U.S.NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

U.S. NRC Regulatory Perspective on Aircraft Impact Assessments

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Purpose

Present a summary of the U.S. NRC assessments being conducted for the new reactor designs under 10 CFR 50.150, “Aircraft Impact Assessment” (AIA)

Overview

- Background on NRC AIA regulation and guidance
- Summary of industry guidance (NEI 07-13)
- NRC inspection procedure
- Experience with Design Certification applicants

Assessment of Existing and New Reactors

- Immediately after 9/11/01, NRC evaluated representative existing reactors for aircraft impact utilizing National Labs (2001-2004)
- Regulatory requirements for aircraft impact mitigation were imposed on existing reactors via NRC Orders
- Spent Fuel Pools were evaluated; Interfaced with NAS (2005-2007)
- NRC in-house preliminary evaluations of new reactor designs (AP1000, ABWR, ESBWR, EPR, and APWR) utilizing RES staff (2006-2008)

Assessment of Existing and New Reactors

- NRC amended its regulation to codify NRC Orders to mitigate the effects of losses of large areas of the plant to fires or explosions (10 CFR 50.54(hh)) (2009)
  - **ALL** reactors
  - mitigation strategies

- NRC amended its regulation to require applicants for new nuclear power reactors to perform an assessment of the effects of the impact of a large, commercial aircraft (10 CFR 50.150) (2009)
  - **NEW** reactor designs only
  - design features and functional capabilities

AIA Regulation

10 CFR 50.150 "Aircraft Impact Assessment"

- Published June 2009
- AIA rule applies to new reactor applicants after July 13, 2009*
- Impact of a large, commercial aircraft is a beyond-design-basis event
- Use realistic analyses
- Both safety-related and nonsafety-related features can be relied upon
- Reduced use of operator action is a goal

*[74 FR 28146, June 12, 2009]

AIA Regulation

10 CFR 50.150(a) "Aircraft Impact Assessment"

Identify and incorporate into the design those features and functional capabilities to show that:

- the reactor core remains cooled OR
  the containment remains intact

AND

- Spent fuel pool cooling OR
  spent fuel pool integrity is maintained

AIA Regulation

10 CFR 50.150(b) "Content of application"

This section discusses the what must be documented in the DCD

- Must identify & describe the credited key design features and functional capabilities from the assessment

- Must describe how each key design feature and functional capability meets the rule
  - What is its role(s)
  - Which acceptance criterion/criteria is applicable

AIA Regulation

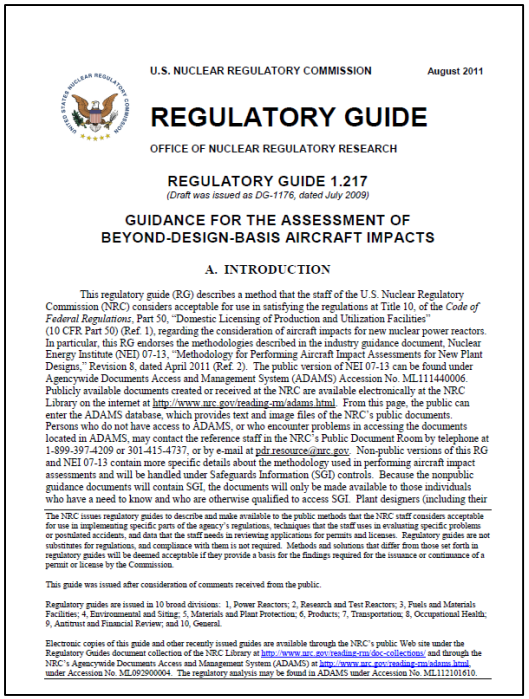
10 CFR 50.150(c) "Control of Changes"

This section discusses the change control process required for key design features credited to meet 10 CFR 50.150.

- Any plant design change evaluated against the AIA
- Change must not invalidate the AIA

NRC Regulatory Guidance

Regulatory Guide 1.217



U.S. NUCLEAR REGULATORY COMMISSION August 2011

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 1.217

(Draft was issued as DG-1176, dated July 2009)

GUIDANCE FOR THE ASSESSMENT OF BEYOND-DESIGN-BASIS AIRCRAFT IMPACTS

A. INTRODUCTION

This regulatory guide (RG) describes a method that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in satisfying the regulations at Title 10, of the *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities" (10 CFR Part 50) (Ref. 1), regarding the consideration of aircraft impacts for new nuclear power reactors. In particular, this RG endorses the methodologies described in the industry guidance document, Nuclear Energy Institute (NEI) 07-13, "Methodology for Performing Aircraft Impact Assessments for New Plant Designs," Revision 8, dated April 2011 (Ref. 2). The public version of NEI 07-13 can be found under Agencywide Documents Access and Management System (ADAMS) Accession No. ML111440006. Publicly available documents created or received at the NRC are available electronically at the NRC Library on the internet at http://www.nrc.gov/reading-rm/adams.html. From this page, the public can enter the ADAMS database, which provides text and image files of the NRC's public documents. Persons who do not have access to ADAMS, or who encounter problems in accessing the documents located in ADAMS, may contact the reference staff in the NRC's Public Document Room by telephone at 1-899-397-4209 or 301-415-4737, or by e-mail at pdr.resource@nrc.gov. Non-public versions of this RG and NEI 07-13 contain more specific details about the methodology used in performing aircraft impact assessments and will be handled under Safeguards Information (SGI) controls. Because the nonpublic guidance documents will contain SGI, the documents will only be made available to those individuals who have a need to know and who are otherwise qualified to access SGI. Plant designers (including their

The NRC issues regulatory guides to describe and make available to the public methods that the NRC staff considers acceptable for use in implementing specific parts of the agency's regulations, techniques that the staff uses in evaluating specific problems or postulated accidents, and data that the staff needs in reviewing applications for permits and licenses. Regulatory guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions that differ from those set forth in regulatory guides will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

This guide was issued after consideration of comments received from the public.

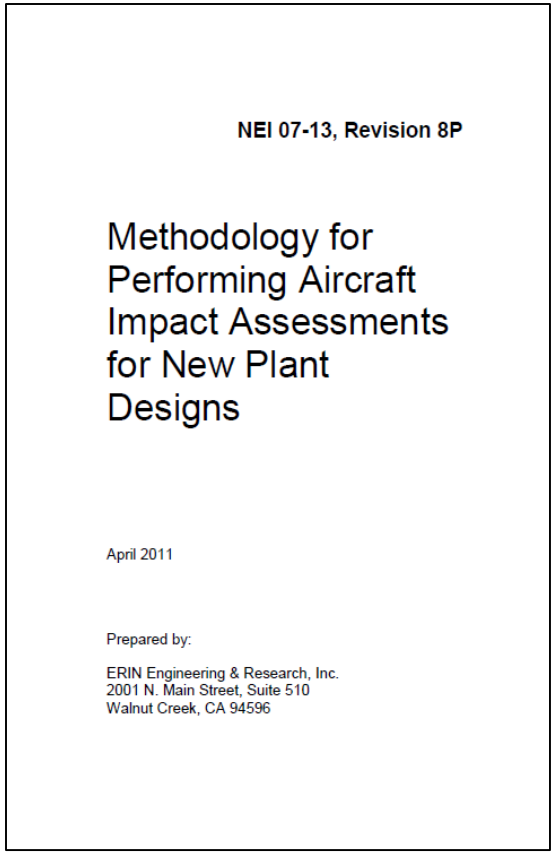
Regulatory guides are issued in 10 broad divisions: 1, Power Reactors; 2, Research and Test Reactors; 3, Fuels and Materials Facilities; 4, Environmental and Siting; 5, Materials and Plant Protection; 6, Products; 7, Transportation; 8, Occupational Health; 9, Antitrust and Financial Review; and 10, General.

Electronic copies of this guide and other recently issued guides are available through the NRC's public Web site under the Regulatory Guides document collection of the NRC Library at http://www.nrc.gov/reading-rm/doc-collections/ and through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html, under Accession No. ML092900004. The regulatory analysis may be found in ADAMS under Accession No. ML112101610.

- Issued August 2011
- Endorses NEI 07-13, "*Methodology for Performing Aircraft Impact Assessments for New Plant Designs*" which was developed by NEI and reviewed by the NRC staff
- Considered insights gained from NRC and industry assessments of operating and new reactor designs
- Provides an acceptable, reasonably formulated methodology to assess the effects of a large, commercial aircraft impact on new reactor designs

Industry Guidance

NEI 07-13, Revision 8


NEI 07-13, Revision 8P

Methodology for Performing Aircraft Impact Assessments for New Plant Designs

April 2011

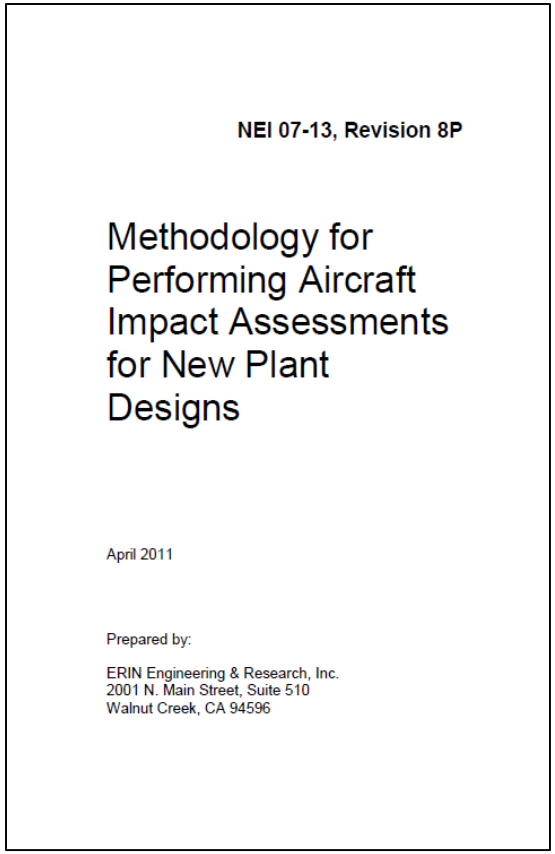
Prepared by:

ERIN Engineering & Research, Inc.
2001 N. Main Street, Suite 510
Walnut Creek, CA 94596

- Issued April 2011
- Methodology divided into three parts:
  - Containment and spent fuel pool evaluation
  - Heat removal evaluation
  - Design enhancements
- Sources of conservatism
  - Centerline containment strikes
  - Normal impact with maximum force
  - No credit for large equipment in limiting damage

Industry Guidance

NEI 07-13, Revision 8



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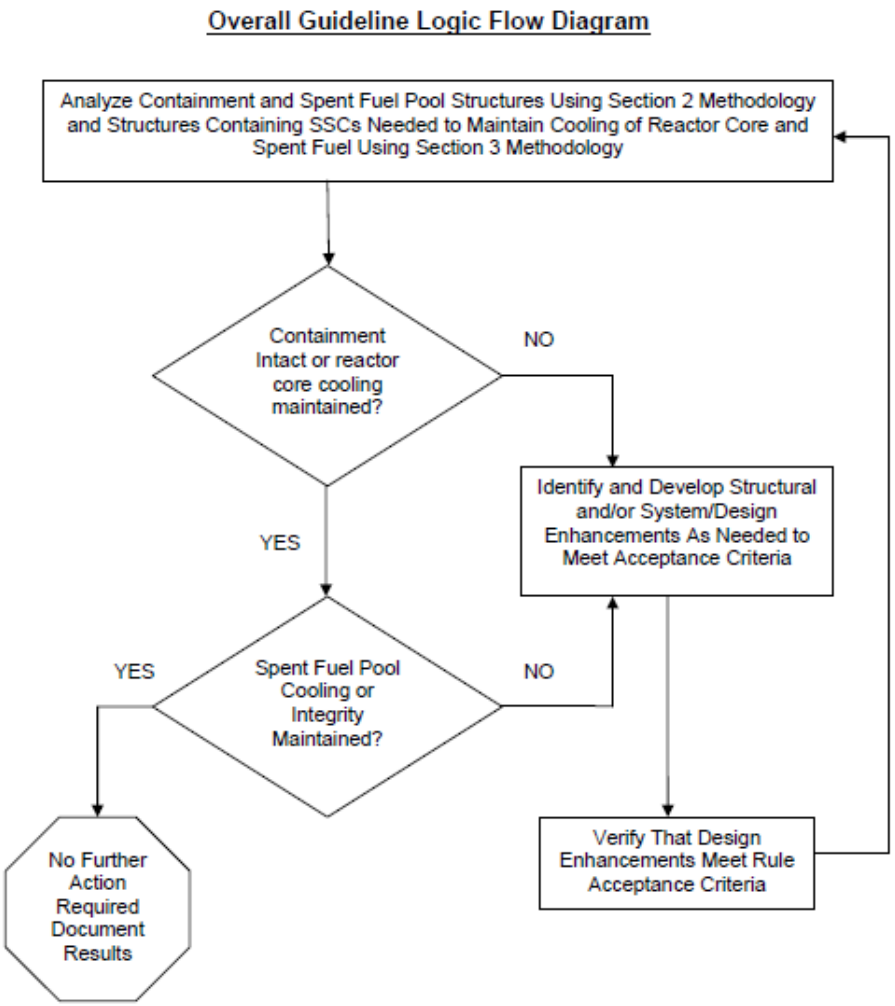
- Uncertainties
  - Definition of threat and load-time function
  - Fire-induced spurious actuation
  - 10 CFR 50.54(hh)(2), “Loss of Large Areas” of the plant due to fire or explosion provide a measure of defense-in-depth

AIA Methodology

- Methodology in NEI 07-13 is a combination of analysis and rule sets
  - Structural analysis for assessing containment & spent fuel pool integrity (local and global effects)
  - Rule sets for assessing fire and shock effects
  - Rule sets for assessing physical damage to buildings other than containment and spent fuel pool structures
  - Use of finite element analysis where rule sets do not apply
  - Based upon experiments, analysis reports, and expert judgement

AIA Analysis Process



Local Structural Assessment

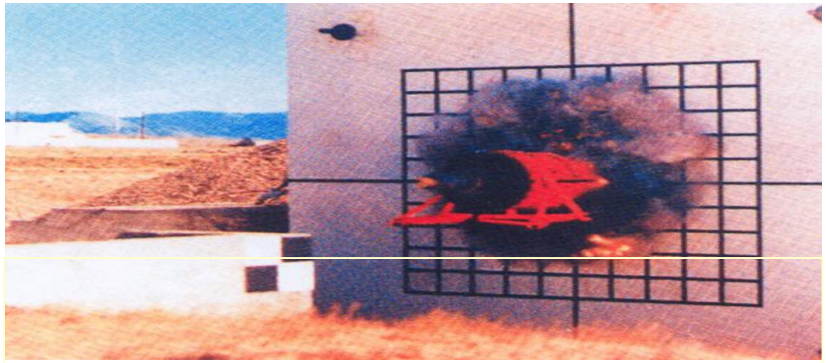
Three potential stages of local loading

- Missile penetration into the target (depth of entry of the missile into the target) – NRDC Empirical Formula
- Spalling and scabbing of the target (ejection of target material from the target front face – spalling and from the back face – scabbing) – Reduced Chang Empirical Formula
- Missile perforation through the target
  - Missile fully penetrates the target
  - Perforation velocity is the missile velocity just sufficient to fully penetrate without exiting
  - Residual velocity is the exit velocity of a missile with initial velocity greater than perforation velocity – CEA-EDF Empirical Formula
  - Prevention of perforation – Reduced Degen Empirical Formula

AIA Experiments

Riera Function Tests

- **Engine Tests**
  - **GE-J79 engine**
  - **481 mph (705 ft/s)**
  - **2’ – 5.25’ thick targets**



- **F-4 Test**
  - **8’ diameter**
  - **481 mph (705 ft/s)**
  - **12’ thick target**

See ADAMS Accession No. ML112690136 for more publically-available information

AIA Experiments

Water Slug (WS) Tests

Note: WS tests were NOT intended to simulate actual missiles or targets

- Tests demonstrated damage potential of “soft” missile
- Tests provided some insight regarding fluid dispersal issues
- Used to benchmark codes

Global Structural Assessment

Two Alternative Analysis Methods

- Force Time-History Analysis Method
  - Riera Function: Impact force time-history is determined from aircraft mass distribution, crushing strength information and impulse conservation principles, assuming that the target is rigid
  - Provides force time-history with specific characteristics
  - Prescribed to designers by USNRC (SGI information)
- Missile-Target Interaction Analysis Method
  - Combined dynamic analysis model of both missile and target
  - Requires demonstration that:
    - Integrated force-time history (impulse) matches or exceeds prescribed Riera function impulse
    - Rigid wall impact reproduces characteristics of prescribed Riera function characteristics (response filtered at 50 to 100 Hz)

Material Characterization and Failure Criteria

Technical Support and Details Provided in NEI 07-13, Appendix B

Material Strength Properties Take Into Account:

- Strain rate effects
- Dynamic increase factors
- Concrete aging strength increase

Material Failure Criteria

- Cast and Stainless Steel plate strain limits
- Reinforcing Steel strain limits
- Reinforced and Prestressed Concrete failure modeling

Structural Assessment: Major Assumptions

Containment Analyses

- Aircraft and engine impact perpendicular to structure centerline
- Potential containment dome impact is a plant-specific consideration
- Free-standing steel containments may require airframe model
- New plant designs may contain design features for which past experience is lacking, with potential failure modes outside the existing experience base
- Regions of the containment with potentially critical penetrations require special consideration

Structural Assessment: Major Assumptions

Spent Fuel Pool Analyses

- Engine and aircraft fuselage impact at mid-height and mid-span of the pool wall
- Other locations with greater damage potential should be assessed
- Engine and aircraft fuselage impact perpendicular to the wall surface
- If credit is taken of pool water inventory, care should be exercised in assuring that the added mass of the water is modeled conservatively
- Potential damage from wall motion on fuel assemblies adjacent to the walls should be evaluated

Structural Assessment: Sufficiency Criteria

Containment Intact

- The containment remains intact if structural analyses performed show that perforation of a steel containment or concrete containment with steel liner does not occur on impact **AND** that the containment ultimate pressure capability, given a core damage event, would not be exceeded before effective mitigation strategies can be implemented
- Effective mitigation strategies are those that, for an indefinite period of time, provide sufficient cooling to the damaged core or containment to limit temperature and pressure challenges below the ultimate pressure capability of the containment as defined in DCD/FSAR Chapter 19.

Structural Assessment: Sufficiency Criteria

Spent Fuel Pool Integrity

- Localized crushing and cracking of the concrete wall of the pool is acceptable provided that no leakage through the spent fuel pool liner compromises the required minimum water level of the pool
- If the fuel pool liner does not have a leakage path below the minimum water level, the fuel is protected and there would be no unacceptable release of radionuclides to the environment
- An aircraft impact at an elevation below the spent fuel pool with the potential for causing subsequent collapse of the spent fuel pool supporting structure must be evaluated, as appropriate

Structural Assessment:
Buildings Other than Containment and Spent Fuel Pool

- Structural or physical damage determined using rule sets in NEI 07-13
- The physical damage rule sets identified were derived based on studies of structures with typical reinforced concrete walls representative of existing plant designs:
  - 24 inch exterior walls, 18 inch interior walls
- Some new plants employ structures similar to those of current plants, others have structures that are significantly more robust.
- If the actual structure to be analyzed varies significantly, “Missile-Target Interaction Analysis Method” should be employed to determine the number of reinforced concrete walls necessary to stop further perforation into the structure on a design-specific basis.

Shock Damage Assessment

- The frequency spectrum associated with an aircraft impact is considerably higher than the spectrum associated with earthquakes.
- All equipment within the shock damage footprint is assumed to fail at the time of impact.
- Rule sets in NEI 07-13 are used to define the shock affects for six categories of equipment based on fragility.
- The shock damage distances are measured from the center of initial impact and then along a structural pathway to the affected equipment (i.e., shock is transmitted through walls, floors and ceilings but not across open air space).
- NSSS vendors have the option of using the values for SD1 through SD6 contained in NEI 07-13 or developing their own distances based on acceleration values filtered at 200 Hz for specific impact locations.

Fire Damage Assessment

- Fire spread rule sets provided in NEI 07-13
- Rule sets are based on previous research reports and experiments
- Fire damage footprint starts where physical damage ends – interface boundary
- Rule set consists of either the 1-barrier option or two-barrier option
  - 1-barrier utilizes 5 psid, 3-hour fire rated barriers
  - 2-barrier utilize 3-hour fire rated barriers
- Fire damage spread is assessed in all 3 dimensions

Fire Damage Assessment

- Fire damage can extend well beyond the physically damaged area due to the overpressure effects from the initial fireball and the spread of fuel through open pathways within the structure.
- Ventilation ductwork in the physical damage footprint is expected to be severely crushed , torn, and/or severed.
- Each fire damage footprint is fully encapsulated with 3-hour fire rated barriers (walls, floors, ceilings). Encapsulation is intended to contain:
  - Fire/Thermal effects
  - Fuel Spread
  - Overpressure from deflagration

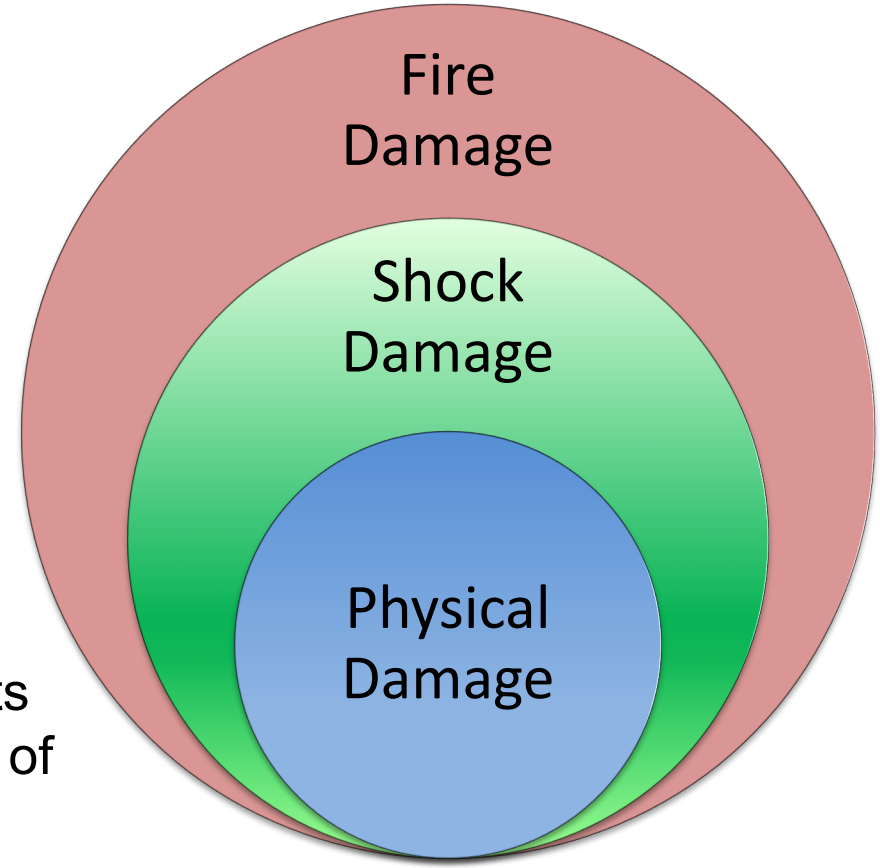
Fire Damage Assessment

- All cabling and electrical equipment within damage footprints:
  - in fire damage footprint - available for five minutes only
  - in physical damage footprint – lost upon impact
- A ventilation controlled internal fire will burn for several hours, thus preventing operations personnel from being able to take manual actions in these areas for several hours.
- Additional considerations:
  - Evaluate structural steel not encased in concrete
  - Smoke/Heat at air intakes

Composite Damage Footprint

- The composite damage footprint for each impact location scenario is developed by enveloping the total damage from structural, fire, and shock damage

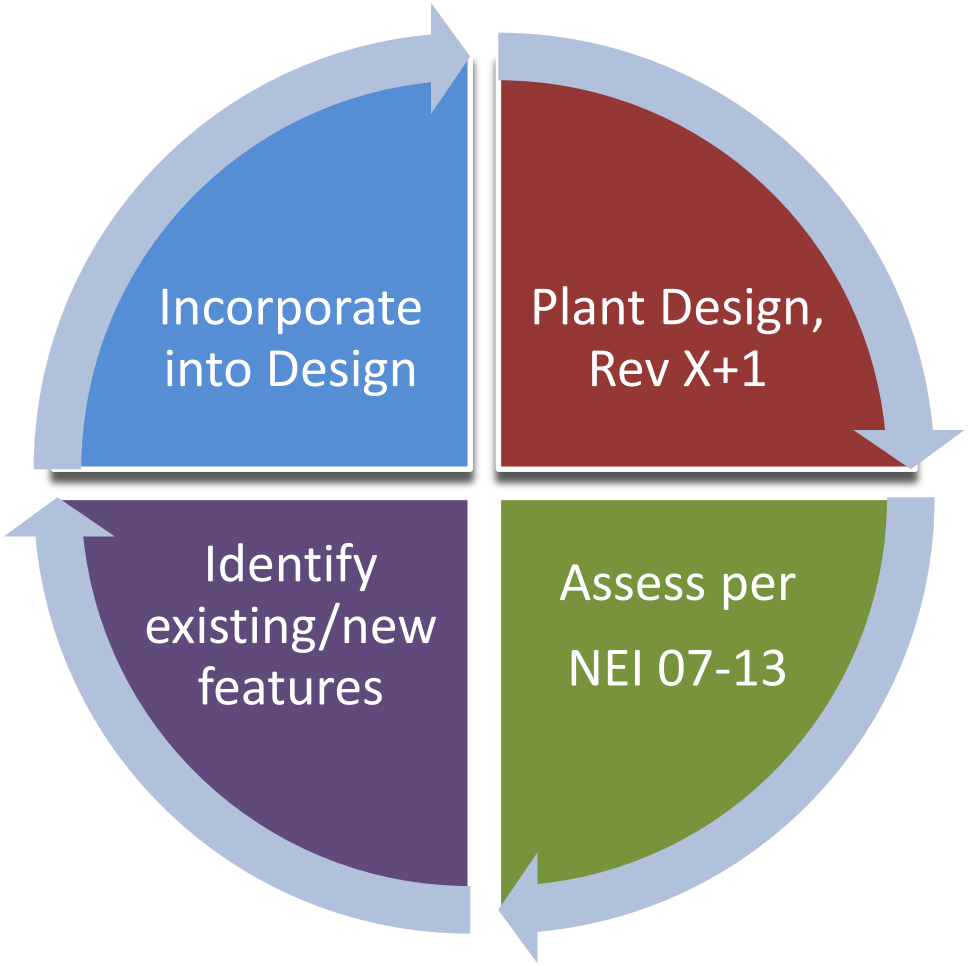
- As each impact location scenario is evaluated, the systemic and functional effects that are precluding protection of the fuel (reactor vessel and spent fuel pool) should be identified



Composite Damage Footprint

- Using plant information such as fire analyses, fire PRAs, internal flooding studies, and plant drawings, the rule sets and methodology will then determine which specific equipment, including cables, is assumed to be damaged
- The combined list of damaged cables and SSCs defines the threat to maintaining cooling of fuel in the vessel and spent fuel pool
- As each impact location scenario is evaluated, the systemic and functional effects that are precluding protection of the fuel (reactor vessel and spent fuel pool) should be identified

Design Enhancements



- Rule acceptance criteria must be met for all postulated impact location scenarios
- 10 CFR 50.150 requires applicants to identify and incorporate design features and functional capabilities to meet the acceptance criteria
- Applicants should document the rationale for the selected approach(s)

Design Enhancements

- Three categories of enhancements
  - Preventing Internal Damage
    - Strengthening external walls or relocating intervening structures
  - Minimizing Internal Damage
    - Relocate equipment, strengthen internal walls, add and/or upgrade fire doors
  - Design-Specific System Enhancements
    - Implement system enhancements to facilitate maintaining fuel cooling

Inspection Activities

- Applicants are not required to submit the actual assessment of the aircraft impact
- Assessments will be subject to inspection
- NRC may take appropriate enforcement action for any violations, including the preparation of an inadequate assessment or failure to prepare an assessment

Inspection Procedure

NRC Inspection Manual

Inspection Procedure 37804

NRC INSPECTION MANUAL

INSPECTION PROCEDURE 37804

AIRCRAFT IMPACT ASSESSMENT

PROGRAM APPLICABILITY: 2502 and 2508

37804-01 INSPECTION OBJECTIVE

To verify that applicants for new nuclear power reactors, as defined in Title 10, Section 50.150, "Aircraft Impact Assessment," of the Code of Federal Regulations (10 CFR 50.150(a)(3)), have effectively implemented the Nuclear Regulatory Commission (NRC) aircraft impact regulations such that, with reduced use of operator action, their design can withstand the effects of a large commercial aircraft impact.

37804-02 INSPECTION REQUIREMENTS

The NRC staff will evaluate the aircraft impact assessments (AIAs) and supporting documentation developed by applicants subject to the requirements of 10 CFR 50.150, to verify that design specific, realistic analyses were used to identify and incorporate design features and functional capabilities that provide additional inherent protection to withstand the effects of a beyond-design-basis large commercial aircraft impact.

02.01 Verify that the applicant identified and incorporated into the design all the necessary design features and functional capabilities to show that, with reduced use of operator actions, the reactor core remains cooled or the containment remains intact, and spent fuel cooling or spent fuel pool integrity is maintained.

02.02 Verify that the AIA is a realistic, design-specific assessment of the physical, fire, shock, and specific plant system-loss effects from the impact of a large, commercial aircraft used for long distance flights in the United States, with aviation fuel loading typically used in such flights, and an impact speed and angle of impact considering the ability of both experienced and inexperienced pilots to control large, commercial aircraft at the low altitude representative of a nuclear power plant's low profile.

02.03 Verify that the AIA is being documented, and maintained consistent with the requirements of the rule.

37804-03 INSPECTION GUIDANCE

General Guidance The NRC staff will inspect each AIA methodology, implementation, and results to verify regulatory compliance, technical accuracy and completeness, independent of the NRC licensing review and approval process for the relevant application.

Issue Date: 02/09/12 1 37804

- Most-recent revision (February 2012)
- Verify that applicant identified and incorporated into the design all the necessary design features and functional capabilities that provide additional inherent protection to withstand aircraft impact
- Verify realism in assessment of structural, fire, shock, and plant specific loss effects
- Verify AIA documentation is being maintained consistent with the requirements of the rule

Experience with Design Certification Applicants

- Westinghouse AP1000
- General Electric Hitachi ESBWR
- AREVA EPR
- Toshiba ABWR (South Texas)
- GEH Renewal ABWR
- Mitsubishi US-APWR
- KHNP APR1400

Lessons Learned

- Applying Fire Damage Rule Sets
  - 5psid fire barriers versus 5psid fire doors
  - Close arrangement of barriers under two-barrier option
  - Physical and Fire footprint interface assumptions and requirements
  - Fire intrusion via external wall impacts
- Use of Intervening Structures
- Gantry Cranes to be evaluated
- Mesh Size Analysis

Lessons Learned

- Documentation
  - Identifying ALL credited key design features
    - Everything credited in assessment must be identified in DC application
    - Needed support equipment must be included
  - Balancing level of detail required in DCD without inclusion of unnecessary SUNSI or SGI information

Conclusion

- AIA rule applies to new reactor applicants after July 13, 2009*
- Impact of a large commercial aircraft is a beyond design basis event
- Applicants to use realistic analyses to identify important design features
- NRC endorsed NEI 07-13 as an acceptable method for meeting the rule
- Methods and results are inspected
- Lessons learned used in updating regulatory guidance and inspection procedures

Links

Aircraft Impact Assessment rule:
https://www.gpo.gov/fdsys/pkg/FR-2009-06-12/pdf/E9-13582.pdf

Aircraft Impact Assessment Inspections:
https://www.nrc.gov/reactors/new-reactors/oversight/aia-inspections.html#insrpt

RG 1.217:
ML092900004

NEI 07-13, Revision 8P:
ML111440006

Center for Nuclear Waste Regulatory Analyses' Response of Reinforced Concrete Structures to Aircraft Crash Impact:
ML112690136

Acronyms

ABWR	Advanced Boiling-Water Reactor
AIA	aircraft impact assessment
AP1000	Advanced Passive 1000
APR1400	Advanced Power Reactor 1400
APWR	Advanced Pressurized-Water Reactor
CEA-EDF	French Alternative Energies and Atomic Energy Commission-Électricité de France
COL	combined license
CFR	Code of Federal Register
DIF	dynamic increase factors
DC	design certification
DCD	design certification document
EPR	Evolutionary Pressurized-Water Reactor
ESBWR	Economic Simplified Boiling-Water Reactor
FSAR	final safety analysis report
GE	General Electric
GEH	GE-Hitachi
KHNP	Korea Hydro & Nuclear Power
NAS	National Academy of Sciences
NRDC	Natural Resources Defense Council
NEI	Nuclear Energy Institute
NRC	Nuclear Regulatory Commission
PSID	pressure per square inch differential
PRA	probabilistic risk assessment
RES	Office of Research (NRC)
RG	regulatory guide
SFP	spend fuel pool
SGI	safeguards information
SNL	Sandia National Laboratories
SUNSI	sensitive unclassified non-safeguards information
WS	water slug

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Protecting People and the Environment

Thank you.

Questions??