	X
Jimkyoo Yoon	KEPCO	X	X	X
Idhwan Moon	KEPCO	X	X	X
Changsun Park	KEPCO	X	X	X
Stephen Floyd	Jensen Hughes	X	X	X
Daejoong Kim	KEPCO	X	X	X
Y. Kim	KEPCO	X	X	X
Woon Keongho	KEPCO	X	X	X
K. Sunghynn	KEPCO	X	X	X
Dan Parker	Structural Integrity	X	X	X
Andy Oh	KHNP	X	X	X

2. Inspection Procedures Used

Inspection Procedure 37804, “Aircraft Impact Assessment,” dated February 9, 2012.

3. List of Items Opened, Closed, and Discussed

Item Number	Status	Type	Description
05200046/2016-202-01	Open	NOV	10 CFR 50.150(a)(1)

4. Documents Reviewed

Documentation and Quality Assessment and Systems-Loss Assessment

- APR1400-E-P-NR-14002-P-SGI, “Aircraft Impact Assessment Report Volume II: Heat Removal,” Revision 1, April 2017
- APR1400-E-P-NR-14001-P, “Probabilistic Risk Assessment Summary Report,” Revision 0, January 2015,
- ARP1400-K-X-FS-14002-NP, “APR1400 Design Control Document Tier 2,” Revision 1, March 2017.

Fire Damage Assessment

- APR1400-E-P-NR-14002-P-SGI, "Aircraft Impact Assessment Report Volume II: Heat Removal", Revision 1, April 2017
- APR1400 Design Control Document, Revision 1, March 2017
- APR1400 DCD Quadrant Color Code (tool aid showing safety divisions).

Structural Damage Assessment

- APR1400-E-P-NR-14002-P-SGI, Aircraft Impact Assessment Report, Volume 1: “Structural Report Analysis,” Revision 1, February 2017, KOREA ELECTRIC POWER CORPORATION & KOREA HYDRO & NUCLEAR POWER CO., LTD.
- APR1400-E-P-NR-14002-P-SGI, Aircraft Impact Assessment Report, Volume 2: Heat Removal, Revision 1, February 2017, KOREA ELECTRIC POWER CORPORATION & KOREA HYDRO & NUCLEAR POWER CO., LTD.
- Design Control Document (DCD) Tiers 1 and 2, revision 1.
- Drawings Reviewed:
    - Drawing No. 1-324-P186-001, Revision 3, “General Arrange Auxiliary Building EL: 120’-0”
    - Drawing No. 1-325-P186-001, Revision 3, “General Arrange Auxiliary Building EL: 137’-6”
    - Drawing No. 1-326-P186-001, Revision 3, “General Arrange Auxiliary Building EL: 156’-0”
    - Drawing No. 1-327-P186-001, Revision 3, “General Arrange Auxiliary Building EL: 174’-0”
    - Drawing No. M248-DG-A01-02, “Containment Polar Crane”
- DCD Tier 2, Figure 1.2-16, “General Arrange AB EL:137’-6”

5. ACRONYMS USED:

APR1400	advanced power reactor 1400
ADAMS	Agencywide Documents Access and Management System
AIA	aircraft impact assessment
ATWS	anticipated transient without scram
CFR	*Code of Federal Regulations*
DCD	design control document
DCIP	Division of Construction Inspection and Operational Programs
HELB	high energy line break
HVAC	heating, ventilation, and air conditioning
IP	inspection procedure
KHNP	Korea Hydro and Nuclear Power Co., Ltd
LOCA	loss of coolant accident
NEI	Nuclear Energy Institute
NRC	(U.S.) Nuclear Regulatory Commission
NRO	Office of New Reactors
PRA	probabilistic risk analysis
PSID	pounds per square inch differential
QVIB	Quality Assurance Vendor Inspection Branch
RCB	reactor containment building
RCS	reactor coolant system
RG	regulatory guide
SGI	safeguards information
SFP	spent fuel pool
SSC	systems, structures, and components
U.S.	United States (of America)