This document is the Non-Proprietary version.

Westinghouse Small Modular Reactor PRA Overview

Nuclear Regulatory Commission

August 2013

Westinghouse

AGENDA

- Introduction
- SMR Overview
- Level 1 At Power PRA
- Level 2 At Power PRA
- Severe Accident Analysis
- RTNSS and DRAP
- PRA Inputs to SMR Risk Informed Design
- NRC Audit Preparations and Expectations
- Questions and Wrap Up

Introduction

- Goals of the meeting
- Regulatory Basis for Westinghouse PRA effort
  - Recent (i.e. Subsequent to AP1000 DCD application) Evolutions in Regulatory Requirements and Westinghouse Response
  - Latest SRP guidance and Westinghouse Proposed Chapter 19 DCD Structure

WSMR Chapter 19 Structure ?

a,c

[ ]

WSMR Chapter 19 Structure..vs RG 1.206 App A "Standard Format and Content for FSAR Chapter 19?"

a,c

[ ]

SMR Design Overview

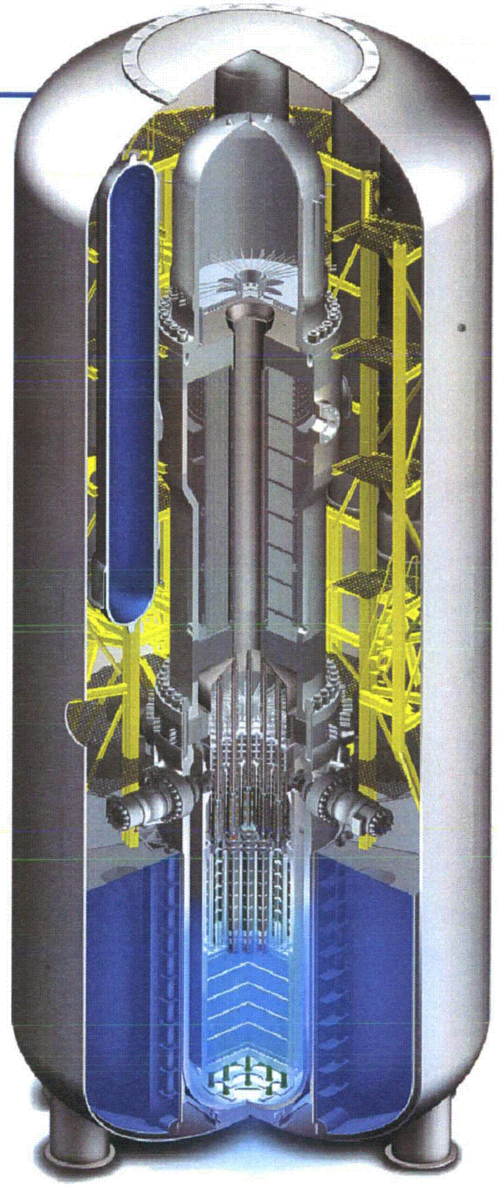
Containment Vessel

- **Compact, high-pressure, steel containment vessel**
- **Sized for ease of modular construction**

[

]a,c

  - Derivative of **AP1000®** plant design



a,c

Nuclear Island Layout

a,c

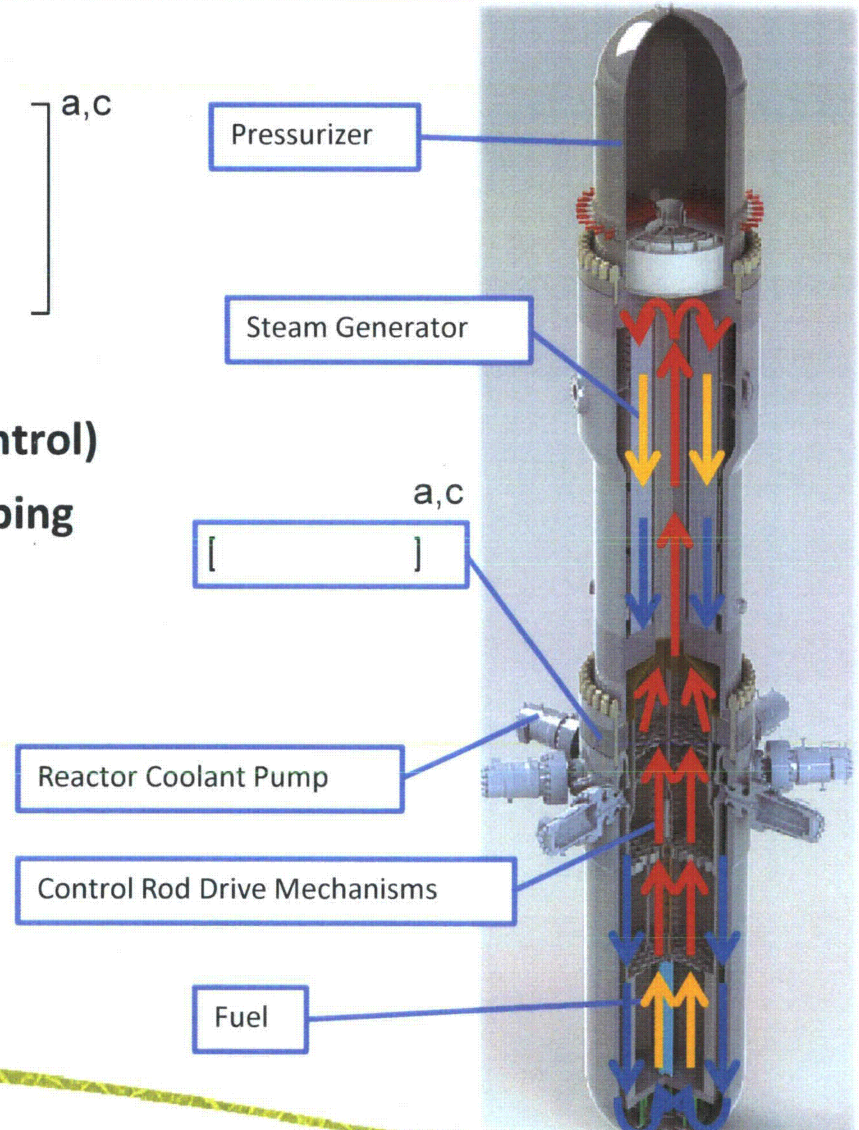
[ ]

Reactor Design

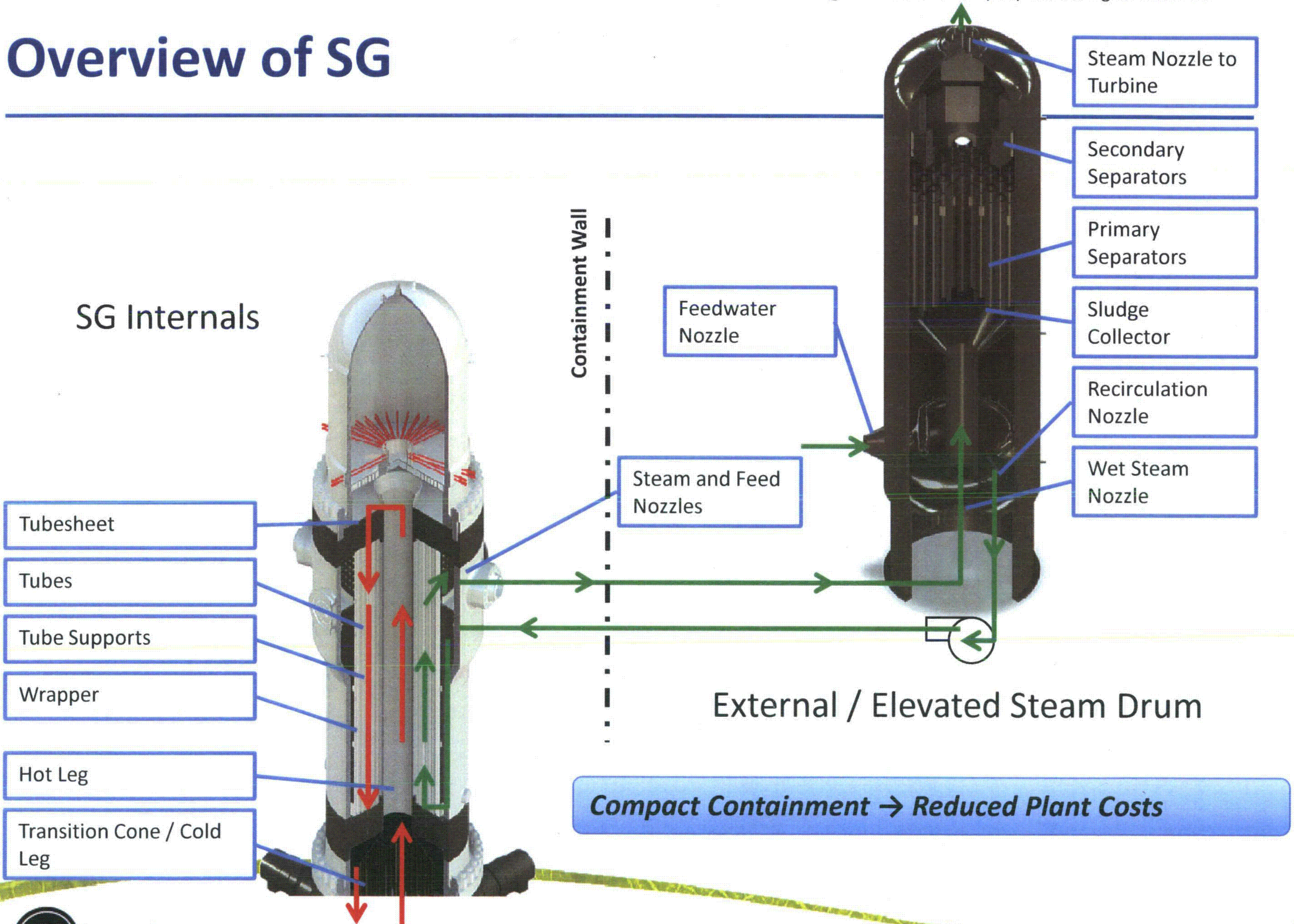
- **ASME Section III Subsection NB Vessel**

[ ]a,c

- **Design flow rate of 100,000 gpm**
- **37 internal control rods (shutdown and control)**
- **Integral reactor with no large-bore loop piping**
- **Straight tube Steam Generator (SG) with external circulation**
- **No penetrations below top of core**
  - In-vessel retention for severe accidents



Overview of SG



Steam Generator System (SGS)

[ ] a,c

a,c

SMR Operating Conditions / Design Parameters

Parameter	Value
Reactor Coolant System	
Core Power	800 MWt
Operating Pressure	2250 psia
RCS Average Temperature	588.2 °F
Best Estimate Flow	100,000 gpm
Number of RCPs	8
Active Fuel Length	8 ft
Reactor Vessel	
Design Pressure	2500 psig
Design Temperature	650 °F
Steam Generator	
Number of Tubes	9188
Steam Pressure	800 psia
Containment Vessel	
Design Pressure	250 psig

Probabilistic Risk Assessment

- **Level 1 Analysis for Internal Events**
  - Internal initiating events evaluation
  - Event tree and success criteria analyses
    - Success criteria based on analyses performed with the MAAP 5.0 code
    - Insights incorporated into design
  - Plant systems analysis using fault tree models
  - Common cause failure and human reliability analyses
  - Fault tree and event tree quantification to calculate core damage frequency
    - Multiple Levels of Defense included in design

Probabilistic Risk Assessment

- **Level 2 Analysis for Internal Events**
  - Evaluation of severe accident phenomena and fission product source terms
  - Modeling of containment event tree and associated success criteria
  - Analysis of hydrogen burning and mixing
    - Analyses demonstrate effectiveness of passive hydrogen recombiners
  - Analysis of in-vessel retention
- **Level 3 Analysis for Internal Events**
  - Offsite dose evaluation
- **Sensitivity, Importance and Uncertainty Analyses for Internal events**

Probabilistic Risk Assessment

- **Shutdown Risk Assessment**
- **External Events Risk Assessment**
  - Internal fire assessment
  - Internal flooding assessment
  - Seismic margin assessment
  - High winds assessment
  - External flooding assessment
  - Transportation and nearby facility accident assessment

SMR Level 1 At Power PRA

Westinghouse

Internal Events At-Power PRA

- Scope
  - IE analysis
  - Accident sequence analysis
  - Success criteria analysis
  - [ ]c
  - [ ]c
  - Data analysis
  - Model integration and quantification
  - ISLOCA
  - RPV rupture
  - Severe accident model

Initiating Event Analysis

- IE identification
  - Existing IE review [ ]c
  - SMR specific
    [

]a,c

- IE identification, categorization, and quantification are documented in IE notebook

Initiating Event Analysis

PRA Initiating Events

a,c

Westinghouse

Accident Sequence Analysis

- Accident sequence model developed using SMR specific features
  - Bases
    - DBA results, design specification, AP1000 EOP insights
  - Event tree framework
    - Minimize use of sequence transfer
    - Each IE has a corresponding event tree
  - End states defined
    - No undefined end state
    - L1 and L2 linked directly

Success Criteria Analysis

[

]a,c

Accident Sequence - LOCA

a,c

Success Criteria Analysis (Continued)

- Success criteria analysis using MAAP5
  - MAAP5 benchmarked with safety analysis codes
    [

    ][a,c]
  - Core damage prevented
    [

    ][a,c]

Success Criteria Analysis (Continued)

- Detailed analysis of passive safety system
  [

  ]a,c

System Analysis

- System notebooks are developed
  - SMR specific systems
    [
    ]a,c
  - SMR control systems (AP1000 DCD model basis)
    [
    ]a,c
  - DID systems - SMR Specific
    [
    ]a,c

Human Reliability Analysis

- Preliminary HRA performed
  - EPRI HRA Calculator 4.21
  - Initial work based on AP1000 plant actions as appropriate to SMR design
  - Basis of developed AP1000 EOP insights used to support improved analysis estimates
  - Iterative additions and revisions to HFEs performed throughout SMR plant analysis
  - HFEs primarily backup actions for actuated systems

Quantification Results

- EPRI CAFTA code is used to develop and quantify the PRA model
  [

  ]a,c

Results – CDF Distribution

- [ ]a,c

Results – Dominant Cutsets

- Top 5 cutsets (group)
  [

]a,c

Results – Risk Importance

- Top 10 RAW (excluding IE)
  [

  ]a,c

Results – Risk Importance

- Top 10 RAW (continued)
  [

]a,c

Results – Risk Importance

[

]a,c

Results – Risk Importance

[

]a,c

ISLOCA - SMR Design Features

a,c

Hi-Low Interface

[

]a,c

ISLOCA IE Frequency

[

]a,c

RPV Rupture

[

]a,c

[ ]a,c

[

]a,c

RPV Rupture Results

[

]a,c

SMR
Level 2 At Power Quantification

L2 Model

- Severe accident
  - SMR L1 sequences directly linked to L2 sequences
  - All L1 sequences are included
  - IVR is the focus of the level 2 PRA
    [

    ]a,c

L2 Model

- Severe accident
  [

  ]a,c

L2 Quantification Results

- EPRI CAFTA code used to develop and quantify the PRA L2 model

[

]a,c

L2 Model

Plans for L2 model improvements.

[

]a,c

Results – Release Distribution

a,c

Results – Dominant Cutsets

- Top 5 cutsets (group)

[

]a,c

Results – Risk Importance

- Top 10 RAW (excluding IE)
  [

  ]a,c

Results – Risk Importance

- Top 10 RAW (continued)
  [

]a,c

Results – Risk Importance

[

]a,c

Results – Risk Importance

[

]a,c

SMR Severe Accident Analysis

SMR Severe Accident Model

- Severe accident phenomena to be considered
  - Containment pressurization from the RCS loss of coolant accident (LOCA) blowdown
  - Molten fuel-coolant interactions (FCI or steam explosion)
    - In-vessel steam explosion
    - Ex-vessel Steam Explosion
  - In-vessel retention of molten core debris via external reactor vessel cooling
  - Hydrogen combustion
  - High pressure core melt
  - Molten core-concrete interaction
  - Long-term containment pressurization from decay heat
  - Elevated containment temperatures (equipment survivability)

Severe Accident Model - Phenomena

- Containment pressurization from the RCS loss of coolant accident (LOCA) blowdown
  - Analyzed in Chapter 15 and is a SMR design criterion
  - The likelihood of containment over-pressure failure is much less than other release mechanisms
  - Hydrogen release considerations
- Molten fuel-coolant interactions (FCI or steam explosion)
  [

  ][a,c]

Severe Accident Phenomena (continued)

- Hydrogen combustion
  - Deflagration – subsonic flame front
  - Detonation – accelerated or sonic flame front
  - Diffusion Flame – burning of an unmixed plume
  - Potential locations outside of the containment
    - Leakage pathways
    - Filtered Vent
- Practically eliminated in containment by the SMR design and severe accident model
  - ~Zero Oxygen content at time the accident initiation – design
  - RCS depressurization (containment high pressure) to prevent oxygen in-leakage throughout the severe accident mitigation – severe accident model
    - Tech. Spec in-leakage rate

Severe Accident Phenomena (continued)

- High pressure core melt
  - Challenge to steam generator tube integrity
  - High pressure melt ejection (HPME)
  - Direct containment heating (DCH)
  - Melt impingement on containment pressure boundary

[

]a,c

Severe Accident Phenomena (continued)

- Molten core-concrete interaction
  [
  ]a,c
- Long-term containment pressurization from decay heat
- [
  ]a,c
- Elevated containment temperatures (equipment survivability)
  - No non-qualified equipment credited in the severe accident model
- In-vessel retention of molten core debris via external reactor vessel cooling.

Severe Accident Model (continued)

- Severe accident modeling approach
  - SMR L1 sequences directly linked to L2 sequences
  - All L1 sequences included
    [

    ]a,c

SMR Severe Accident Event Tree Structure

a,c

SMR RTNSS and DRAP

WEC SMR RTNSS & RAP

- Following most recent SRP guidance for 17.4 (D-RAP) and 19.3 (RTNSS)
- Regulatory Treatment of Non-Safety Systems
  - Identification of RTNSS SSCs based on probabilistic and deterministic evaluations
  - Development of specific reliability/availability missions for the significant non-safety related SSCs
  - Specification of proposed regulatory treatment for each of the missions developed
- Design Reliability Assurance Program (D-RAP)
  - Evaluate SSCs using probabilistic tools and expert judgment
  - Ensure reliability of identified components

WEC SMR RTNSS

- RTNSS SSC Identification:
  - PRA sensitivity study
  - PRA initiating event frequency evaluation
  - ATWS evaluation (10 CFR 50.62)
  - SBO evaluation (10 CFR 50.63)
  - Post 72-hour actions
  - Containment performance
  - Adverse interactions with safety systems
  - Seismic considerations
- Define Reliability/Availability requirements for RTNSS SSCs

WEC SMR D-RAP

- Use PRA to rank risk-importance of SSCs by:
  - Risk Achievement Worth (RAW)
    - Set SSC reliability to 0.0; RAW values ≥ 2 are considered
  - Risk Reduction Worth (RRW)
    - Set SSC reliability to 1.0; RRW values ≥ 1.005 are considered
  - Fussel-Vesley Worth (FVW)
    - FVW values ≥ 1.005 are considered
- Results of ranking are evaluated in an expert panel process, and some SSCs that may not meet above criteria can be added
- Identify risk insights and key assumptions for each SSC
  - Define boundaries of SSC that are included in D-RAP

WEC SMR D-RAP cont'd

- D-RAP identified components will be noted in design documentation, and subject to additional requirements in order to increase confidence in their reliability
  - Apply augmented quality requirements to non-safety related SSCs included in D-RAP
    - Safety related SSCs already are subject to 10 CFR 50 Appendix B requirements
    - Same augmented quality program for RTNSS and D-RAP components
  - Require experience reports for safety related SSCs included in D-RAP

RTNSS Sensitivity Run

[

]a,c

SMR
PRA Inputs to SMR Risk Informed Design

Westinghouse

Risk Informed Design

Many Touch Points Directly with Designers

- PRA Event Tree (Accident Sequence) and System analysts have open exchange of information with designers.
- PRA team is included in meetings where possible SMR design changes are discussed.
- PRA team periodically discusses quantifications with SMR team to exchange ideas:
  - Design changes and PRA modeling changes going forward
  - PRA model enhancements that need to be made
- Examples that follow are from 10 January 2013 Meeting

Risk Informed Design

[

]a,c

Risk Informed Design

[

]a,c

Risk Informed Design

[

]a,c

Risk Informed Design

[

]a,c

Risk Informed Design Summary

- SMR design is risk informed.
- Risk informed insights in AP1000 design are used as applicable to SMR
- Examples above from 10 January 2013 meeting after test quantification of SMR PRA model Rev. A.
- Documented exchanges of information, initiated by PRA, with designers April 2012 to present.
- Other one-on-one information exchanges are documented in PRA Notebooks (Calculation notes).

Outline of Chapter 19 DCD Content

- Proposed outline developed to be consistent with Chapter 19 SRP's

Fourth Quarter 2013 NRC PRA Audit

- Scope of the PRA Audit
  - PRA Analyses that will be available that support DCD input
  - Notebooks that will have "alpha" revision status

Conclusions

- PRA work underway for risk hazards defined in Chapter 19 SRPs.
- There are many examples of PRA and Design efforts proceeding in parallel with open information exchanges.
- Chapter 19 DCD PRA sections are underway with current PRA information. Realistic schedule for completion on time.
- Current PRA work is being done with goal of meeting ASME PRA Category 2 requirements, where possible, for this stage of design.

Questions and Answers