Turbine Missile Analysis

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Introduction (1/4)

Purpose

- Describe approach to resolve NRC acceptance review comments for Design Control Document (DCD) resubmission
- Explain reasons and precedents for revised approach as outlined in this presentation
- Obtain NRC feedback regarding sufficiency of planned information in the DCD resubmission

Introduction (2/4)

Approach Determined by Available Data

- **Detailed turbine design characteristics not known yet**
- **Specifically how protection against turbine missiles is assured will depend on unit selected by COL applicant**
  - Rotor design (monoblock vs. shrunk on disk)
  - Materials properties, including fracture toughness
  - Vendor specific turbine missile probability analysis methodology
  - Probability results depend on preceding items
  - Inspection frequency and methods depend on missile probability analysis

Introduction (3/4)

Plan for Changes for APR1400 DCD

- **Remove details specific to particular turbine design**
- **Add new COL Items and Inspections, Tests, Analyses, and Acceptance Criteria (ITAACs)**
  - Requirements for Probability Analysis of Turbine Missiles to be performed by COL applicant
  - Functional requirements for redundancy, independence, and diversity of overspeed protection systems
- **Revise descriptive sections consistent with new approach and to resolve NRC comments (e.g., required material properties)**

Introduction (4/4)

Regulations and Guidance

- **KHNP has considered applicable regulations and guidance in preparing the APR1400 DCD**
  - 10CFR50 Appendix A General Design Criteria (GDC)
  - Regulatory Guide (RG) 1.206 identifies specific DCD format, organization, and expected content
  - NUREG-0800, Standard Review Plan (SRP), instructs NRC staff on what to look for and what is sufficient
  - Other documents (e.g., RG 1.115) address issues specific to turbine missiles
  - Interim Staff Guidance on Post-Combined License Commitments ESP/DC/COL-ISG-015

2013 DCD Approach (1/3)

Tier 1: 2.7.1.1

- **Information provided on:**
  - Valve configuration
  - Overspeed trip systems
- **ITAAC (Table 2.7.1.1-1)**
  - #1 confirms functional arrangement
  - #2 confirms functionality of overspeed protection systems
  - #4 confirms valves close on normal turbine trip

2013 DCD Approach (2/3)

Tier 2: 3.5

- **Information provided on:**
  - Turbine orientation (favorable)
  - Probability of turbine failure
- **No missile generation probability analysis**
- **COL Items:**
  - 3.5(2) confirm probability of missile generation is acceptable

2013 DCD Approach (3/3)

Tier 2: 10.2

- **Information provided on:**
  - Turbine generator components
  - Turbine control system
  - Overspeed protection system
  - Materials selection
  - Fracture toughness
  - Preservice and inservice inspection programs
- **Evaluation**
  - Probability of destructive overspeed $<10^{-5}$ per year
- **No probability analysis provided**
- **Brief mention of redundancy and independence**

NRC Acceptance Review (1/2)

Comment

- FSAR Section 10.2 lacks a detailed description about how redundancy, independency, and diversity is incorporated into the turbine overspeed design, a discussion on operation and reliability, detailed system and control drawings showing important components, operational insights, and inspection and testing information.

NRC Acceptance Review (2/2)

Comment

- In APR1400 DCD Section 10.2.3, the applicant discusses how the integrity of the APR1400 turbine rotor will be maintained over the operating life of the plant. However, the turbine missile probability analysis was not provided, which forms the basis and determines that the information, including the following, is valid in order to meet the requirements of 10 CFR Part 50, Appendix A, GDC 4
  - Required inspections of the turbine rotor
  - Required testing of associated valves
  - Substantiate the material properties specified in the DCD which currently do not meet the guidelines of SRP Section 10.2.3

Regulatory Requirements/Guidance (1/7)

SRP & RG 1.206: 3.5.1.1

- **Provide information on SSCs outside containment that need to be protected**
  - Locations
  - Applicable seismic category and quality group
  - Sections of the FSAR where the items are described
  - Missiles to be protected against, their sources, and the bases for their selection for analysis
  - Description of missile protection provided

Regulatory Requirements/Guidance (2/7)

SRP & RG 1.206: 3.5.1.3

- **Demonstrate SSCs important to safety are protected**
  - Identify if orientation is favorable or unfavorable
  - Provide dimensioned plant layout drawings
  - Barriers, including structural characteristics
  - SSCs important to safety (i.e., essential SSCs in accordance with Appendix A of RG 1.115
  - All TG units (present and future) in the vicinity of the plant
  - Quantitative description of TG (e.g., component characteristics, rotational speed, and turbine internals)
  - Postulated missiles
  - Methods, analyses, results of TG missile probability analysis
  - ISI and testing program
  - Demonstration of capability of structural barriers

Regulatory Requirements/Guidance (3/7)

SRP & RG 1.206: 3.5.1.3

- **Missile generation probability at design speed based on:**
  - Rotor design parameters
  - Material properties
  - Operating conditions
  - Intervals of inservice examinations of disks
- **Missile generation probability at destructive overspeed based on:**
  - Speed sensing and tripping characteristics of governor
  - Overspeed protection system reliability
  - Diversity: Electric and mechanical trip systems
  - Design/arrangement of main steam stop & control valves
  - Test frequency of major turbine valves
- **Probability of destructive overspeed is function of initiating event frequency (i.e., loss of load)**

Regulatory Requirements/Guidance (4/7)

SRP 3.5.1.3

- **Commit to following program if turbines are obtained from manufacturers that have not submitted, or received NRC approval for, their methods and procedures for calculating turbine missile generation probabilities:**
  - An ISI program should be used to detect rotor or disk flaws that could lead to unacceptable brittle failure probability at or below design speed in rotor assembly within a given period of time…
  - In accordance with manufacturer's procedures, ISI program should use visual, surface, and volumetric exams to inspect turbine components…
  - Surveillance test interval for governor and overspeed protection system to ensure high reliability …
  - Design, inspection, and operating conditions should provide assurance that the probability of turbine missile generation will not exceed those described in Table 3.5.1.3-1 [10^{-4}]…

Regulatory Requirements/Guidance (5/7)

SRP & RG 1.206: 10.2

- **Describe how GDC 4 is met (10.2.1)**
- **Requirements to meet GDC 4**
  - The turbine control and overspeed protection system should control turbine action under all normal or abnormal operating conditions…

Regulatory Requirements/Guidance (6/7)

SRP & RG 1.206: 10.2

- **Describe TG control and overspeed system in detail including redundancy and diversity and how GDC 4 is met (10.2.2), including valve characteristics**
- **Requirements to meet GDC 4**
  - The turbine main steam stop and control valves and reheat steam stop and intercept valves should protect the turbine from exceeding set speeds…They are tripped in three independent ways:
    - Normal speed electro-hydraulic control trips valves at ~103%
    - Mechanical overspeed trip actuates at ~111%
    - Independent, redundant electrical overspeed trip actuates at ~112%
  - The [turbine generator system] should have the capability to permit periodic testing of components important to safety…

Regulatory Requirements/Guidance (7/7)

SRP & RG 1.206: 10.2.3

- **Demonstrate rotor integrity, specifically:**
  - Materials Selection. Forged or welded rotor made from material and by process to minimize flaw occurrence and maximize fracture toughness properties; material should be examined and tested
  - Fracture Toughness. LP disk forged or welded rotor fracture toughness properties acceptable if specified criteria are met.
  - Pre-service Inspection. Acceptable if meets specified criteria
  - Turbine Rotor Design. Designed to withstand normal conditions, anticipated transients, and accidents resulting in a turbine trip without loss of structural integrity and meets specified criteria
  - Inservice Inspection. Acceptable if meets specified criteria.

Unavailability of Proprietary Data (1/1)

New approach for Resubmission of APR1400 DCD

- **KHNP**
  - Is not turbine designer/manufacturer
  - Has no access to needed data to perform probability analysis
  - Does not have access to vendor proprietary methodology
  - Wants to retain flexibility to allow COL applicant to choose specific design within constraints that ensure acceptable turbine missile probability
- **Missile evaluation based on other than COL applicant's selected turbine's design and vendor-specific methodology is not relevant**
- **Lack of availability of turbine vendor's detailed proprietary data and methodology precludes a meaningful example analysis**
- **Any analysis not design specific sets non-applicable acceptance and inspection criteria, requiring departures for each COL**
  - Specific acceptance criteria ensure acceptable probability.
  - Additional details ensure acceptability of overspeed protection.

Unavailability of Proprietary Data (2/2)

DCD Changes Needed

- Eliminate turbine vendor specific details
- Establish design/functional requirements needed for acceptably low turbine missile probability such as for overspeed protection redundancy, independence, and diversity.
- Consistent with SRP 3.5.1.3, and ISG-015 stipulate COL Items
- Capture tests, analyses, and acceptance criteria in ITAAC to ensure complete, proper treatment of turbine missile risk by COL holder/applicant.

ESBWR Precedents (1/5)

#1 - RAI 10.2-21*

- DCD Tier 2, Rev. 3, Section 10.2.5.1 states that the COL Holder will provide an evaluation of the probability of turbine missile generation using criteria in accordance with NRC requirements. The probability of turbine missile generation should be completed prior to license issuance so that the staff can verify whether the probability of turbine missile generation is within NRC requirements…

- Response: The Turbine Missile Probability Analysis will not be available until after the as-built turbine material properties and final as-built rotor design details are available…. and is therefore specified as a COL holder item…[see ITAAC] "An analysis exists that documents that the probability of turbine material and overspeed related failures, resulting in external turbine missiles, is $<1x10^{-4}$ per turbine year."

* ADAMS Accession No. ML072250088

ESBWR Precedents (2/5)

#1 continued - SER

- The Turbine Missile Probability Analysis will not be available until as-built turbine material properties and final as-built rotor design details are available.
- In addition, DCD Tier 1 discusses external turbine missile probability and requires it to be less than 1×10^{-4} per turbine year. Based on proposed turbine rotor designs that utilize integral forgings, probability of turbine missile generation is less than 1×10^{-5} for the ESBWR. This probability is to be confirmed by calculation and/or analysis in the Turbine Missile Probability Analysis.
- In response to RAIs, the applicant proposed to add new Section 10.2.3.8 that required the turbine missile probability analysis to include the aspects described in COL Information Items. The staff accepted the explanation and requested inclusion in an ITAAC.

ESBWR Precedents (3/5)

#2 - RAI 10.2-22*

- The Staff noticed that the overspeed basis report and the inservice test and inspection report are incorporated in Section 10.2.3.4. However, it is not clear in Section 10.2.3.4 who provides these reports and when. Also, the submission of turbine material property data and warmup time is not specified in Section 10.2.3. Therefore, GE needs to either reinstate all three COL Action Items, or state in Subsection 10.2.3.4 that the COL Applicant will submit the relevant documents.
- Response: [The COL Action Items were relocated but remain as COL actions.]

*ADAMS Accession No. ML072250088

ESBWR Precedents (4/5)

#2 continued - SER 10.2.3.2.1 Turbine Rotor Design

- The staff asked for additional information on turbine rotor design, such as diagrams of the turbine rotor, number of stages, bucket design, how buckets are attached to the rotor, and rotor fabrication. The applicant proposed a new Section 10.2.3.8, Turbine Missile Probability Analysis, …that includes a requirement to provide turbine rotor design details as part of this analysis.
- In addition, …the applicant included an ITAAC to discuss the design and structural integrity of the turbine rotor.
- The applicant proposed to add a COL information item to require the COL applicant to provide a turbine missile probability analysis meeting requirements specified in proposed Section 10.2.3.8.
- DCD Rev. 6 deleted the ITAAC, replacing it with a COL information item that states that the COL applicant will provide an evaluation of the probability of the turbine missile generation using the criteria in accordance with NRC requirements. The staff finds this acceptable for addressing the turbine rotor design details.

ESBWR Precedents (5/5)

#3 - SER 10.2.3.2.3 Turbine Rotor Material Specification

- The staff asked why details pertaining to the turbine inservice test and inspection program were deleted from the DCD. The applicant responded that this information was relocated to an ITAAC that required that the turbine and turbine valve inservice test and inspection program include scope, frequency, methods, acceptance criteria, disposition of reportable indications, corrective actions, and technical basis for inspection frequency.
- In DCD Revision 6, the applicant deleted the ITAAC, replacing it with a COL Information Item: Inservice test, inspection, and operating procedures are to be in accordance with industry practice and meet original equipment manufacturer (OEM) requirements.
- The staff finds this acceptable because the information provided in DCD Tier 2, Section 10.2.3.8 and the COL Information Item will ensure that the turbine test and inservice program will be conducted and that the turbine will meet the OEM requirements for turbine missile probability.

New Approach (1/9)

APR1400 DCD Options

- **In accordance with SRP, since KHNP is not a turbine vendor and does not have detailed information available from a vendor:**
  - Establish ITAAC to verify appropriate analyses and component characteristic are sufficient
  - Establish COL items to ensure COL includes sufficient information OR
  - Combination of above
    - ITAAC for items that must occur or be verified after COL issuance
    - COL items for those items that the applicant can satisfactorily address early as part of the COL review

New Approach (2/9)

ITAAC 1

- **1a. Functional Arrangement (existing)**
  - The as-built T/G conforms with the functional arrangement as described in the Design Description of Subsection 2.7.1.1.1
  - Precedent: AP1000, ABWR, APWR, ESBWR
- **1b. Turbine Orientation (new)**
  - An analysis exists that confirms that any essential SSCs listed in Tier 2 that are located inside the low trajectory turbine missile strike zone are failsafe or are protected by physical barriers.
  - Precedent: ABWR, ESBWR

New Approach (3/9)

ITAAC 2

- **Valve Closure on Turbine Trip (existing)**
  - The as-built MSVs, CVs, ISVs, and IVs close when the mechanical overspeed system initiates the T/G trip upon reaching the setpoint for overspeed protection.
  - The as-built MSVs, CVs, ISVs, and IVs close when the electric overspeed system initiates the T/G trip upon reaching the setpoint for overspeed protection
  - Precedent: APWR, ABWR

New Approach (4/9)

ITAAC 3

- **Inspection & test (new)**
  - The turbine and turbine valve inservice test and inspection program includes scope, frequency, methods, acceptance criteria, disposition of reportable indications, corrective actions, and technical basis for inspection frequency. In-service test, inspection and operating procedures are in accordance with industry practice and ensure assumptions/input of Probability Analysis of Turbine Missiles Report are valid.
  - Precedent: ESBWR

New Approach (5/9)

ITAAC 4

- **Turbine missile probabilistic analysis (new)**
  - Probability Analysis of Turbine Missiles Report(s) exist and conclude that the probability of turbine failure resulting in the ejection of turbine rotor (or internal structure) fragments through the turbine casing is less than $1x10^{-5}$ per year.
  - Precedent: ESBWR (limit of $1x10^{-5}$ per year)

New Approach (6/9)

ITAAC 5

- **As-built compliance (new)**
  - The as-built turbine material properties, turbine rotor and blade designs, pre-service inspection and testing results, and in-service inspection and testing requirements meet the requirements of the Probability Analysis of Turbine Missiles
  - Precedent: APWR, ESBWR

New Approach (7/9)

Functional Requirements

- **COL shall identify how the functional requirements of DCD 3.5.1.3 and 10.2 are met:**
  - Independence, Redundancy, and Diversity of Overspeed Protection Systems
  - Schematic of turbine control and protection system concept
  - Specification for turbine design and materials
- **Discussion of how redundancy, independence, and diversity are provided by the overspeed protection systems**
- **Use of both mechanical and electric overspeed trips**

New Approach (8/9)

Changes for APR1400 DCD

- **Add new ITAAC**
  - Turbine orientation favorable
  - Turbine missile probability analysis exists
  - Turbine inspection and test programs fulfill turbine missile probability analysis
  - As-built turbine properties comply with analysis
- **Add discussion describing information to be included in Probability Analysis of Turbine Missiles**
- **Discuss functional requirements for protection against overspeed**
- **Remove details specific to any particular turbine design**

New Approach (9/9)

COL Items

- **10.2**
  - The COL applicant shall identify how the functional requirements for the overspeed protection system are met and provide a schematic of the turbine generator control and overspeed protection systems.
  - The COL applicant shall provide a description of how the specification for the turbine generator will ensure that requirements for protection against turbine missiles (e.g., preparation of a turbine missile probability analysis, applicable material properties, method of calculating the fracture toughness properties, preservice inspections) will be met.

Resolution of NRC Comments

- Detailed functional requirements for redundancy and independence will be included. Diversity addressed by combination of mechanical and electrical overspeed protection. Provision of figures, inspection, and testing information is addressed as COL items and ITAACs, since these depend on specific turbine design.
- Added discussion and ITAAC will address requirements on missile probability. Rotor inspections, valve testing, and substantiation of material properties will be addressed.

Summary of Planned Approach

- KHNP does not have access to data to perform a probability analysis for turbine missiles
- An analysis done now is unlikely to have future applicability
- Nuclear steam turbine vendors have ability to design and manufacture systems and perform probabilistic failure analysis meeting criteria
- Once COL applicant chooses turbine vendor, then can determine the turbine design and provide relevant probability analysis for turbine missiles
- Acceptability can be assured with added ITAAC for key turbine characteristics and analyses
- KHNP will provide additional detail on functional requirements for overspeed protection system
- Planned approach consistent with recent DCDs accepted by the NRC