Treatment of PRA Uncertainties in Risk-Informed Decision Making

Public Workshop

May 5, 6, 2009

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Workshop Structure

- Questions, comments and discussion encouraged during entire workshop
- Individuals are to state their name and affiliation
- Questions/discussions may be limited to ensure agenda times are met
- Workshop is NOT being transcribed
  - Workshop discussion will be summarized and posted
- Communication form, please complete and turn in (or mail)
- Please remember to sign the registration form
- Category 3 meeting

Opening Remarks

U.S. Nuclear Regulatory Commission

Opening Remarks

Electric Power Research Institute

Project History – The Goal

- Goal is to develop guidance on the treatment of uncertainty in the base PRA model and its application
- Objective is to develop this guidance to:
  - Meet PRA Standard requirements
  - Provide a consistent and pragmatic process
  - Facilitate implementation by providing generic information and an example

EPRI Project History – Early Years

- 2004 – Treatment of Uncertainty in Risk-Informed Regulation: Technical Basis Document
  - January 2004 – Plan Developed
  - December 2004 – Published (1009652)
- 2005 – Treatment of Uncertainty in Risk-Informed Regulation: Applications Guide
  - July 2005 – Draft
  - Pilots (Limerick and EDF)

EPRI Project History – The Middle Years

- 2006 – Treatment of Uncertainty in Risk-Informed Regulation: Applications Guide (1013491)
- 2007 – NRC/EPRI formal collaboration begins
  - RG 1.200 and PRA standard changes
    - Clarifications to "key" sources of uncertainty
    - Acceptance guidelines and decision-making
  - NUREG-1855 & EPRI document revision

EPRI Project History – Current

- 2008 – Products
  - EPRI 1016737 – "Treatment of Parameter and Model Uncertainty for Probabilistic Risk Assessments"
  - NUREG – 1855 issued in draft (after much public and ACRS interaction)
- 2009 – Implementation
  - NUREG-1855 (Volume 1) issued
  - May public workshop

Workshop Agenda

Tuesday, May 5, 2009

Time			Topic
7:30 am	-	8:30 am	Reception
8:30 am	-	8:45 am	• Opening remarks, introduction
8:45 am	-	9:30 am	Overview— • Purpose and objective of program • Scope and Limitations • Overall approach • Relationship of NRC and EPRI reports
9:30 am	-	10:10 am	Discussion on guidance regarding • Risk model • Parameter uncertainties
10:10 am	-	10:30 am	BREAK
10:30 am	-	11:30 am	Discussion on guidance regarding • Model uncertainties

Workshop Agenda

Tuesday, May 5, 2009

Time			Topic
11:30 am	-	12:45 pm	LUNCH
12:45 pm	-	1:30 pm	Discussion on guidance regarding • Completeness uncertainties • Treatment of uncertainties in risk-informed decisionmaking
1:30 pm	-	2:45 pm	Example application illustrating how to use the process in the NRC and EPRI reports to support a risk-informed decision – Step 1 • Understanding the application • Screening analysis
2:45 pm	-	3:15 pm	BREAK
3:15 pm	-	5:00 pm	Example (cont'd) – Step 2 • Comparison of PRA results to acceptance guidelines

Workshop Agenda

Wednesday, May 6, 2009

Time			Topic
7:30 am	-	8:30 am	Reception
8:30 am	-	9:15 am	Example (cont'd) – Step 2 (cont'd) • Assessment of uncertainty • Sensitivity studies
9:15 am	-	9:45 am	Example (cont'd) – Step 3 • Presentation of results • Summary
9:45 am	-	10:45 am	Regulatory (i.e., NRR, NRO and Regional) and industry perspectives on implementation of NUREG and EPRI work on respective activities
10:45 am	-	11:00 am	BREAK
11:00 am	-	12:00 pm	Open discussion on the NRC and EPRI reports and on the workshop, future work
12:00 pm	-	12:15 pm	Wrap-up
12:15 pm			ADJOURN

OVERVIEW

Objective of Workshop

- Illustrate how to implement/apply the guidance contained in US Nuclear Regulatory Commission (NRC) NUREG and Electric Power Research Institute (EPRI) reports on Probabilistic Risk Assessment (PRA) uncertainties in risk-informed decisionmaking

NRC and EPRI Collaboration

- NRC and EPRI both independently initiated effort on PRA uncertainties
- Decision made that it would be more efficient and effective to work together
- Under a Memorandum of Understanding, NRC and EPRI combined efforts such that both documents are meant to be complementary and used together
- Unless noted, discussion speaks to the entire program (both NRC and EPRI efforts)

Purpose of Program

- Provide guidance in support of the requirements addressing uncertainty in the ASME/ANS PRA Standard
- Provide guidance on how to treat uncertainties associated with PRA in risk-informed decisionmaking in support of risk-informed activities

Scope and Limitations

- Sources of uncertainties:
  - Limited to addressing the uncertainties associated with risk assessment models
    - Does not address sources of uncertainties associated with other analyses
  - Limited to at-power internal events and internal floods associated with core damage frequency and large early release frequency
    - Does not address sources associated with internal fire and external hazards, and for low power shutdown conditions

Scope and Limitations (cont'd)

- Guidance not provided for performing expert judgment or elicitation
- Guidance not provided for employing an expert panel
- Guidance focuses on currently operating reactors
- Process is applicable for advanced LWRs and non-LWRs, and reactors in the design stage
  - the screening criteria and the specific sources of uncertainty may not be applicable
  - sources unique to these reactors not addressed

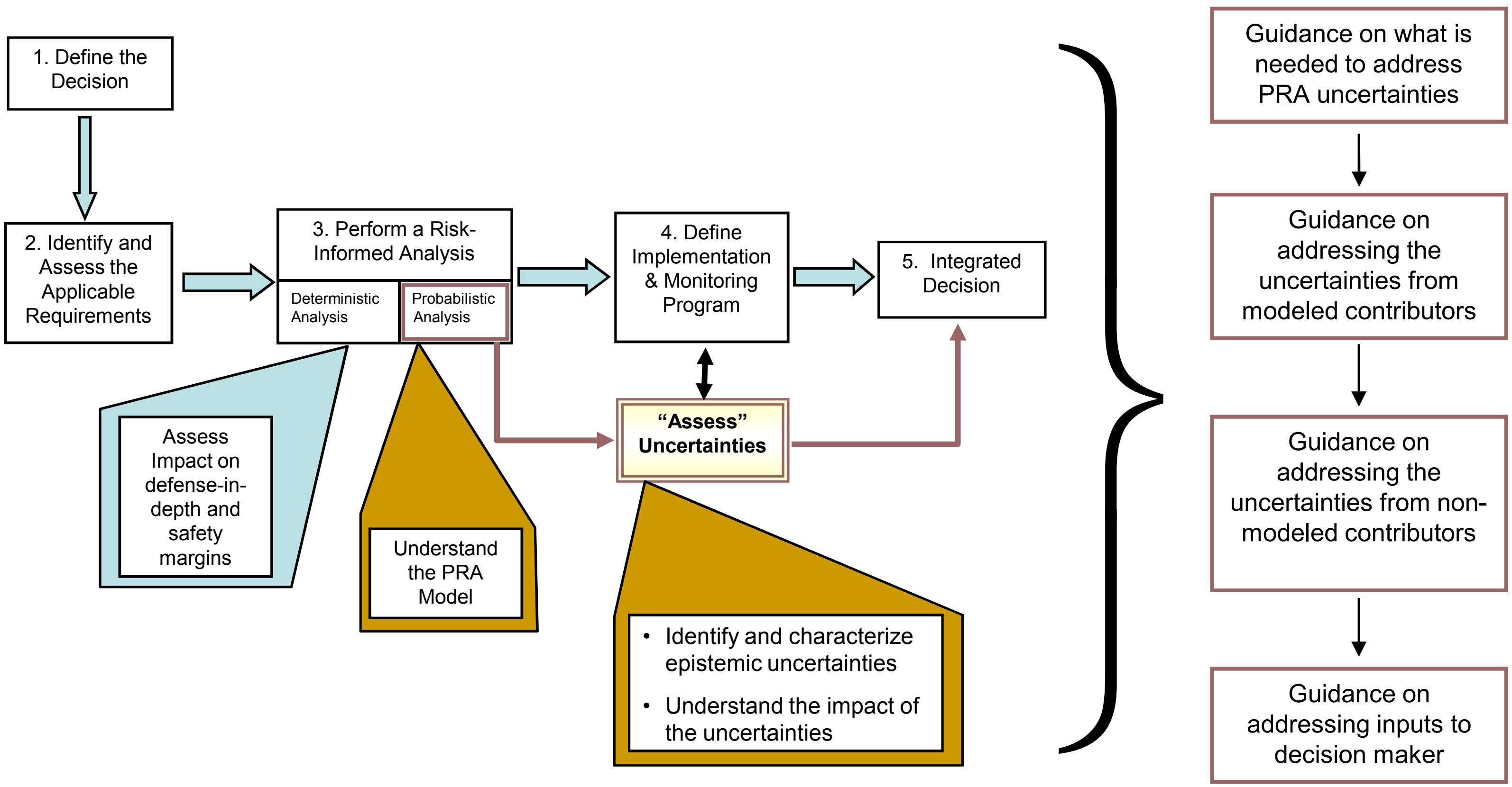
Scope and Limitations (cont'd)

- A model uncertainty needs to be distinguished from an assumption or approximation that is made to limit scope of model (e.g., with respect to level of detail)
- These assumptions and approximations are generally not considered to be model uncertainties
- Methods for addressing this aspect are not explicitly included, but are addressed when assessing the validity of conclusions

To Accomplish the objective. . . .

- Need to understand
  - The risk-informed decisionmaking process
  - The role of the PRA in the process
  - What are the uncertainties
  - How are the uncertainties addressed in the PRA
  - What are the uncertainties that could influence the decision
  - How the results from the uncertainty analyses are factored into the decisionmaking

General Approach



Integrated Decisionmaking Process

Treatment of PRA Uncertainties

Regulatory and Industry Understanding Needed Regarding

- Risk-informed decisionmaking process
  - Define the decision
  - Identify and assess the applicable requirements
  - Perform a risk-informed analysis
  - Define implementation and monitoring program
  - Integrated decision
- PRA model
  - Identification of results needed
  - Construction of model to generate needed results
  - Comparison of results to acceptance guidelines
  - Documentation of conclusions

Regulatory and Industry Understanding Needed Regarding

- PRA standard
  - Characterization of parameter uncertainties
  - Calculation of event probabilities
  - Calculation of core damage frequency (CDF) and large early release frequency (LERF) and associated uncertainty interval
  - Identification of sources of model uncertainty
  - Characterization of model uncertainties and related assumptions
- Types of epistemic uncertainties
  - Parameter
  - Model
  - Completeness

Uncertainty From Modeled Contributors – Parameter Uncertainties

- Objective is to provide guidance for
  - Meeting the Supporting Requirements (SRs) related to parameter uncertainty of the ASME/ANS PRA Standard
  - Characterizing parameter uncertainty for basic event and risk metrics
  - Detailed and approximate methods

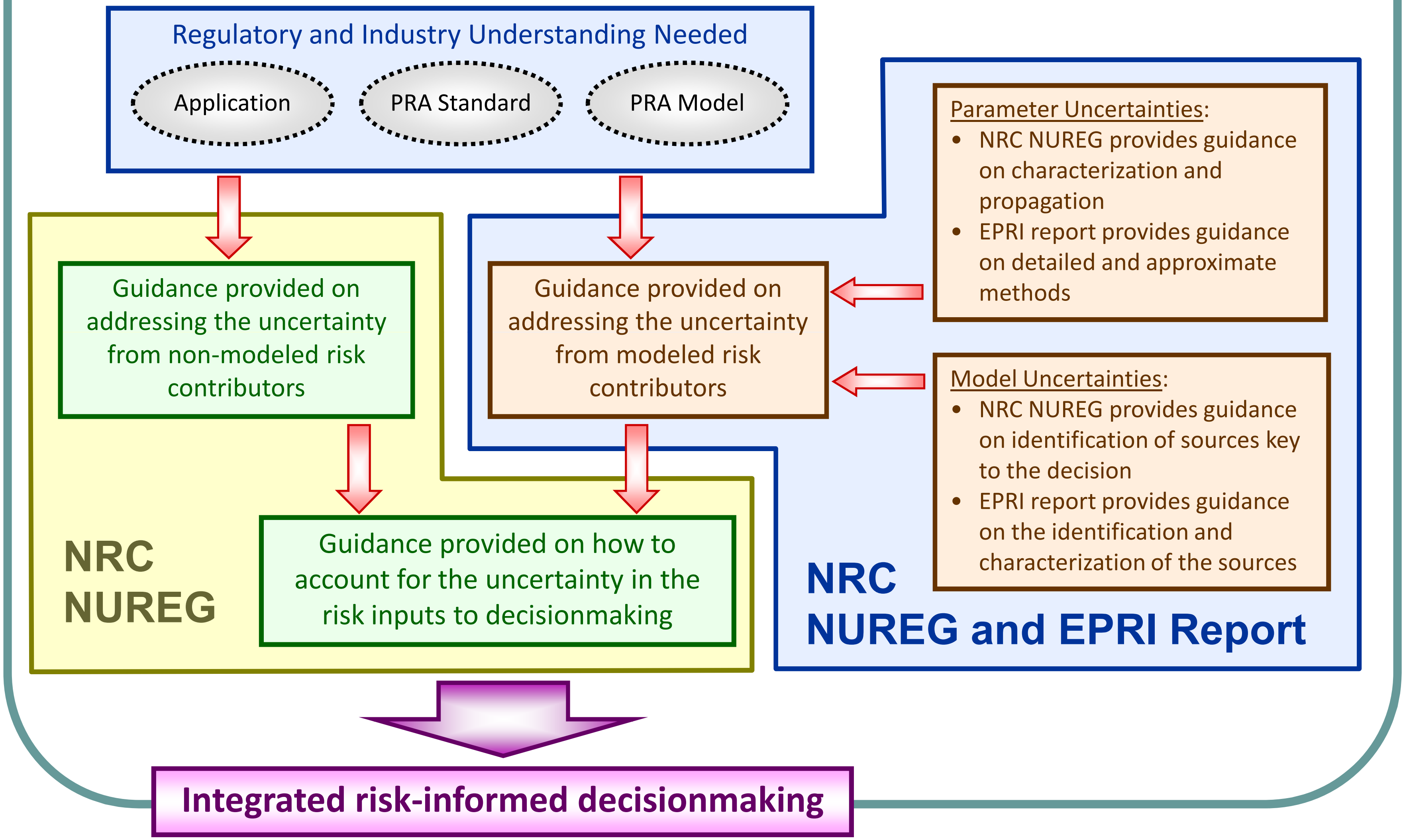
Uncertainty From Modeled Contributors – Model Uncertainties

- Objective is to provide guidance for
  - Meeting the SRs related to model uncertainty of the ASME/ANS PRA Standard
  - Understanding concepts of key sources of model uncertainty
  - Process to identify and characterize realistic key sources
  - Process to develop generic list of uncertainties and their characterization for application relevance

Uncertainty From Non-Modeled Contributors

- Standard does note that if an item is not included in the PRA, “other alternatives” (e.g., bounding analyses) can be used, but when used, is outside the scope of the standard
- Objective is to provide guidance on
  - Defining the types of screening and conservative/bounding analyses
  - Selecting and using screening and conservative/bounding approaches

NRC NUREG and EPRI Report Roadmap



Risk Model

Understanding the Risk Model

- Defining the risk assessment needed
- Understanding the features of a PRA that impact confidence in the results
  - Scope and level of detail
  - Approximations
  - Uncertainty
- Overview of the sources of uncertainty and how they are addressed

Defining the Risk Assessment

- Principal steps:
  - Identify results required
    - Guidance documents (e.g., RG 1.177, NEI 00-04)
      - Acceptance guidelines
  - Construct the risk model to generate the results
    - Modification of base PRA model
  - Compare results to acceptance guidelines
  - Document results

Results Required: Example

- RG 1.174
  - Acceptance guidelines given in terms of CDF and ΔCDF, and LERF and ΔLERF
    - Defines numerical results required
  - All contributors (i.e., hazard groups and plant operating states) to risk are to included
    - Defines the scope of the assessment of risk, but not necessarily the scope of the PRA

Construct the Risk Model

- General guidance on using a PRA model given in EPRI PSA Applications Guide and RG 1.174
  - Determine cause-effect relationship for the issue being addressed
  - Modify the base PRA as necessary
- Guidance for specific applications, e.g., NEI 00-04, RG 1.177
- For regulatory applications, Commission Phased Approach to PRA Quality identifies scope of PRA model to include all significant contributors to CDF/LERF

Comparison of Results to Acceptance Guidelines

- As discussed in subsequent slides, the results are subject to uncertainty
- Robustness of the results needs to be demonstrated in order to have confidence in the decision being made
- Level of confidence has to be conveyed to the decision maker using the conclusions of the risk assessment

Characteristics of a PRA Model

- Structure of a PRA model
- Scope
- Level of detail
- Assumptions associated with the model
- Combining results from different hazard groups

Characteristics of a PRA Model (Cont'd)

- Structure:
  - Logic model (event trees and fault trees) that represents a simplification of the potentially unlimited set of scenarios into a manageable representative set in as realistic a way as practicable
  - The elementary units of the model are basic events
  - Probabilities (frequencies) of basic events derived from probability models

Characteristics of a PRA Model (Cont'd)

- Scope of PRA model
  - Risk metrics addressed, e.g.,
    - Level 1 (CDF)
    - Limited level 2 (CDF and LERF)
  - POSs
    - At-power
    - Low power and shutdown
  - Hazard groups, e.g.
    - Internal events
    - Internal flood
    - Internal fire
    - Seismic
    - Etc.
- Level of detail
  - What is required is determined by the application

Characteristics of a PRA Model (Cont'd)

- Assumptions in the PRA model:
  - Related to scope or level of detail
    - Assumptions made to simplify the model
      - Grouping initiating events
      - Assume room cooling is necessary
  - Related to a model uncertainty
    - Assumptions made to respond to incomplete knowledge about how to model certain aspects

Combining PRA Results for Different Hazard Groups

- Concern has been expressed about adding the numerical results from PRAs for different hazard groups, as required by the acceptance guidelines
- Models for different hazard groups may be developed to differing levels of detail or levels of conservatism
  - For example, internal fire and internal flood PRAs use successive screening of fire/flood areas and perform detailed analyses for the most significant
  - Some models are argued to be inherently conservative (e.g., seismic)
- These differences have to be recognized when comparing the results to the acceptance guidelines
  - Will return to this later

PRA Models and Uncertainty

- Two types of uncertainty:
  - Aleatory uncertainty
    - Associated with the random nature of the events being modeled
    - Reflected in the probabilities or frequencies of the basic events
  - Epistemic uncertainty
    - Associated with limitations in our collective knowledge
    - This is the focus of this workshop

Classes of Epistemic Uncertainty

- Parameter uncertainty
  - Imperfect knowledge about the values of parameters of the basic event models
- Model uncertainty
  - Exists when there is no consensus approach to modeling specific phenomena or events
  - Can affect the structure of the logic model, or the form of the probability model for basic events
- Completeness uncertainty
  - Known unknowns – failure modes or mechanisms that are known but not included in the model
  - Unknown unknowns – phenomena or failure mechanisms are unknown

Addressing Epistemic Uncertainty

- The remainder of this first section of the workshop will discuss approaches to addressing these categories of uncertainty and taking the uncertainty into account in the context of a risk-informed decision

ASME/ANS PRA Standard

SRs for Parameter Uncertainty for Basic Events

- IE-C1: CALCULATE the initiating event frequency accounting for relevant generic and plant specific data . . .
- IE-C15: CHARACTERIZE the uncertainty in the initiating event frequencies and PROVIDE mean values for use in the quantification of the PRA results
- HR-D6: PROVIDE an assessment of the uncertainty in the HEPs consistent with the quantification approach. USE mean values when providing point estimates of HEPs.
- HR-G8: Characterize the uncertainty in the estimates of the HEPs consistent with the quantification approach, and PROVIDE mean values for use in the quantification of the PRA results.
- DA-D1: CALCULATE realistic parameter estimates for significant basic events . . . . USE a Bayes update process or equivalent statistical process that assigns appropriate weight to the statistical significance of the generic and plant specific evidence and provides an appropriate characterization of uncertainty, CHOOSE prior distributions as either non-informative, or representative of variability in industry data. CALCULATE parameter" estimates for the remaining events by using generic industry data.
- DA-D3: PROVIDE a mean value of, and a statistical representation of the uncertainty intervals for, the parameter estimates of significant basic events. Acceptable systematic methods include Bayesian updating, frequentist method, or expert judgment.

SRs for Parameter Uncertainty for Risk Metrics

- QU-A3: ESTIMATE the mean CDF accounting for the "state-of-knowledge" correlation between event probabilities when significant. NOTE: This SR has a note briefly describing this correlation.
- QU-E3: ESTIMATE the uncertainty interval of the CDF results. ESTIMATE the uncertainty intervals associated with parameter uncertainties (DA-D3, HR-D6, HR-G9, IE-C13), taking into account the "state-of-knowledge" correlation.
- LE-E4: QUANTIFY LERF consistent with the applicable requirements ….

SRs for Model Uncertainty

- QU-E1: IDENTIFY sources of model uncertainty
- QU-E2: IDENTIFY assumptions made in the development of the PRA model
- QU-E4: For each source of model uncertainty and related assumptions identified in QU-E1 and QU-E2, respectively, IDENTIFY how the PRA model is affected (e.g., introduction of a new basic event, changes to basic event probabilities, change in success criterion, introduction of a new initiating event)
- LE-F3: CHARACTERIZE the LERF sources of model uncertainty and related assumptions, consistent with the applicable requirements of Tables 2-1.4.8-2(d) and 2-1.4.8-2(e) (of the Standard).

Parameter Uncertainties

Guidance Provided on Parameter Uncertainty

- Guidance on meeting the Supporting Requirements (SRs) of the ASME/ANS PRA Standard related to parameter uncertainty:
  - Characterization of parameter uncertainty of basic events
  - Obtaining the mean value and uncertainty interval of a risk metric
- Guidance on when it is acceptable to avoid explicit calculation of the epistemic correlation (EC) [referred to as the state-of-knowledge correlation (SOKC) in the ASME/ANS PRA Standard]

SRs Associated with Uncertainty Characterization

- Certain SRs do not differentiate between capability categories
  - IE-C1, IE-C15, HR-D6 and HR-G8
- Certain SRs do differentiate between capability categories
  - DA-D1 and DA-D3
  - QU-A3, QU-E3 and LE-E4

*Capability category in the standard differentiates a requirement by level of scope and detail, plant-specificity, and realism.

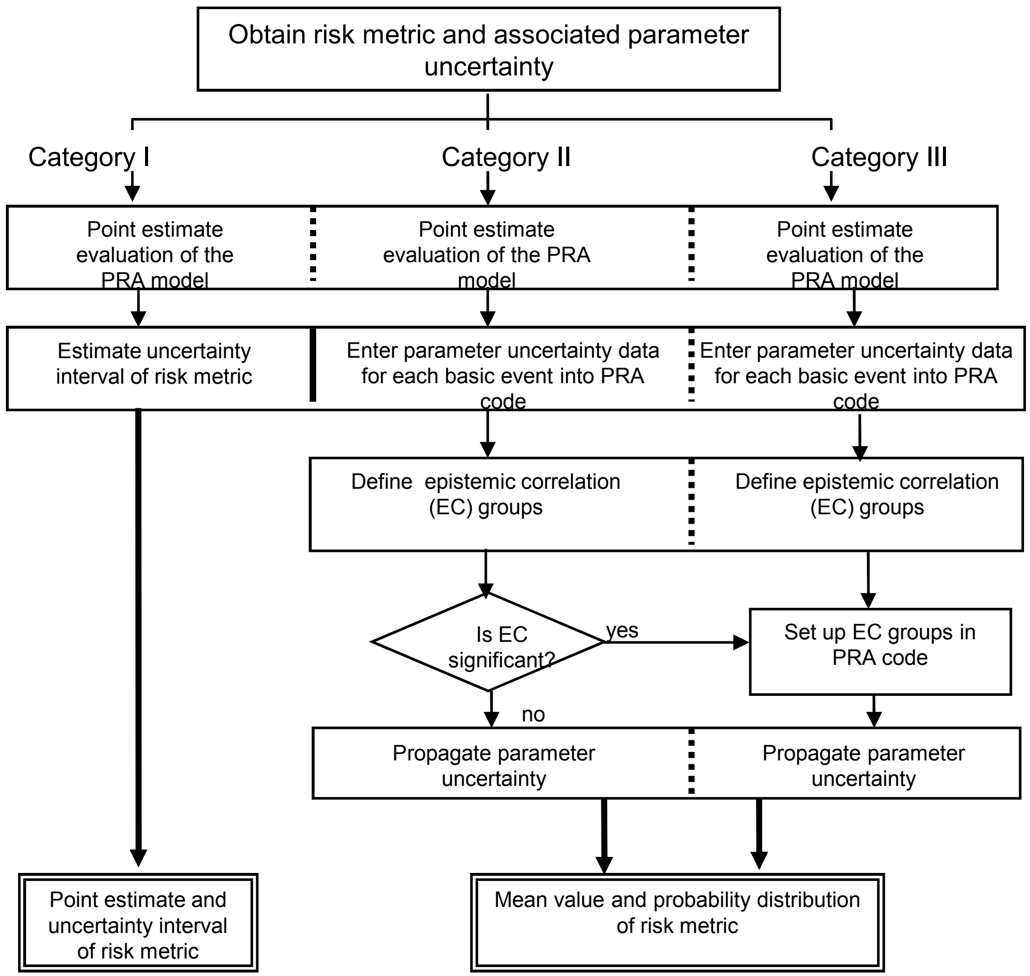
Characterization of the parameter uncertainty of basic events

- Although certain SRs (for IE, HR and DA) use a variety of language, the intent of the SRs related to characterizing parameter uncertainty is the same:
  - Calculate the probability of a basic event
  - Characterize the uncertainty associated with the parameters of the basic event
- Although certain SRs do not differentiate between the CCs, because of their relationship to other SRs that do differentiate among the CCs, this dependency needs to be addressed
  - Use DA-D1 and DA-A3 as guides
- Numerous references exist that can be used to characterize the various types of basic events

Evaluation of a Risk Metric and its Associated Uncertainty

- The SRs for evaluating CDF and LERF differ depending on the CC
- CC I requires only an estimate of the uncertainty interval and its basis
- CCs II and III require that the probability distribution of the risk metric is obtained by propagating the parameter uncertainty through the PRA model
  - The epistemic correlation (EC) (referred to as SOKC in the Standard) must be taken into account
  - For CC II the EC may be ignored if it is shown not to be significant for the case being assessed

Evaluation of a Risk Metric and its Associated Uncertainty



Epistemic Correlation

- Provides guidance for when it is acceptable to use a simplified approach to estimate risk metric and its associated uncertainty
- Current PRA tools support full propagation of parametric uncertainties, including the EC, for base models
- Addressing the EC can be difficult in some cases:
  - Applications relying on importance measures
  - Applications requiring rapid quantification of multiple cases

Guidance for Risk Metric Mean Value Characterization

- Base Model
  - Guideline 1a: Recommended approach for CC II and III is to ensure EC is accounted for and use Monte Carlo or similar approach to calculate mean of risk metric
  - Guideline 1b: Otherwise use PRA from a similar plant that calculates difference between true mean of risk metric and point estimate generated from mean values of basic events
    - Use this difference to estimate mean of risk metric, accounting for EC, of plant being assessed
    - May suffice for CC II but depends on level of detail, etc.
- Application
  - Guideline 2a: Ensure EC is accounted for and use Monte Carlo to calculate mean
  - Guideline 2b: If the risk metric used for application is determined by cut sets that do not involve EC then use point estimate directly (determination may not be practical in some cases)

Guidance for Uncertainty Interval Characterization

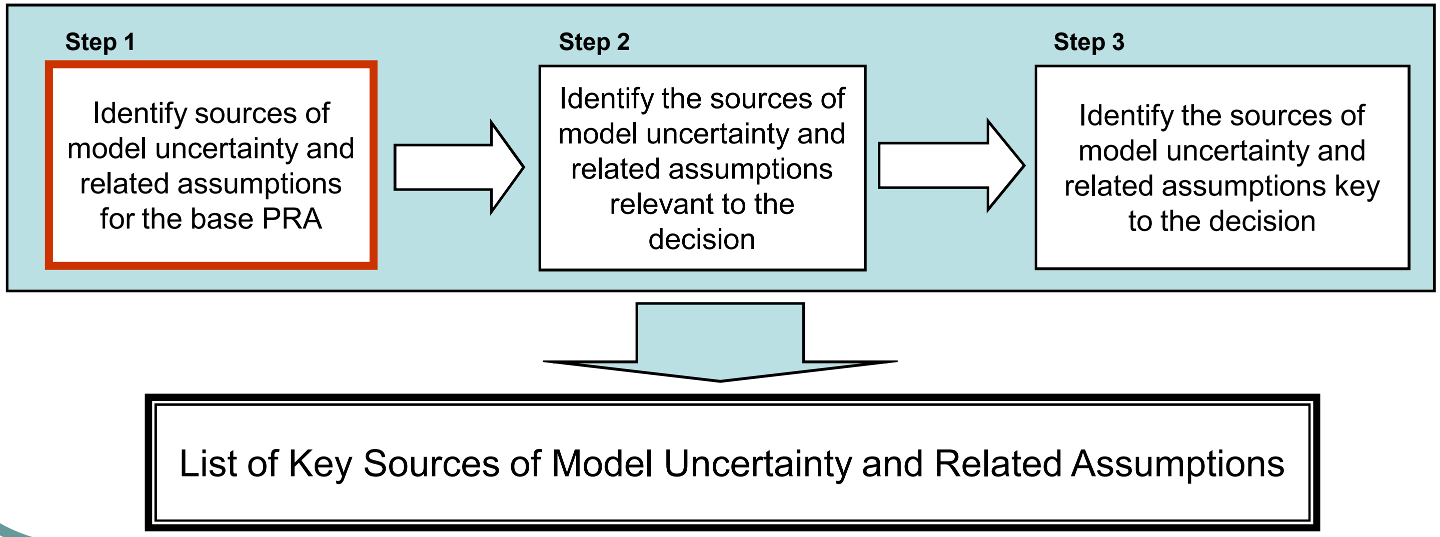
- Base Model
  - Guideline 3a: Recommended method is to ensure EC is accounted for and use of Monte Carlo or similar approach to propagate uncertainty and establish 5% and 95% bound on risk metric
  - Guideline 3b: If above cannot be completed use uncertainty calculated for similar plant with a PRA model that takes EC into account
    - May suffice for CC II but depends on level of detail, etc. – not recommended method
- Application
  - Most applications do not require that uncertainty interval is provided. If it is required, either :
    - Guideline 4a: Demonstrate that uncertainty interval Is not expected to significantly change from the base model uncertainty interval
    - Guideline 4b: Perform another uncertainty propagation, as for the base model above

Model Uncertainties

Identification of Key Sources

Three Step Process:

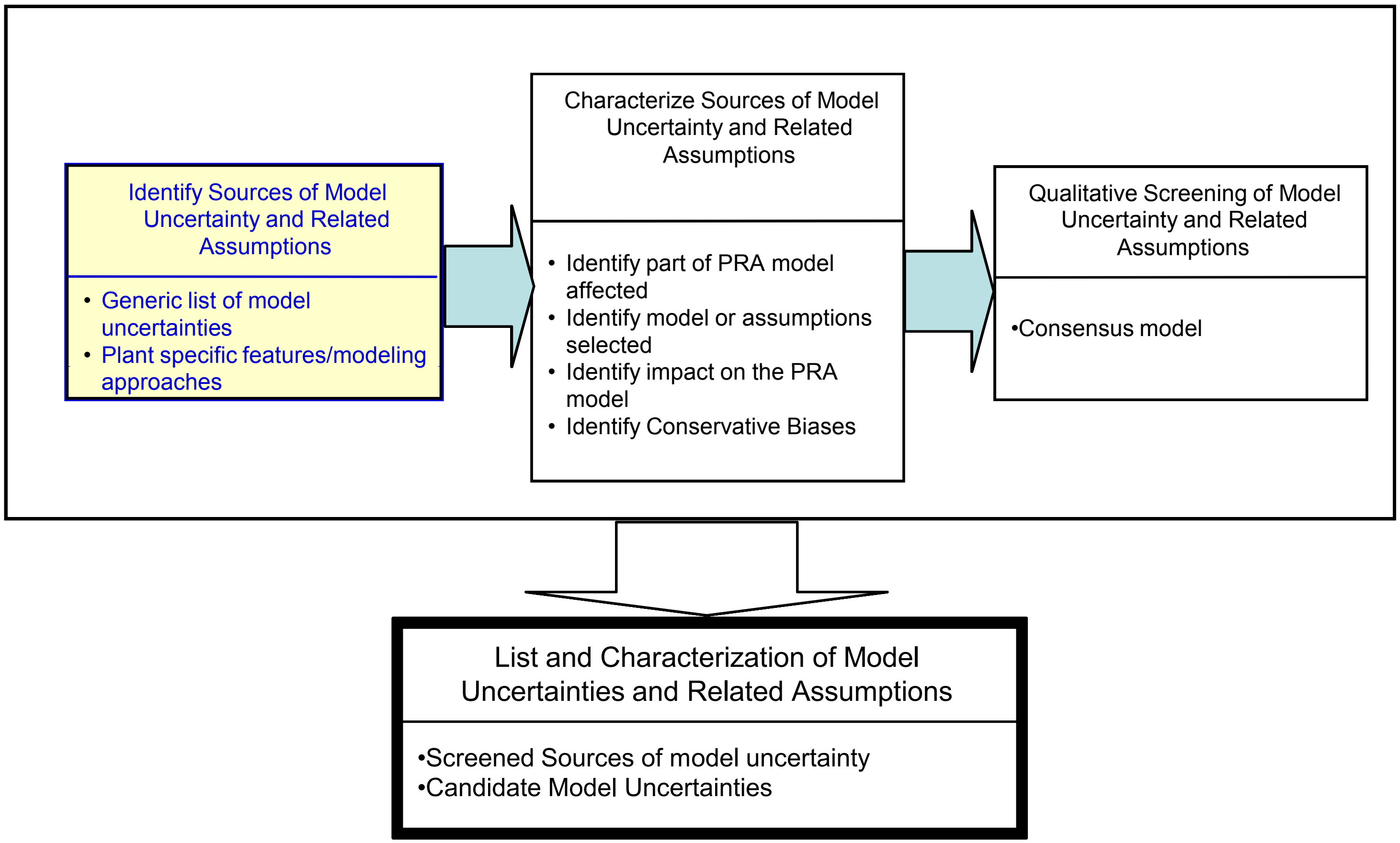
1. Review Base PRA to Identify and Characterize Sources of Model Uncertainties and Related Assumptions
2. Perform Qualitative Analyses – Sources Relevant to Application
3. Perform Quantitative Analyses – Sources Key to Application



ASME/ANS Standard – Model Uncertainties

- Standard only requires analyst to identify and characterize the sources of model uncertainty
- Guidance directed to address QU-E1, QU-E2, QU-E4, and LE-F3 as previously defined as well as the individual sources of model uncertainty documentation requirements for each element

Model Uncertainty Identification, Characterization, and Screening



Definitions

- Consistent with the ASME/ANS Combined PRA Standard
  - Source of model uncertainty
  - Key source
  - Assumption
  - Assumption related to a model uncertainty
  - Reasonable alternative assumption
  - Assumption related to scope or level of detail
  - Key assumption

Model Uncertainty Definition

- A ***source of model uncertainty*** is one that is related to an issue in which there is no consensus approach or model and where the choice of approach or model is known to have an effect on the PRA (e.g., introduction of a new basic event, changes to basic event probabilities, change in success criterion, introduction of a new initiating event).

- A source of model uncertainty is labeled ***key*** when it could impact the PRA results that are being used in a decision and, consequently, may influence the decision being made. Therefore, a key source of model uncertainty is identified in the context of an application. This impact would need to be significant enough that it changes the degree to which the risk acceptance criteria are met and, therefore, could potentially influence the decision. For example, for an application for a licensing basis change using the acceptance criteria in RG 1.174, a source of model uncertainty or related assumption could be considered “key” if it results in uncertainty regarding whether the result lies in Region II or Region I, or if it results in uncertainty regarding whether the result becomes close to the region boundary or not.

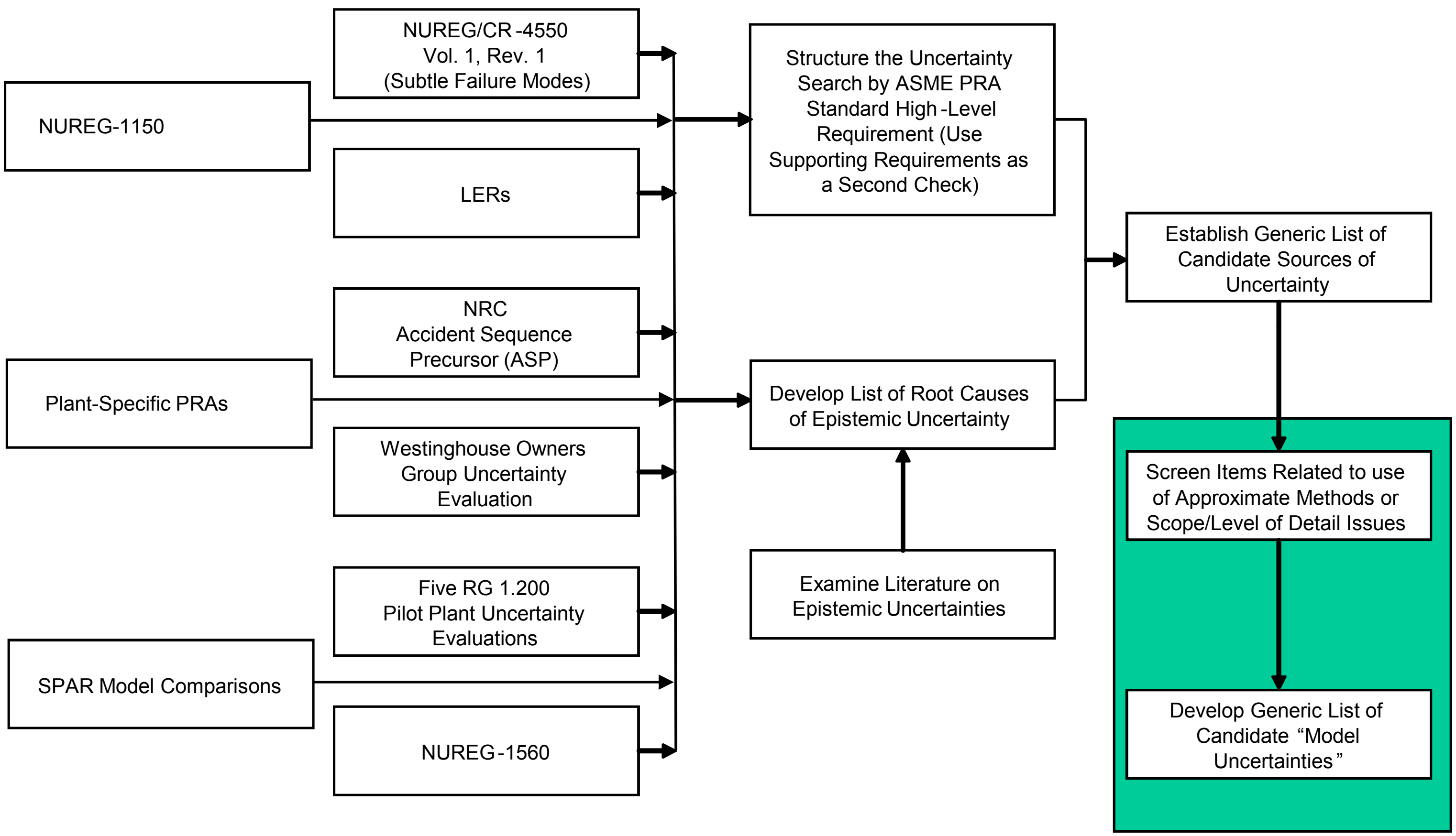
Assumption Definition

- An ***assumption*** is a decision or judgment that is made in the development of the PRA model. An assumption is either related to a source of model uncertainty or is related to scope or level of detail.
- An ***assumption related to a model uncertainty*** is made with the knowledge that a different reasonable alternative assumption exists. A ***reasonable alternative assumption*** is one that has broad acceptance within the technical community and for which the technical basis for consideration is at least as sound as that of the assumption being made.
- An ***assumption related to scope or level of detail*** is one that is made for modeling convenience.
- An assumption is labeled ***key*** when it may influence (i.e., have the potential to change) the decision being made. Therefore, a key assumption is identified in the context of an application.

Candidate Sources of Model Uncertainty

- The phenomena or nature of the event or failure mode is not completely understood,
- Significant interpretations to infer behavior are required to develop a model (this is the case where some information is available, but is not sufficient to derive a definitive model or value), or
- There is a general agreement that the issue represents a potential source of modeling uncertainty.

Process Used to Identify Generic List



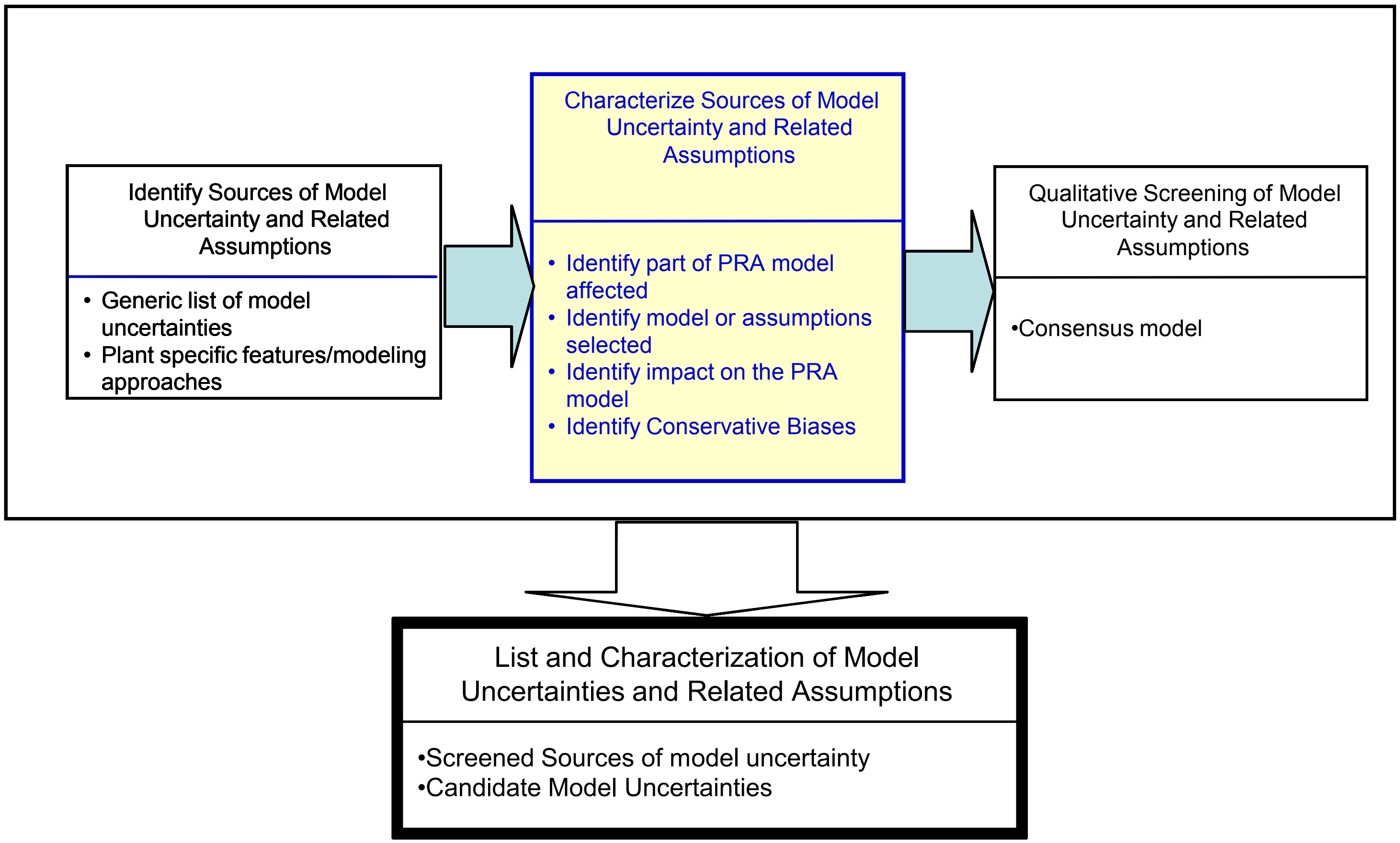
Example Generic Sources

- Initiating Event Analysis
  - Grid stability
  - Support System Initiating Events
  - LOCA initiating event frequencies
- Accident Sequence Analysis
  - Operation of equipment after battery depletion
  - RCP seal LOCA treatment –PWRs
  - Recirculation pump seal leakage treatment – BWRs w/ Isolation Condensers

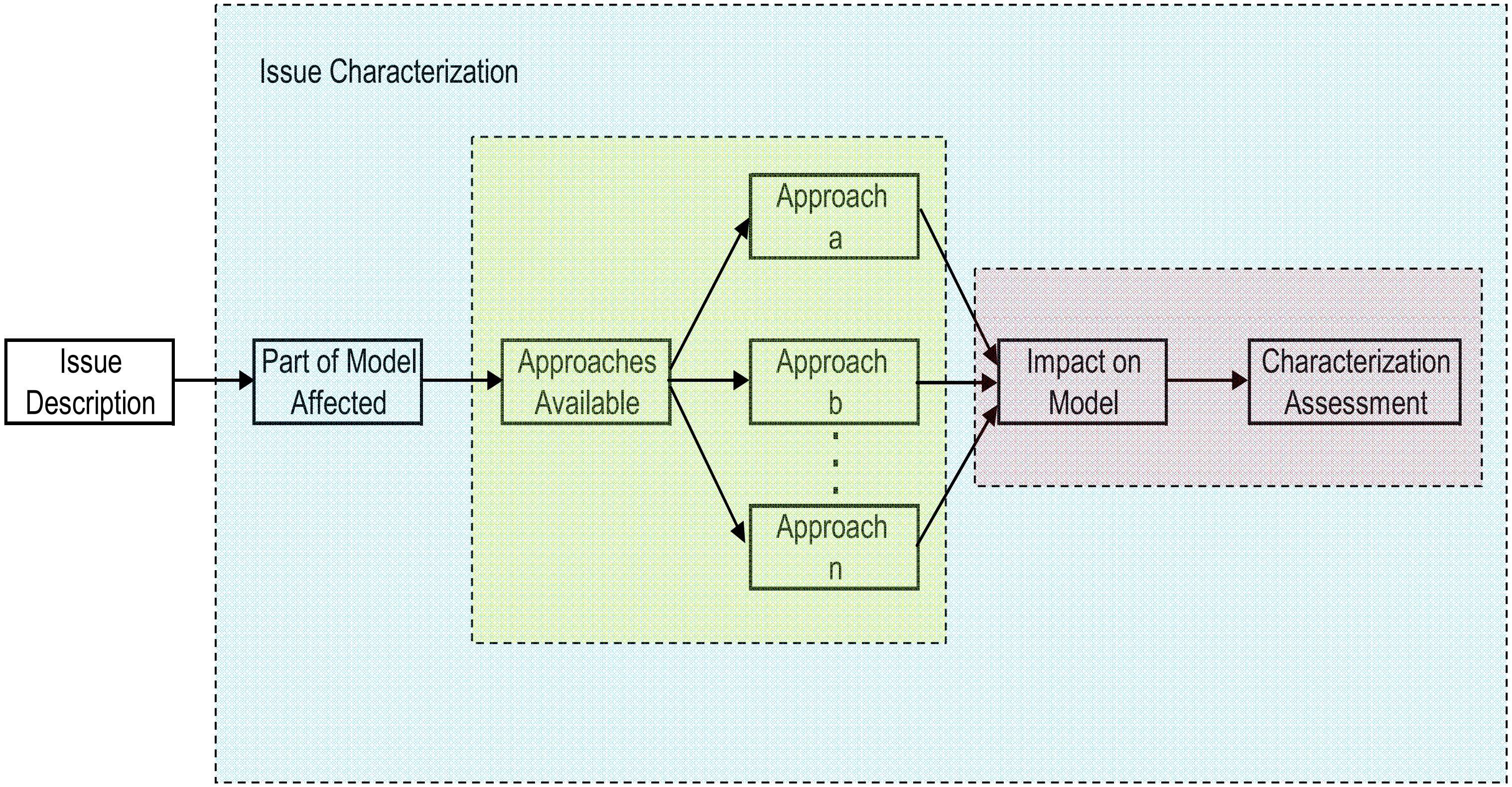
Example Generic Sources (Cont'd)

- Success Criteria
  - Impact of containment venting on core cooling system NPSH
  - Core cooling success following containment failure or venting through non hard pipe vent paths
  - Room heatup calculations
  - Battery life calculations
  - Number of PORVs required for bleed and feed – PWRs

Model Uncertainty Identification, Characterization, and Screening

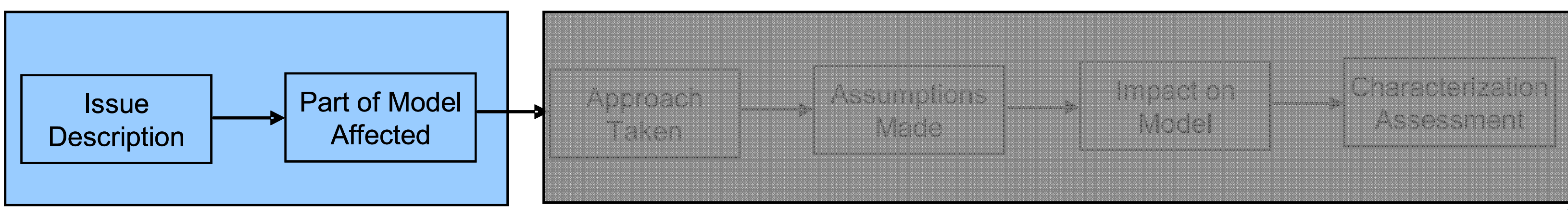


Template for Model Uncertainty Issue Characterization



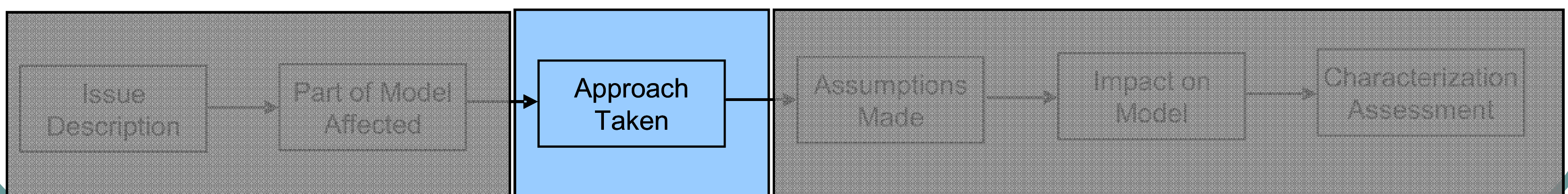
Example Model Uncertainty Issue Characterization Template

- **Issue:** Impact of containment venting on core cooling system NPSH
- **Part of Model Affected:** Loss of containment heat removal scenarios with containment venting successful



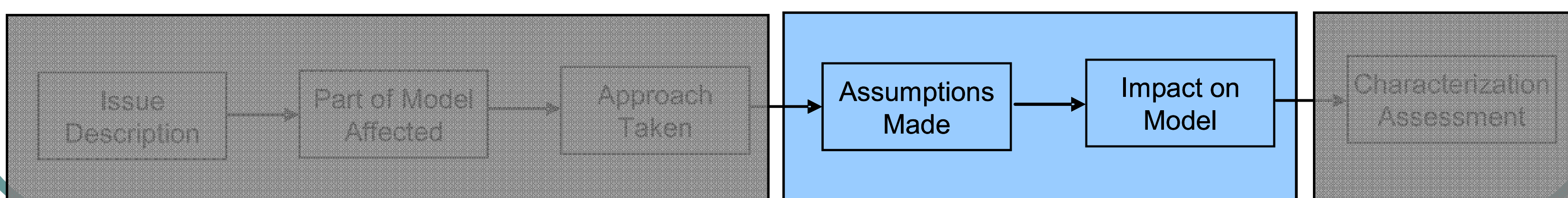
Example Template (cont'd)

- **Possible Approaches (Not Exhaustive)**:
  - No credit for injection from suppression pool following venting
  - Human failure event defined and incorporated into PRA for control of containment pressure in order to assure adequate NPSH
  - Analysis developed to demonstrate continued injection, despite reduction in NPSH
  - Injection from suppression pool assumed to be unaffected by venting



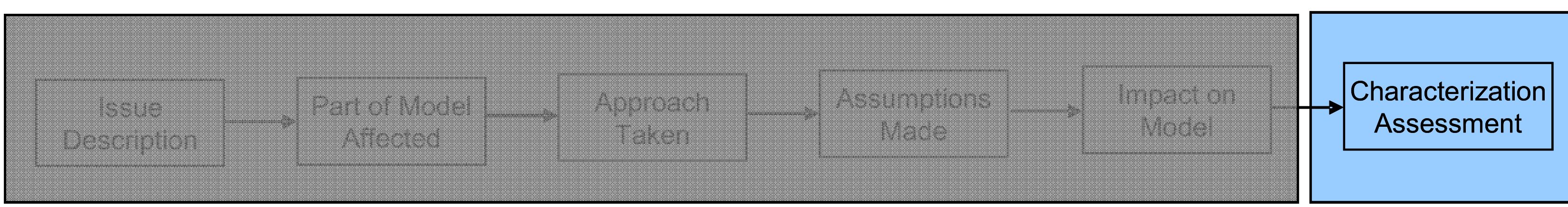
Example Template (cont'd)

- Plant-Specific Characterization
  - **Assumptions Made:** Upon successful initiation of containment venting, it is assumed that NPSH is lost for all systems taking suction from the suppression pool (i.e., HPCI, RCIC, and LP ECCS – CS and LPCI)
  - **Impact on Model:** HPCI, RCIC, LPCI and Core Spray are not credited for success after containment venting

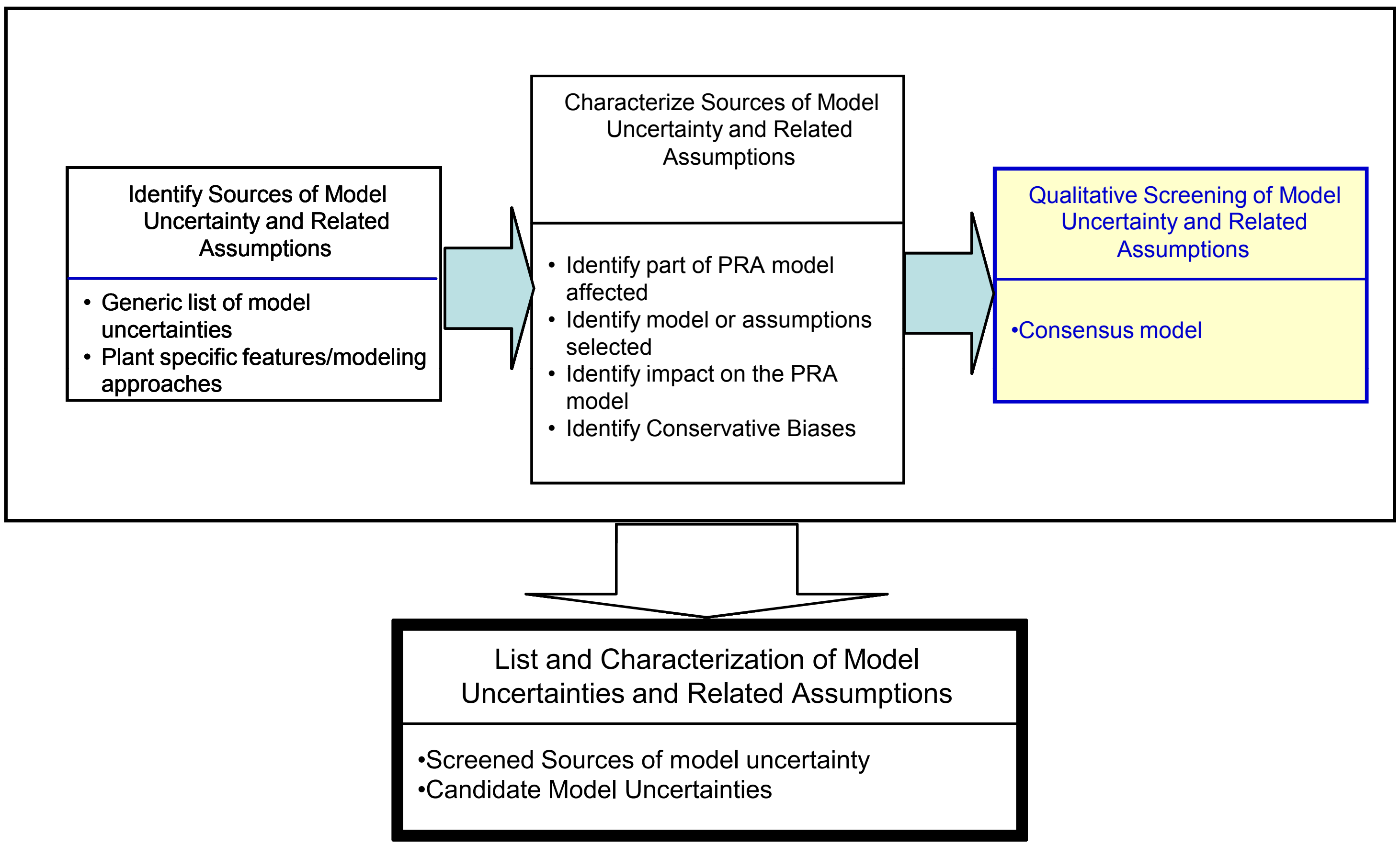


Example Template (cont'd)

- Plant-Specific Characterization
  - **Assessment:** No credit for these systems after containment venting represents a slight conservative bias treatment. This should not be a source of model uncertainty in most applications.



Model Uncertainty Identification, Characterization, and Screening



Consensus Model

- Screen sources that are a consensus model
- Definition:

  In the most general sense, as a model that has a publicly available published basis and has been peer reviewed and widely adopted by an appropriate stakeholder group. In addition, widely accepted PRA practices may be regarded as consensus models. Examples of the latter include the use of the constant probability of failure on demand model for standby components and the Poisson model for initiating events. For risk-informed regulatory decisions, the consensus model approach is one that the NRC has utilized or accepted for the specific risk-informed application for which it is proposed.

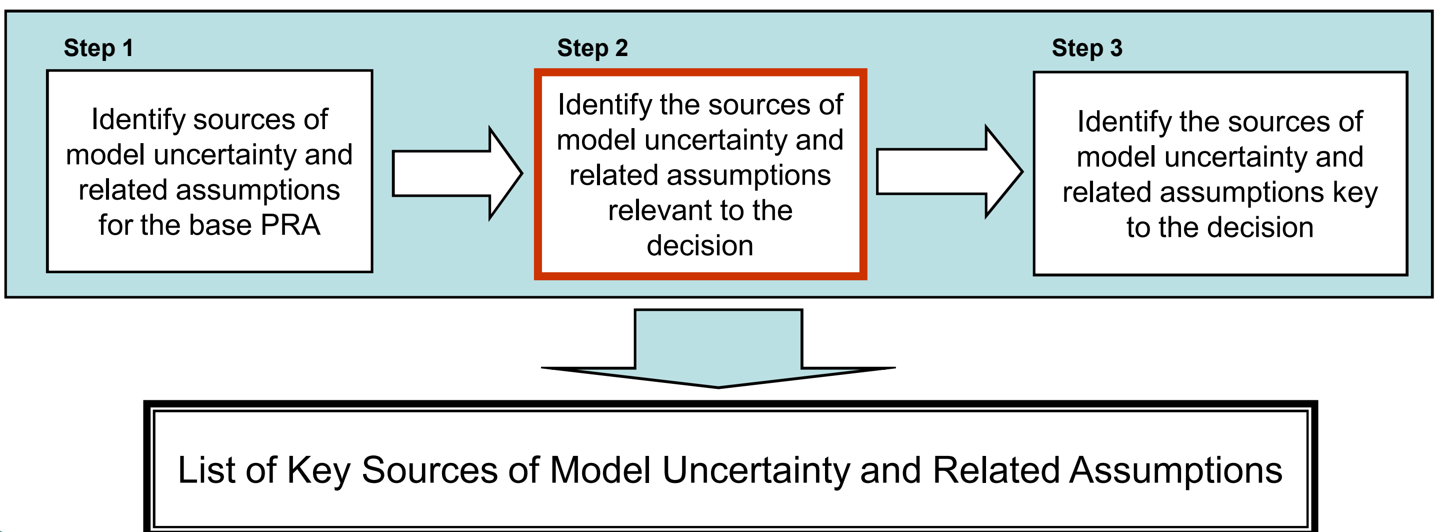
Model Uncertainties – Base Model Assessment

- Conclusions
  - Candidate generic sources of model uncertainty identified
  - Framework established for the identification and characterization of sources of model uncertainty for base model to address QU-E1, QU-E2, QU-E4, QU-F4, LE-F3, IE-D3, AS-C3, SC-C3, SY-C3, HR-I3, DA-E3, LE-G4, IFPP-B3, IFSO-B3, IFSN-B3, IFEV-B3, and IFQU-B3
  - Framework established for the assessment of key sources of uncertainty for applications

Identification of Key Sources

Three Step Process:

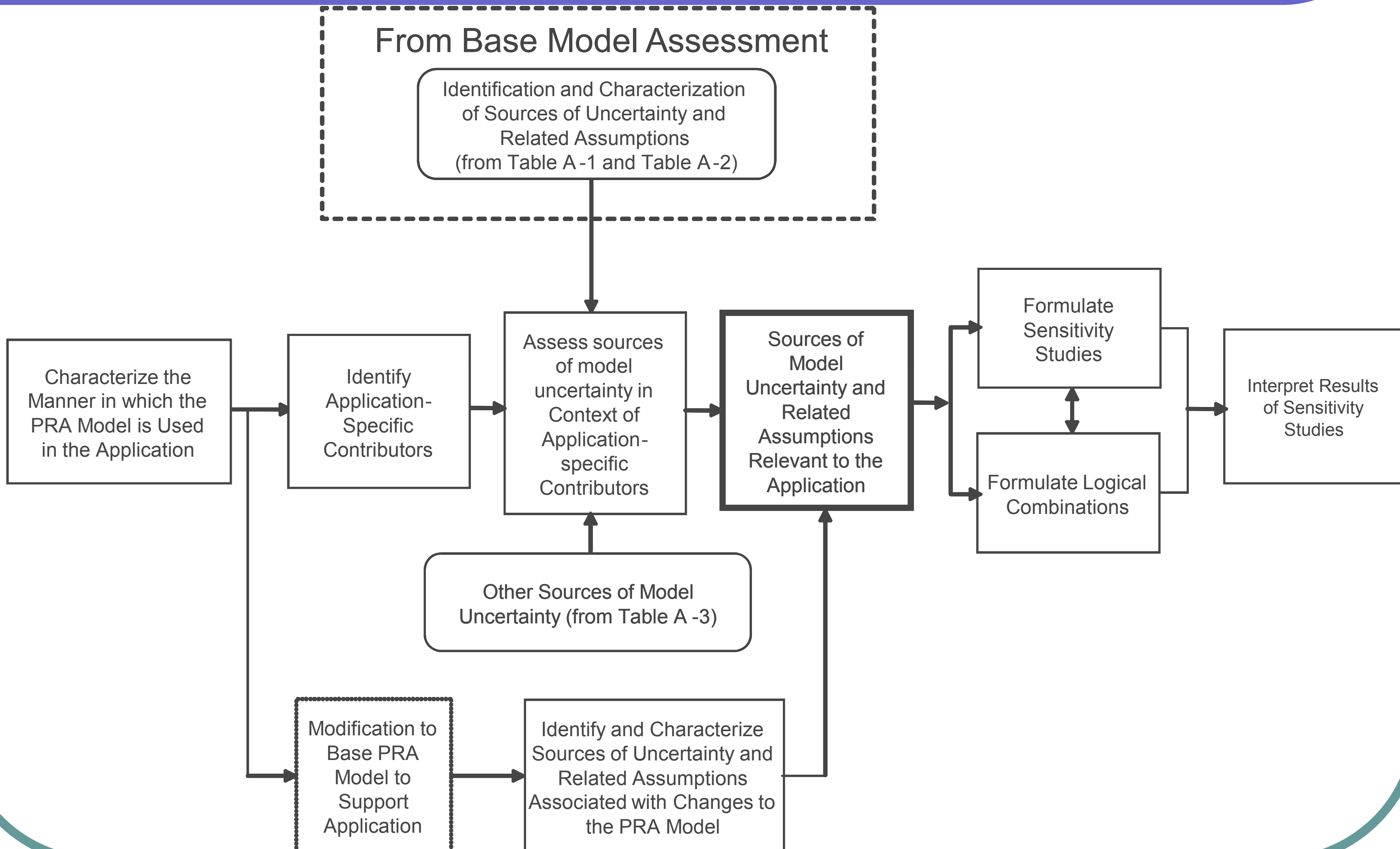
1. Review Base PRA to Identify and Characterize Sources of Model Uncertainties and Related Assumptions
2. Perform Qualitative Analyses – Sources Relevant to Application
3. Perform Quantitative Analyses – Sources Key to Application



Sources Relevant to Application

- Generic and plant specific sources of uncertainty must be evaluated as to their relevance to an application
  - Perform qualitative analyses
- Identify new model uncertainties introduced by modified PRA

Application Relevant Sources



Understanding the Application

- How is PRA used for application?
- Identify sources of model uncertainty in Base PRA relevant to application
- Identify & characterize relevant sources of uncertainty due to modified PRA
  - Introduced by changes to base PRA to address application

How is PRA Used for Application?

- What results are needed?
  - Decision?
  - Acceptance guidelines?
    - These define the PRA results needed.
      - Single metric – e.g., CDF
      - Two dimensional – e.g., RG 1.174 (Δ CDF vs. CDF)
- Establish cause-effect relation between decision & PRA model
  - Which parts of base PRA needed – part, all?
  - How will base PRA be modified?
    - New basic events
    - New estimates of existing events
    - Change logic structure
    - Combination of these

Assessing Sources of Uncertainty of Base PRA

- Relevance to part of PRA used in application
  - Eliminate sources of uncertainty not relevant to those portions of the base PRA being used in the application
    - e.g., AOT for DG only requires LOSP sequences
    - Uncertainties unrelated to LOSP sequences can be eliminated as potentially key

Assessing Sources of Uncertainty of Base PRA (cont'd)

- Screen sources of uncertainty not important to the results
  - Identify and understand significant contributors
    - Sometimes this is straightforward, e.g., when source of uncertainty can be directly associated with a significant basic event
    - Sometimes more subtle
      - Certain events can be dominant due to modeling approximations, e.g., if a preferred system is assumed incapacitated by an IE, then secondary systems may appear as significant for that IE.
      - Examine cut sets, understand underlying assumptions
    - Consider assumptions that cause events to be non-significant
- This requires in-depth understanding of assumptions underlying the logic model
  - Absent such understanding, do not screen out potential sources of uncertainty. Assess all sources (Step 3).

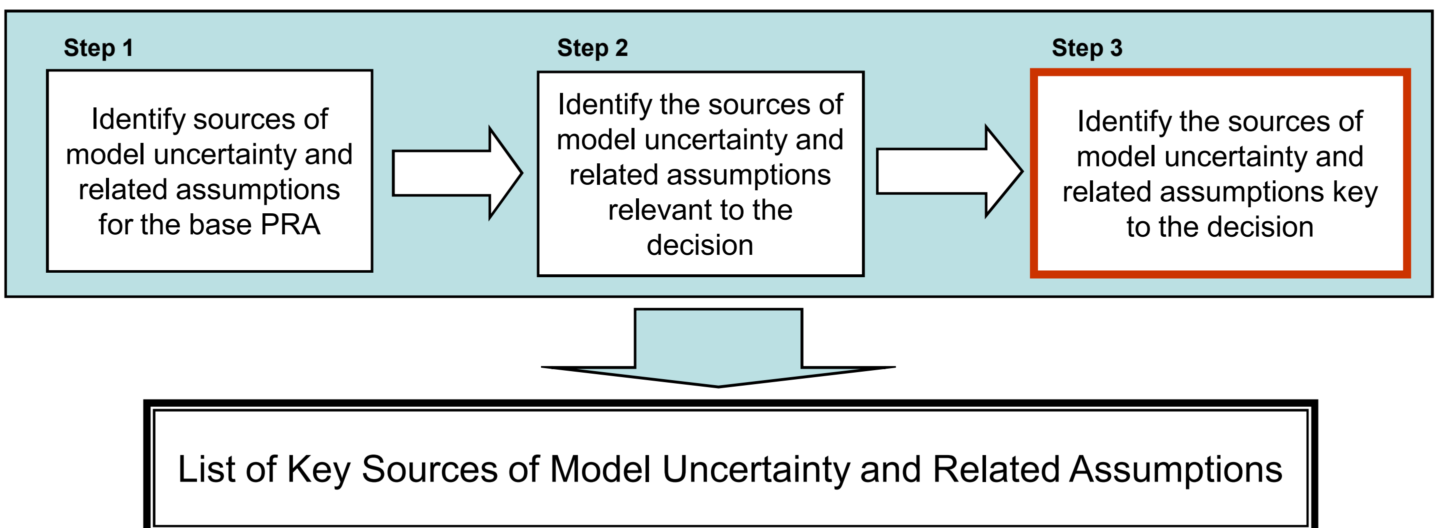
Assessing Sources of Uncertainty of Modified PRA

- Modifications to PRA may introduce new sources of uncertainty
- The process of Step 1 is repeated for the modifications to the PRA
  - Review modifications against applicable ASME/ANS PRA Standard SRs

Identification of Key Sources

Three Step Process:

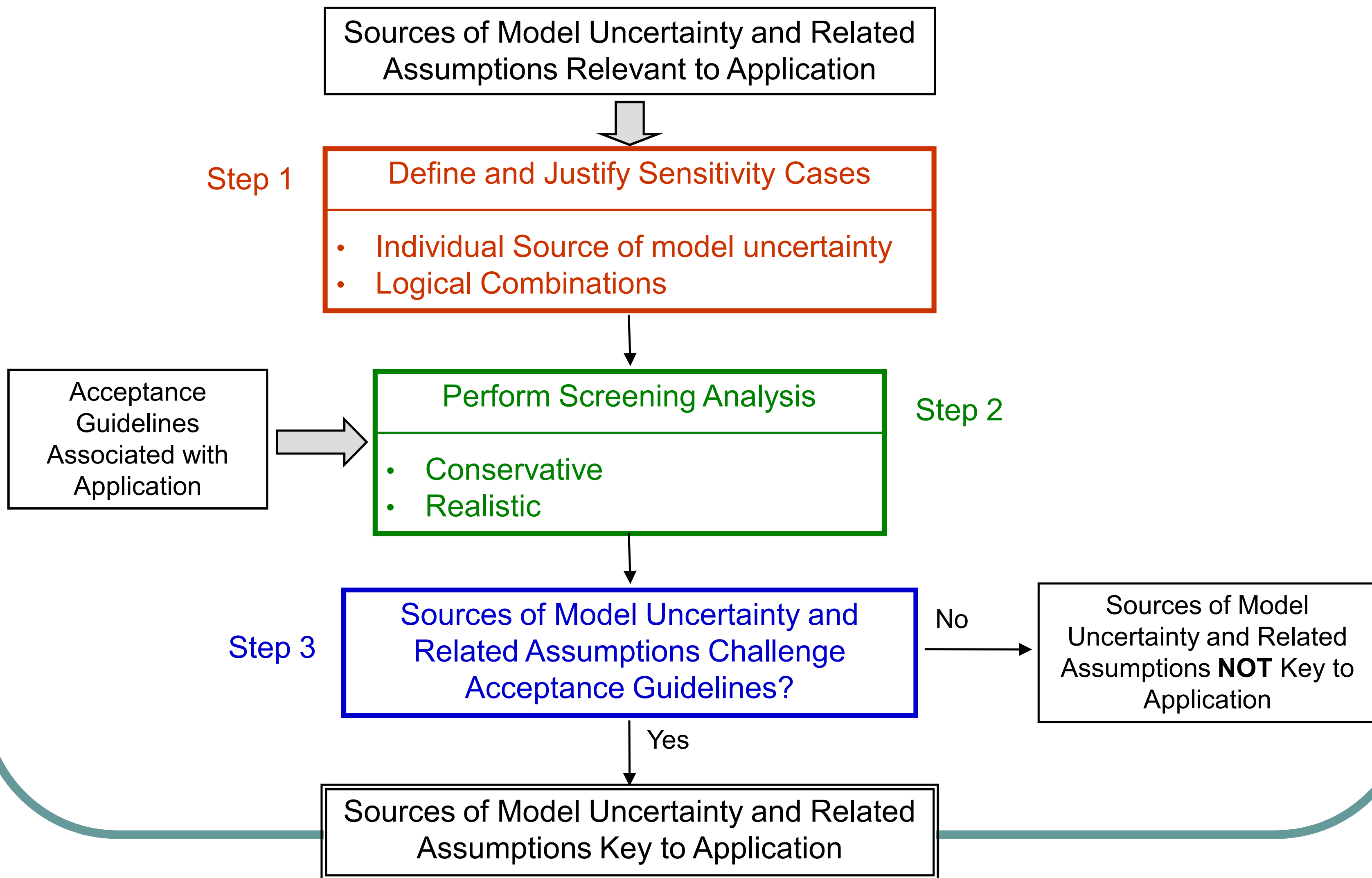
1. Review Base PRA to Identify and Characterize Sources of Model Uncertainties and Related Assumptions
2. Perform Qualitative Analyses – Sources Relevant to Application
3. Perform Quantitative Analyses – Sources Key to Application



Sources Key to Application

- Relevant sources of uncertainty must be evaluated to determine if key or not
  - Conservative assessment
    - Screening for identify potential key sources
  - Realistic assessment
    - Utilizes realistic sensitivity analyses to identify actual key sources

Three Step Process Used to Identify Key Sources



Define & Justify Sensitivity Analyses

- Define acceptable, realistic sensitivity analysis
  - Develop/Identify reasonable alternatives
    - Broad acceptance in technical community
    - Sound technical basis
  - Requires in-depth understanding of the issues associates with the source of model uncertainty.

Perform Screening Sensitivity Analyses

- Analyst can choose either path
  - Conservative screening
    - Conservative analysis 1st - followed by realistic sensitivity analysis if necessary.
      - Conservative Analysis (e.g., set basic event values to 1) challenge acceptance criteria?
        - No – source of uncertainty is not key.
        - Yes – Need to go to realistic uncertainly analysis
  - Realistic sensitivity analysis
    - Analyst can choose to bypass conservative analyses

Perform Screening Sensitivity Analyses (cont'd)

- The sensitivity analysis is impacted by two attributes:
  - Characterization of the source of uncertainty:
    - Single basic event
    - Multiple basic events
    - The logic structure of the PRA
    - Logical combinations of uncertainties
  - The acceptance guidelines
    - Single metric (using base PRA only)
    - Two metric (using modified PRA)

Conservative Screening Path

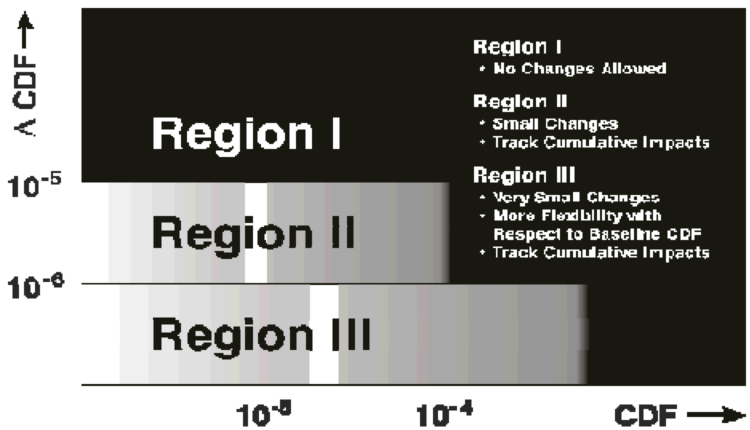
- Single basic event
  - Set value = 1
- Multiple basic events
  - Set all relevant basic events = 1
- Logic structure of PRA model
  - Bounding evaluations
- Logical combinations
  - Set all relevant basic events = 1
- In all cases, reevaluate base PRA and/or modified PRA as appropriate
  - e.g., new CDF, new ΔCDF

Realistic Sensitivity Screening Path

- Single basic event
  - Set basic event to realistic values
- Multiple basic events
  - Set each basic event to realistic values
- Logic structure of PRA model
  - Develop reasonable options for alternate models
  - Requantify PRA for each reasonable alternate model
- Logical combinations
  - Select reasonable options for alternate models for the relevant issues
  - Requantify PRA for each reasonable alternate model

Determine if Application Acceptance Guidelines Challenged

- Acceptance guidelines challenged?
  - No – source is not key
  - Yes – key source



Completeness

Completeness Uncertainty

- ASME/ANS PRA Standard indicates that if an item is not included in the PRA, “other alternatives” (e.g., bounding analyses) can be used
  - Bounding analyses is addressed in the external hazards portion of ASME/ANS PRA Standard
- Guidance provided on one aspect of completeness uncertainty (i.e., incomplete PRA scope or level of detail) in risk-informed applications
  - Guidance involves the performance of screening (qualitative and quantitative) and conservative/bounding analyses

Guidance on Completeness Uncertainty

- Guidance for
  - Determining the required scope and level of detail required to support an application
  - Defining the types of screening and conservative/bounding analyses
  - Selecting and using screening and conservative/bounding approaches
- Major issues . . .
  - What constitutes a conservative/bounding analysis
  - What makes a conservative/bounding analysis acceptable

How to Address Missing PRA Scope

Four options:

1. Upgrade the PRA to address the required scope or level of detail
2. Use a screening analysis to demonstrate that the missing scope items are not significant to the decision
3. Use a conservative analysis to quantify the risk from missing contributors
4. Modify the application such that missing scope or level of detail does not affect decision

Approach for Addressing Completeness Uncertainty

- Two step process for Options 2 and 3
  - Step 1: Determine the PRA Scope and Level of Detail Required to Support an Application
  - Step 2: Perform Screening and Conservative Analyses

Step 1: Determine Required PRA Scope and Level of Detail

- Understand the decision and application
  - Cause-and-effect relationship between the application and its impact on risk
- Establish the needed PRA scope in terms of:
  - Metrics used to evaluate risk
  - POSs for which risk is to be evaluated
  - Types of hazard groups and initiating events
- Establish the needed PRA level of detail
  - PRA models need to be of sufficient detail to ensure the impact of the application can be assessed

Step 2: Perform Screening and Conservative Analyses

- Screening Analysis – demonstrate missing PRA item can be eliminated from consideration
  - Qualitative screening
  - Quantitative screening
    - Realistic
    - Conservative
- Conservative Analysis – used to either:
  - Screen the risk contribution from missing PRA item from the risk assessment
  - Bound the risk contribution for consideration in application decision

Screening vs. Conservative Analysis

- Screening analysis can involve limited but realistic or conservative analyses
- Conservative analysis can range from analyses that are demonstrably conservative (compared to realistic analyses) to truly bounding assessments (reflect the worst possible outcome)

Screening Analysis - Qualitative

- Examples of screening analyses
  - Qualitative – missing item can not impact risk or is not important to change in risk associated with proposed plant modification
    - At-power tech spec change would not impact risk during LPSD
    - Plant change would not impact SSCs relied upon to mitigate a specific hazard (e.g., seismic)
    - Plant change would not impact risk potential from hazards (e.g., fire or flood) in specific areas

Screening Analysis - Quantitative

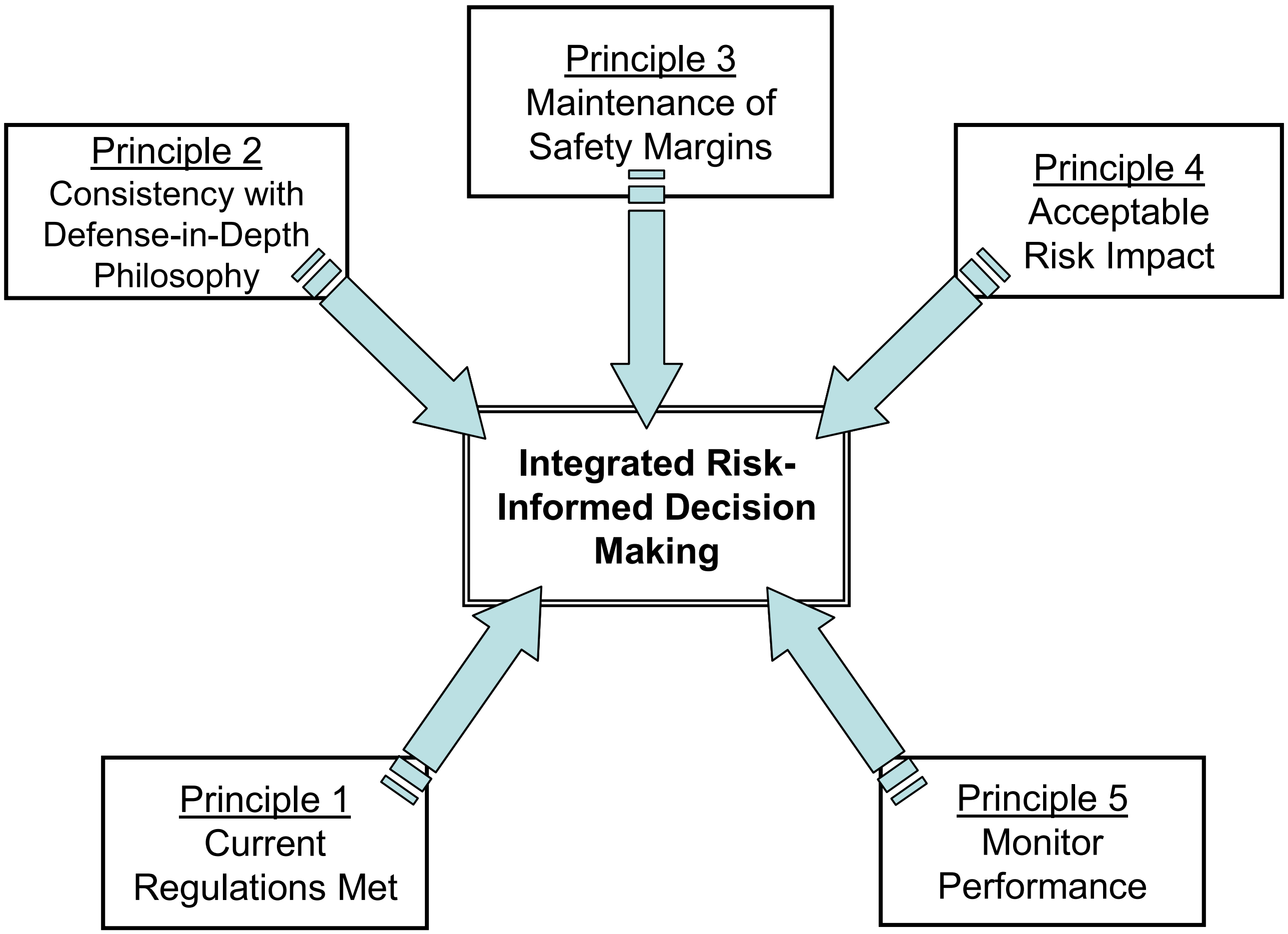
- Examples of screening analyses
  - Quantitative – missing item has a small impact on change in risk associated with proposed plant modification
    - Realistic or conservative/bounding thermal-hydraulic analysis shows missing event can not result in plant damage (e.g., loss of HVAC or pressurized thermal shock)
    - Limited/realistic or conservative/bounding assessment indicates frequency of a hazard is less than 10^{-7}/yr
    - Limited/realistic or conservative/bounding assessment indicates frequency of a hazard is less than 10^{-5}/yr and conditional CDF (CCDF) is less than 0.1
    - Limited/realistic or conservative/bounding assessment indicates CDF from missing event is less than 10^{-6}/yr and LERF is less than 10^{-7}/yr

Conservative/Bounding Analysis

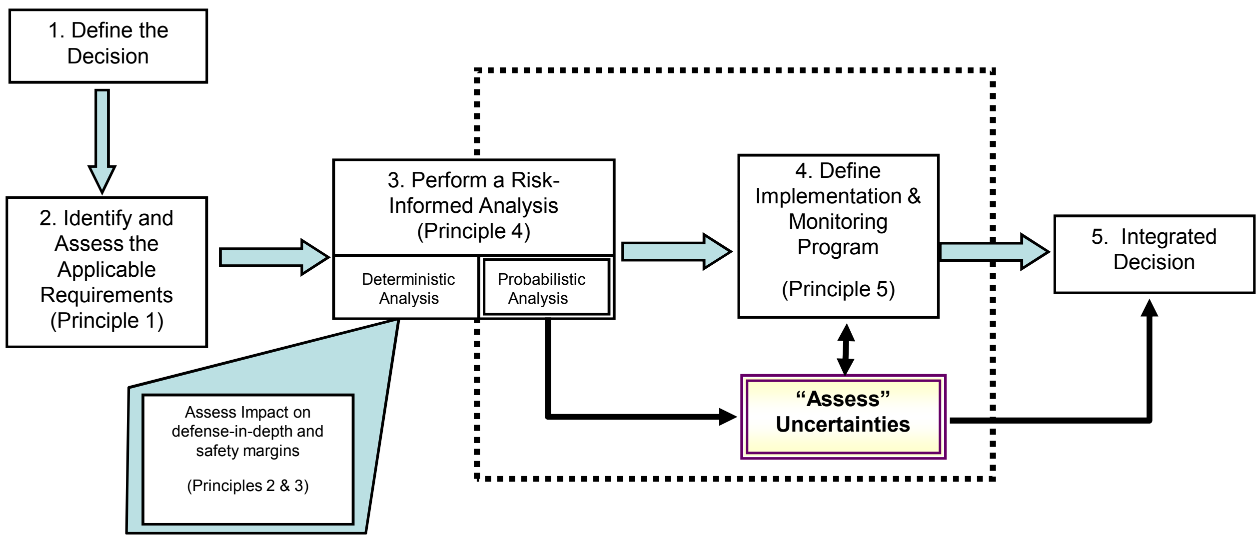
- Examples of conservative/bounding analyses
  - Simplified or detailed risk assessment using conservative/bounding hazard frequencies, structures, systems, and components (SSCs) failure probabilities, and consequences (e.g., all SSCs could be assumed to fail from an airplane crash leading to core damage)
  - Conservative/bounding deterministic analyses (e.g., determining the ultimate strength of the containment)

Addressing Uncertainty in Risk-Informed Decisionmaking

Principles of Risk-Informed Decisionmaking



Elements of Risk-Informed Decisionmaking



Process Overview

- Description of the risk assessment
- Comparison with acceptance guidelines
- Presentation of results

Description of the Risk Assessment

- Scope of the risk assessment
  - Determined by the relevance of the hazard groups or plant operating states (risk contributors) to the application
- The PRA model
  - Scope of PRA model determined by significance of relevant risk contributors to the application
- Use of the PRA model
  - Generate results to be compared with acceptance guidelines

Comparison with Acceptance Guidelines

- Although the comparison with the acceptance guidelines is quantitative, understanding the contributors to the numerical results is essential to establishing confidence in the conclusions drawn from the comparison
  - PRA models for different contributors vary in level of detail and level of realism
  - Different sources of uncertainty affect different contributors

Comparison with Acceptance Guidelines – Understanding the Results

- Identifying conservative or non-conservative bias
  - Level of detail
    - Model assumptions and approximations
- Decomposition of results
  - Hazard group
    - Differing approaches to modeling of hazard groups introduces different biases
    - Unique sources of model uncertainty
  - Significant accident sequences or cut sets
  - Significant basic events
  - Identify relevant sources of uncertainty

Comparison with Acceptance Guidelines – Addressing Uncertainty

- Parameter uncertainty
  - Acceptance guidelines specify how to perform the comparison
    - Typically it is the mean value of the metric (CDF, LERF, ΔCDF, etc.) that is specified
  - Formal propagation of the uncertainties on parameter values is the preferred approach
  - Use of point estimate calculations using the mean values of input parameters is acceptable under certain conditions

Comparison with Acceptance Guidelines – Addressing Uncertainty

- Model uncertainty
  - For relevant sources:
    - Determine alternate assumptions or model approaches to define sensitivity studies
      - Changes in parameter values
      - Changes in logic structure
      - Special cases:
        - HRA models
        - CCF
    - Identify logical combinations of sources
    - Perform sensitivity studies to identify key sources of uncertainty
  - For key sources:
    - Provide results of sensitivity studies for alternate assumptions
    - Provide an assessment of the credibility of the alternate assumptions

Comparison with Acceptance Guidelines – Addressing Uncertainty

- Human reliability analysis
  - Several HRA approaches with no consensus
  - Unreasonable to expect a reanalysis with a number of methods
  - Perform sensitivity studies varying HEPs as a set
    - Used to determine whether contributors are either masked or artificially elevated in significance
  - Based on the premise that the HRA has been performed to meet the PRA standard
    - Significant HFEs can be candidates for compensatory measures (see example)

Comparison with Acceptance Guidelines – Addressing Uncertainty

- Incompleteness
  - Phased approach requires significant contributors be modeled in a PRA
  - Use screening and bounding approaches for non-significant contributors

Compensating for Unquantified Risk Contributors

- Performance monitoring
  - e.g., to confirm an assumption made in the analysis that is essential to acceptability (assumed maximum effect on unreliability of relaxing special treatment - NEI 00-04 for 10 CFR 50.69)
- Limiting scope of implementation of plant change
  - e.g., to compensate for missing scope in the PRA model (a means of establishing consistency with the Phased Approach in the absence of developing a more complete PRA model)
- Use of compensatory measures (not modeled in the PRA)
  - To neutralize the expected negative impact of some plant feature on risk
  - Need to understand the scenario for which the compensatory action is proposed to ensure its effectiveness

Presentation of Results of the Risk Assessment to Decision Makers

- The risk analyst must justify his conclusion that the risk implications of an application are acceptable or not, based on an analysis of the results and an assessment of the impact of uncertainty
- The acceptance guidelines are not generally interpreted as strict go/no-go criteria because of the realization that there could be things left out of the PRA model that could lead to optimistic results or some assumptions have been made that lead to conservative results
- When the analysis results meet the acceptance guidelines with significant margin for all the sensitivity cases, this is straightforward
- However, as the guidelines are approached, it becomes more important to understand the contributors to the results to identify whether there are any potential sources of conservatism that would bolster the case for acceptability
- If either the base case PRA results or a sensitivity case exceeds the guidelines, justification of acceptability would need to include one or more of the following, as necessary:
  - Identification and assessment of significant conservatism in the risk analysis
  - Justification of compensatory measures proposed
  - A description of limitations on the implementation of the application
  - A description of a performance monitoring program

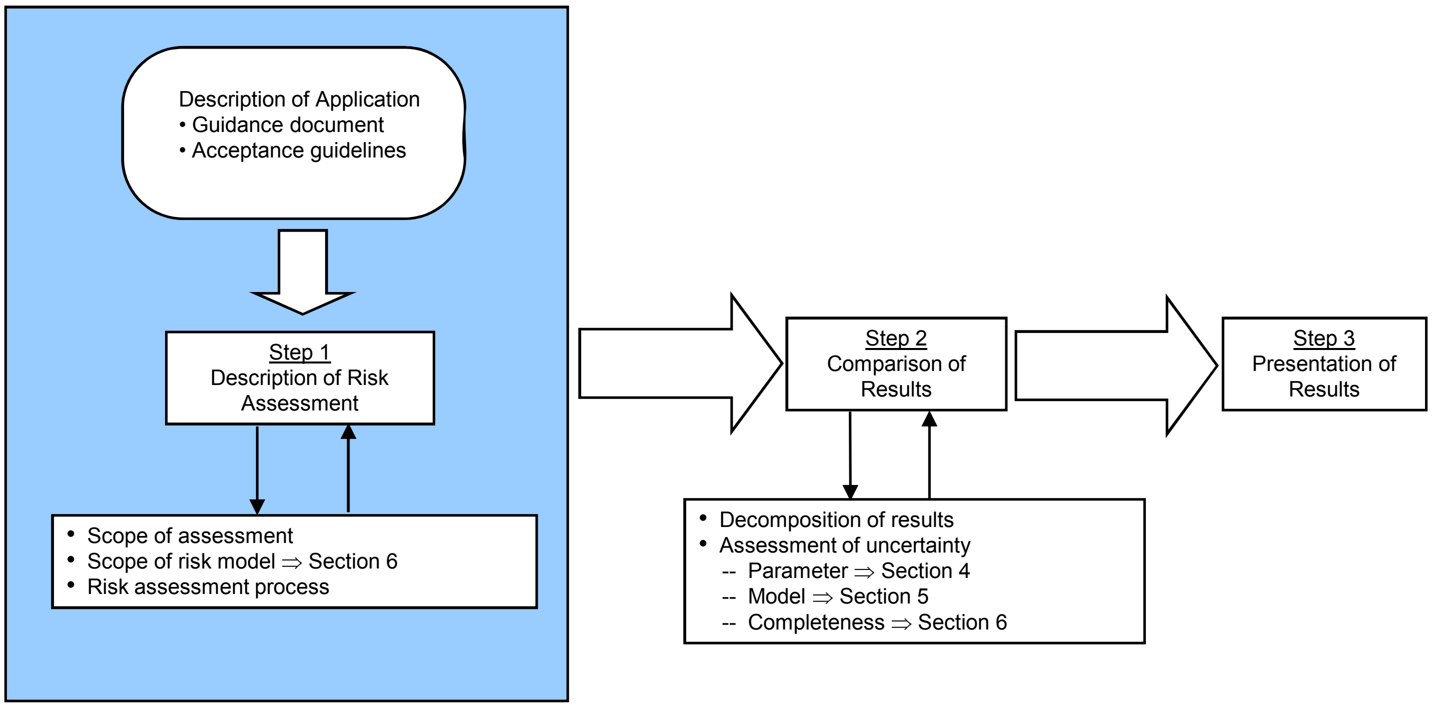
Example

Example Implementation of the Process For Treatment of PRA Uncertainty in a Risk-Informed Regulatory Application

Outline

- Step 1 Description of risk assessment
  - Understanding the application and the required PRA results
  - Determining the scope of the PRA model
    - Understanding the effect of the subject equipment on the risk profile
    - Screening analysis
- Step 2 Comparison of PRA results to acceptance guidelines
  - Using the PRA model
  - Interpreting base case results
  - Identifying sources of uncertainty
  - Assessment of uncertainty
    - Parameter uncertainty
    - Performing analysis to identify potential key sources of uncertainty
  - Perform Sensitivity Studies to identify key sources
- Step 3 Presentation of results
  - Uncertainty characterization for the decision maker

Process for Evaluating the Results of the Risk Assessment



Description of the Application

- Definition of the application
- Identification of PRA results needed:
  - Applicable guidance documents
  - Acceptance guidelines

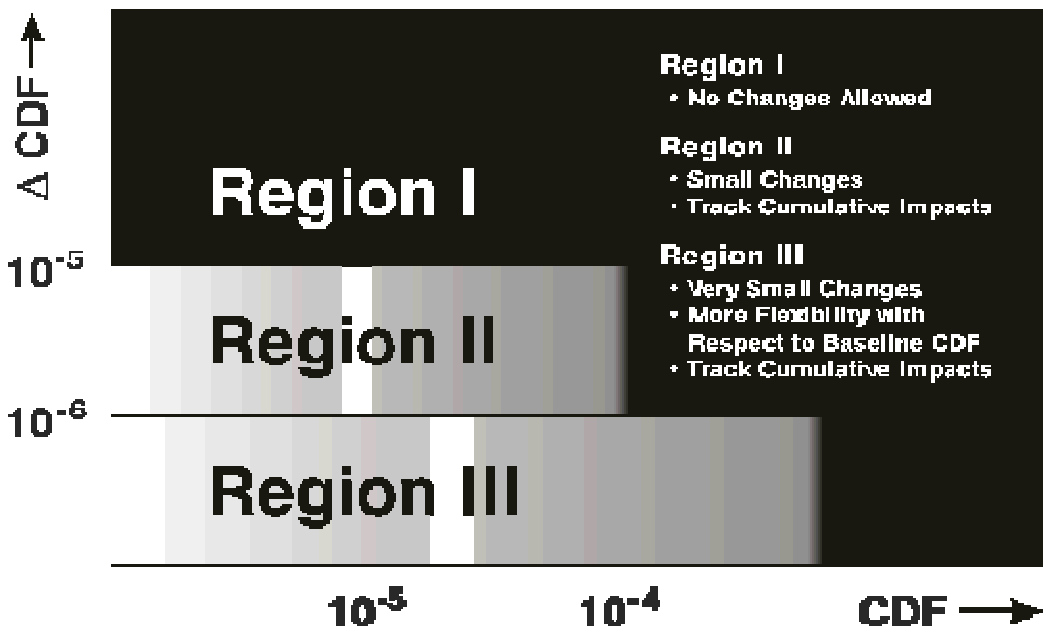
Description of the Application: Definition

- License Amendment Request to revise the technical specification Allowed Outage Time (AOT) from 3 to 7 days for the RHR/SPC system ay a BWR, Mark II plant
- Motivation is to allow routine preventive maintenance currently performed at shutdown to be performed with the reactor at power

Description of the Application: Identification of PRA Results Needed

- Guidance documents are RG 1.177 and RG 1.174
- Acceptance Guidelines:
  - RG 1.177
    - ICCDP < 5E-07
    - ICLERP < 5E-08
  - RG 1.174
    - ΔCDF/CDF and ΔLERF/LERF are in Region II or III of figures 3 and 4 of RG 1.174

Description of the Application: Acceptance Guidelines for ΔCDF



Description of Risk Assessment

- Scope of risk assessment:
  - Hazard groups and plant operational states
  - Scope determined by the acceptance guidelines
- Scope and level of detail of the PRA model:
  - Hazard groups and plant operational states that are significant to the decision

Description of Risk Assessment: Scope of Risk Assessment

- Consistent with the definition of the acceptance guidelines, the scope of risk contributors to be considered includes all hazard groups and all plant operational states that are relevant to the decision
- None is excluded a priori, but several may be excluded from the PRA model based on an assessment of significance to the decision

Available PRA Information

- Up-to-date PRA models for
  - Internal Events
  - Internal Floods
  - Internal Fires
- IPEEE information provides useful insights on plant-specific hazards and capability

Description of Risk Assessment: Scope of PRA Model

- First step:
  - Understand the role that the subject equipment has in the plant risk profile
- Review of the internal events and internal flood PRA results that involve unavailability of the RHR loops

Description of Risk Assessment: Characterization of RHR System Functions

Risk Contribution by Functional Sequence

Functional Sequence Contributor	A Loop OOS		B Loop OOS	
	ΔCDF	Frac.	ΔCDF	Frac.
Sequences Involving Containment Heat Removal	2.32E-06	80.6%	2.33E-06	61.0%
Transient-initiated Sequences Involving Inadequate RPV Makeup	5.38E-07	18.6%	1.42E-06	37.2%
LOCA-initiated Sequences Involving Inadequate RPV Makeup	2.03E-10	0.0%	1.72E-08	0.5%
ATWS Sequences	2.32E-08	0.8%	2.34E-08	0.6%
Containment Bypass Sequences	n/a	n/a	2.92E-08	0.8%
Total ΔCDF	2.89E-06		3.83E-06	

Description of Risk Assessment: Characterization of RHR System Functions

Risk Contribution by Initiator Type

Initiator Type	A Loop OOS		B Loop OOS	
	ΔCDF	Frac.	ΔCDF	Frac.
Medium LOCA	8.29E-07	29%	8.43E-07	22%
Loss of Offsite Power	5.90E-07	21%	8.46E-07	22%
Large LOCA	5.10E-07	18%	5.21E-07	14%
Transients	7.58E-07	26%	1.44E-06	37%
Small LOCA	1.92E-07	7%	1.85E-07	5%
Total ΔCDF	2.89E-06		3.83E-06	

Description of Risk Assessment: Characterization of RHR System Functions

- Both the functions of containment heat removal and RPV makeup are relevant to the risk significance of the RHR Loops
- LOCA, LOOP, and transient initiators all have the potential to create a demand for the RHR Loops

Description of Risk Assessment: Level of Detail

- To support an application, a PRA model has to have sufficient level of detail to model the cause-effect relationship associated with the license amendment request (LAR)
  - Since we are using a PRA that explicitly models the RHR loops in detail, it has the level of detail necessary to support this application

Scope of Hazard Groups Considered

- Section 6 provides list of typical hazard groups to be considered
- Focus is on hazards that could be significant to the decision
  - i.e., where RHR unavailability could significantly contribute to risk

Typical Hazards Groups for Consideration

- Internal Events
- Internal Floods
- Internal Fires
- Seismic Events
- Accidental Aircraft Impacts
- External Flooding
- Extreme Winds and Tornados (including generated missiles)
- Turbine-Generated Missiles
- External Fires
- Accidents From Nearby Facilities
- Release of Chemicals Stored at the Site
- Transportation Accidents
- Pipeline Accidents (e.g., natural gas)

Description of Risk Assessment: Assessment of Significant Hazard Groups

- For RHR Loop AOT, screened from consideration based on likelihood of threat-induced challenge
  - Accidental Aircraft Impacts
  - External Floods
  - Extreme Winds and Tornados (including generated missiles)
  - Turbine-Generated Missiles
  - External Fires

Description of Risk Assessment: Assessment of Significant Hazard Groups

- For RHR Loop AOT, screened from consideration based on limited role of RHR in mitigating hazards
  - Accidents from nearby facilities
  - Release of chemicals stored at the site
- For RHR Loop AOT, explosive hazards screened on the basis of limited impact on the plant
  - Transportation accidents
  - Pipeline accidents (e.g., natural gas)

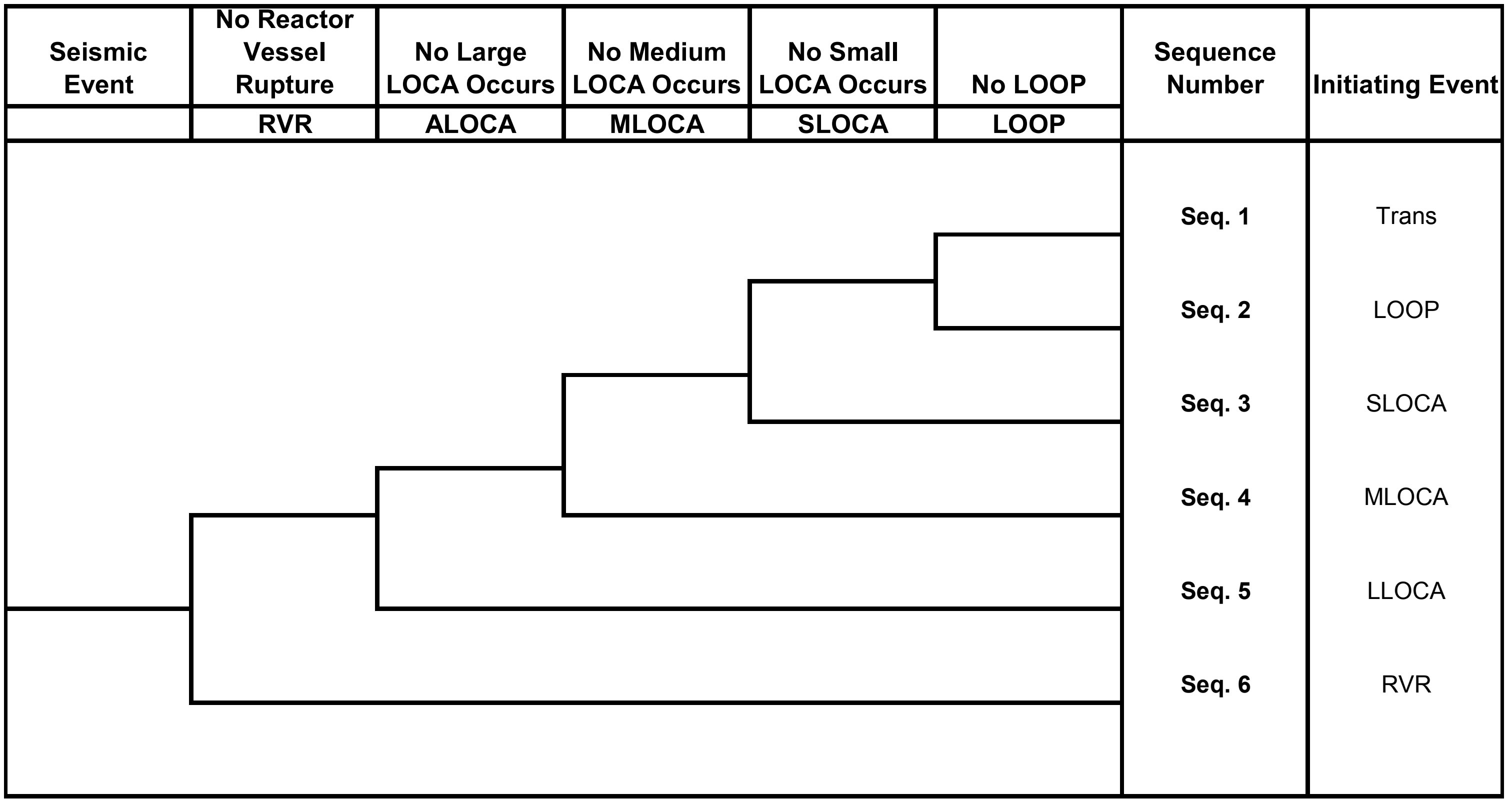
Description of Risk Assessment: Assessment of Significant Hazard Groups

- Addressed quantitatively
  - Internal Events
  - Internal Floods
  - Internal Fires
- Addressed using a conservative approach
  - Seismic Events

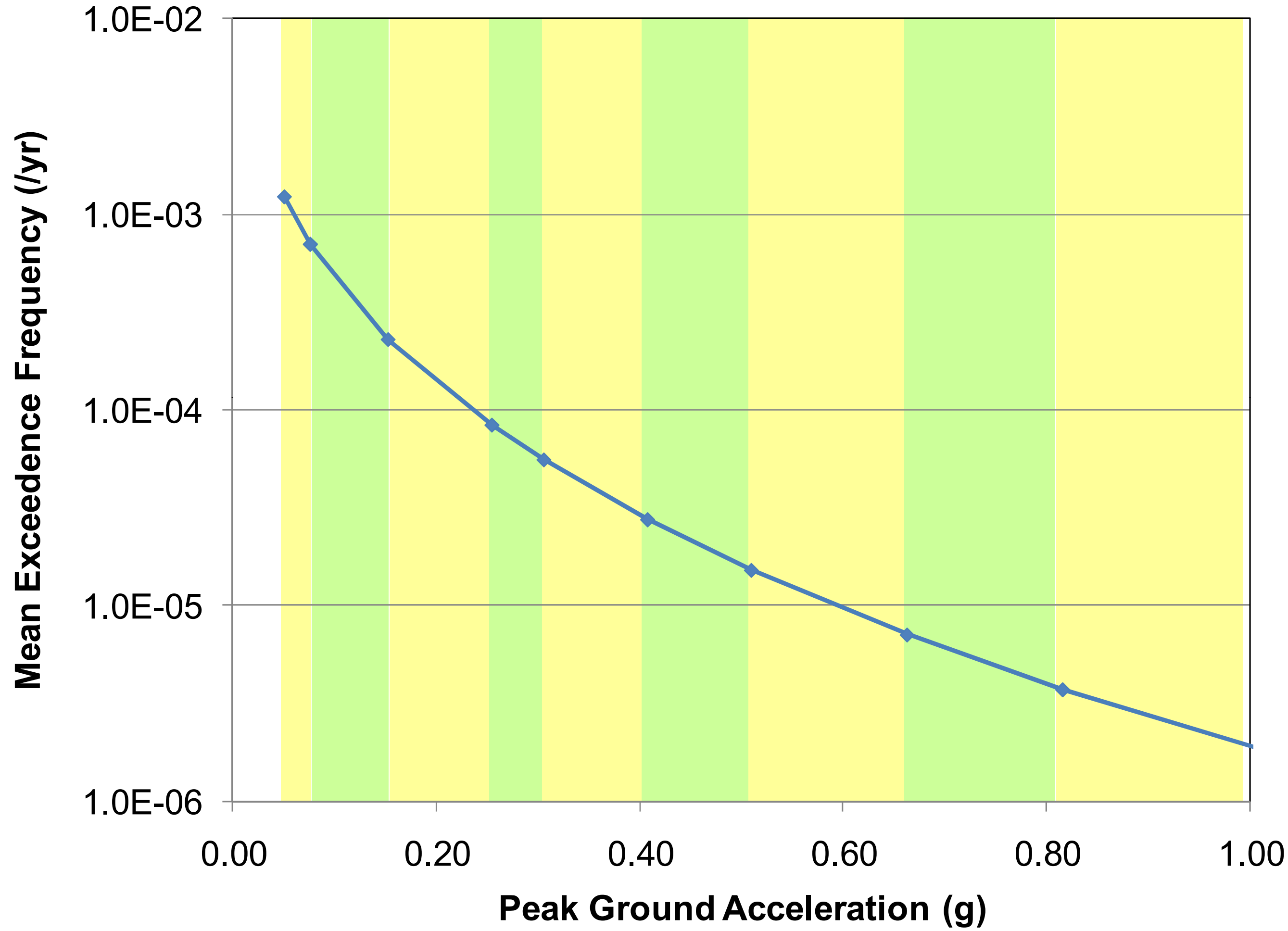
Seismic Risk Implications

- Objective:
  - Evaluate seismic risk implications of out of service (OOS) RHR Loops
- Based on internal events PRA, concerned about:
  - Transients
  - LOOPs
  - LOCAs

Seismic Initiator Pre-tree



Site Seismic Hazard Curve

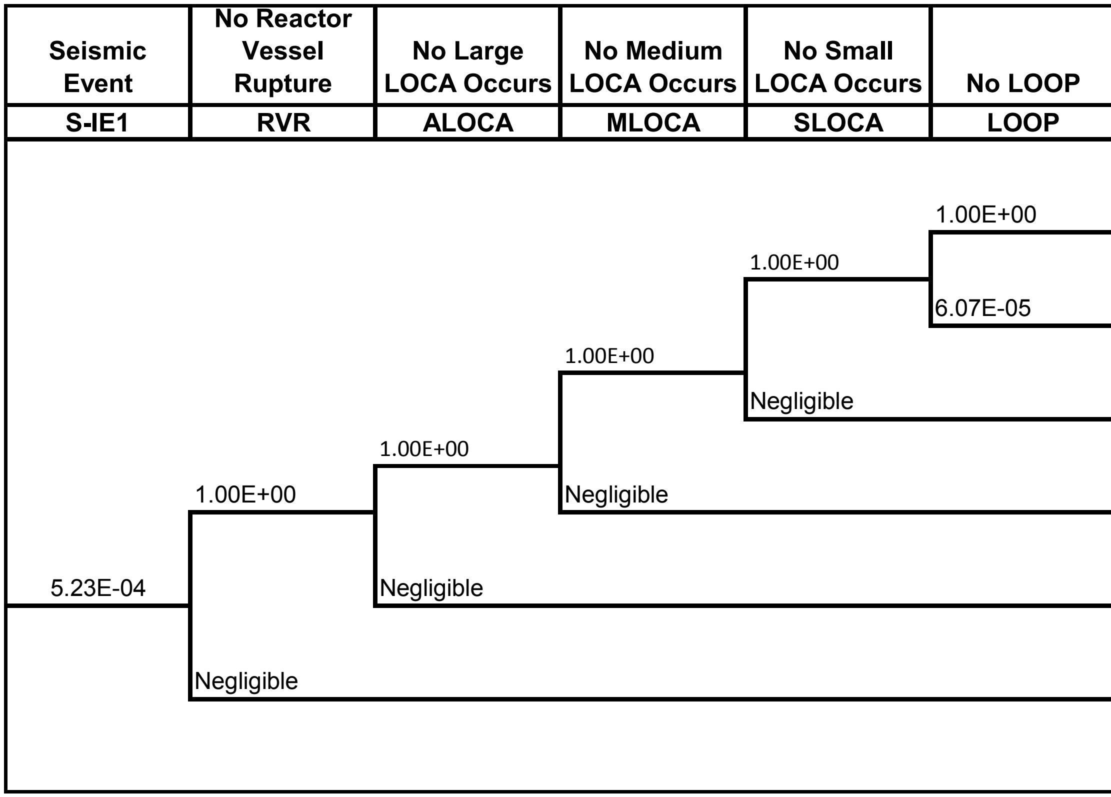


Ref. – NUREG-1488

Basis for Seismic Initiator Probabilities

Initiating Event Category	Basis for Probability of Occurrence
Reactor Vessel Rupture (RVR)	Estimated based on NUREG/CR-4550 [Ref. A.4], Table 4.17 for IE Category 1 (RVR).
Large LOCA	Consistent with NUREG/CR-4550 [Ref. A.4], mean probability of failure based on fragility of Recirc Pump supports (α_m= 1.26, β_r=0.35 β_u=0.36 based on NUREG/CR-4130 [Ref. A.6]).
Medium LOCA	Derived from NUREG/CR-4550 [Ref. A.4], Figure 4.20
Small LOCA	Derived from NUREG/CR-4550 [Ref. A.4], Figure 4.20
Loss of Offsite Power ()	Computed mean probability of failure based on fragility of ceramic insulators given in NUREG/CR-4550 [Ref. A.4], Table 4.9
Transients	All residual seismic events (i.e., those that do not cause one of the above events) are assumed to cause a transient.

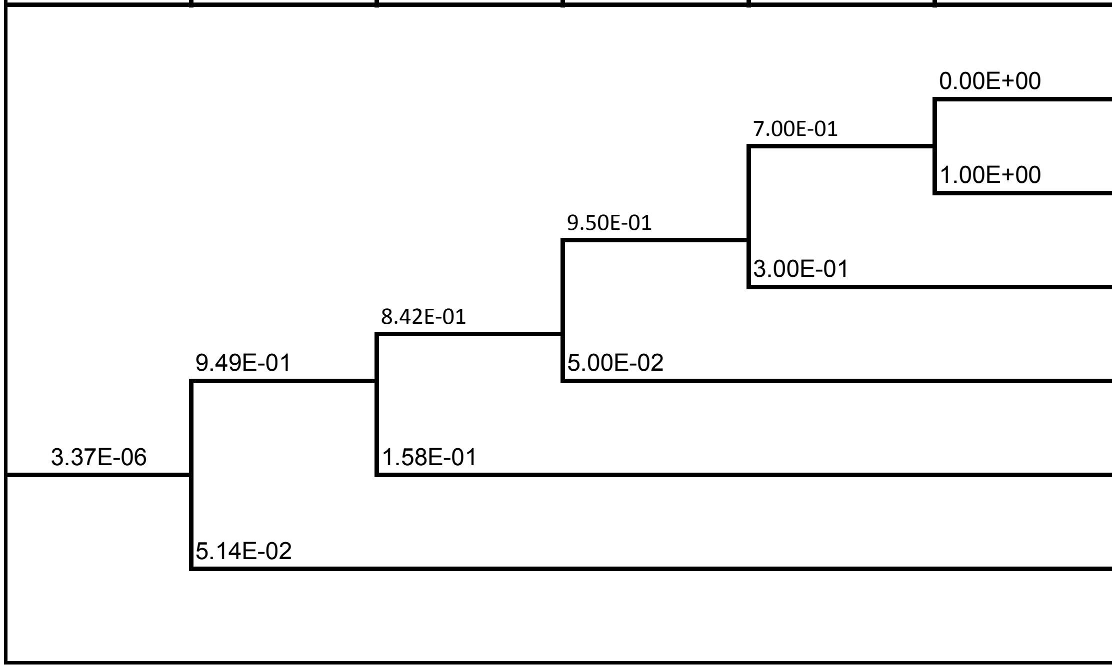
Example:
Seismic Pre-tree for 50-75 cm/s/s



Sequence Number	Initiating Event	Frequency
Seq. 1	Trans	5.23E-04
Seq. 2	LOOP	3.17E-08
Seq. 3	SLOCA	Negligible
Seq. 4	MLOCA	Negligible
Seq. 5	LLOCA	Negligible
Seq. 6	RVR	Negligible

Example:
Seismic Pre-tree for 650-800 cm/s/s

Seismic Event	No Reactor Vessel Rupture	No Large LOCA Occurs	No Medium LOCA Occurs	No Small LOCA Occurs	No LOOP
S-IE8	RVR	ALOCA	MLOCA	SLOCA	LOOP



Sequence Number	Initiating Event	Frequency
Seq. 1	Trans	0.00E+00
Seq. 2	LOOP	1.79E-06
Seq. 3	SLOCA	7.68E-07
Seq. 4	MLOCA	1.35E-07
Seq. 5	LLOCA	5.05E-07
Seq. 6	RVR	1.73E-07

Seismic Risk Implications

- Conservative Quantitative Approach

SUMMARY OF SEISMIC-INDUCED INITIATORS

Seq.	Initiating Event	Frequency	% of Total
Seq. 1	Transient Initiator	1.11E-03	90.5%
Seq. 2	LOOP	1.06E-04	8.7%
Seq. 3	Small LOCA	5.20E-06	0.4%
Seq. 4	Medium LOCA	6.46E-07	0.1%
Seq. 5	Large LOCA	2.70E-06	0.2%
Seq. 6	Reactor Vessel Rupture	1.71E-06	0.1%
	Total Frequency	**1.22E-03**	

Seismic Risk Implications - Transients

- Bound the risk of seismic-induced transients:
  - Assume ***all*** seismic transient events lead to loss of condenser
  - Compare seismic-induced frequency, 1.11E-3/yr, to frequency of loss of condenser events from the internal events PRA, 0.11/yr
  - Seismic-induced ~1% of internal events
- Conclusion:
  - Seismic-induced transients negligible impact on decision

Seismic Risk Implications - LOOP

- Bound the risk of seismically-induced LOOPs:
  - Compare frequency of seismic-induced LOOP events, 1.06E-4/yr, to the frequency of unrecovered LOOP events that are due to other causes, 5E-4/yr
    - Seismic is 20% of internal events
  - LOOP Contributes 20% to Internal Events ΔRisk, or ~4% overall (ΔCDF~2.5E-9/yr)
- Conclusion:
  - Seismic-induced LOOP events have negligible impact on decision

Seismic Risk Implications - LOCAs

- Bound the risk of seismically-induced LOCAs:
  - Assume that the change in RHR reliability will have a direct impact on ***all*** LOCA risk:
    - the remaining loop of RHR not be impacted by the seismic event, and
    - RHR required to mitigate all LOCA events
    - RHR reliability with one loop out and LOOP assumed is 8.4E-3
  - Bounding ΔCDF estimate = 7.2E-8/yr
  - For 7 day AOT = 1.4E-9 (<0.3% of acceptance guideline)
- Conclusion:
  - Seismic-induced LOCAs have negligible impact on decision

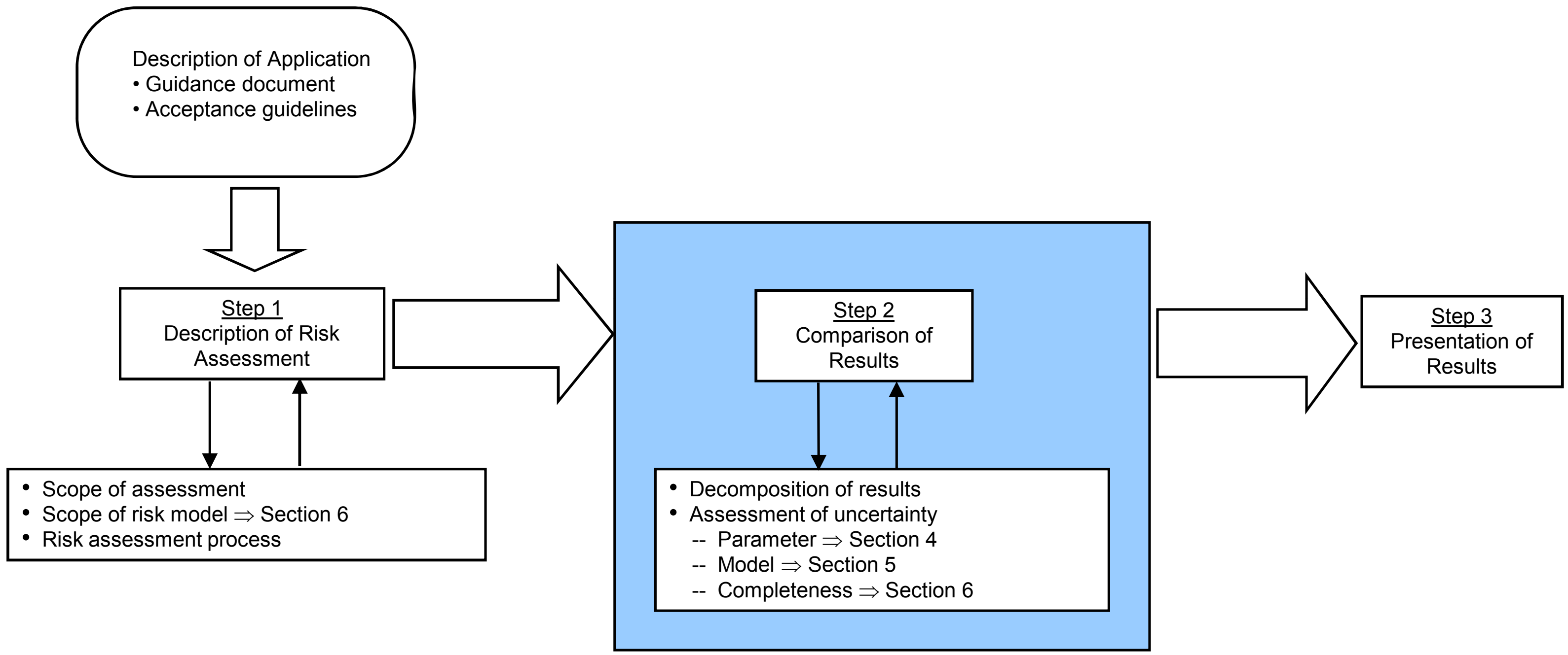
Seismic Risk Implications - RVR

- Reactor vessel rupture (RVR) events cannot be mitigated
- Thus, the unavailability of an RHR loop has no impact on the risk

Seismic Risk Implications - Conclusions

- Simplified, focused seismic PRA developed to evaluate seismic risks
- Bounding analyses demonstrate that consideration of seismic risk would not impact decision
- Seismic risks not considered further

Process for Evaluating the Results of the Risk Assessment



Outline

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    - Screening analysis
- Step 2 Comparison of PRA results to acceptance guidelines
  - **Using the PRA model**
  - Interpreting base case results
  - Identifying sources of uncertainty
  - Assessment of uncertainty
    - Parameter uncertainty
    - Performing analysis to identify potential key sources of uncertainty
  - Perform Sensitivity Studies to identify key sources
- Step 3 Presentation of results
  - Uncertainty characterization for the decision maker

RG 1.174 Calculations

- The new annual average CDF due to the change in the AOT, CDF_{NEW}, is given by the following equation:

$$CDF_{NEW} = \left(\frac{T_A}{T_{CYCLE}}\right) CDF_A + \left(\frac{T_B}{T_{CYCLE}}\right) CDF_B$$

$$+ \left(1 - \frac{T_A + T_B}{T_{CYCLE}}\right) CDF_{base'} \qquad [Eq.\ A1]$$

- The ΔCDF to be compared to the Reg. Guide 1.174 guidelines is given by:

$$\Delta CDF = CDF_{NEW} - CDF_{base'} \qquad [Eq.\ A2]$$

RG 1.177 Calculations

- The ICCDP (incremental conditional core damage probability) associated with each RHR/RHRSW loop equipment being OOS using the new AOT is given by:

$$ICCDP_{RHR\ X} = (CDF_{RHR\ X} - CDF_{BASE}) \times AOT_{NEW} \qquad [Eq.\ A3]$$

- Acceptance Guidelines:
  - RG 1.177
    - ICCDP < 5E-07
    - ICLERP < 5E-08

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  - Assessment of uncertainty
    - Parameter uncertainty
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  - Perform Sensitivity Studies to identify key sources
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  - Uncertainty characterization for the decision maker

Initial Results

INITIAL RISK ASSESSMENT OUTPUT VALUES

Output Parameter	Internal Events and Internal Floods	Internal Fires	Total
CDF_{NEW}	3.86E-06/yr	1.35E-05/yr	1.73E-05/yr
ΔCDF	1.26E-07/yr	7.58E-07/yr	8.84E-07/yr
$ICCDP_A$	1.13E-07	3.76E-07	4.89E-07
$ICCDP_B$	1.28E-07	1.08E-06	1.21E-06
$LERF_{NEW}$	6.49E-08/yr	N/A	<1.0E-05/yr
$\Delta LERF$	2.67E-10/yr	N/A	<1.0E-07/yr
$ICLERP_A$	1.52E-10	N/A	<5.0E-08
$ICLERP_B$	3.61E-10	N/A	<5.0E-08

- Given the results of the initial assessment exceed the acceptance guidelines, further refinement is required

Refined Results

REFINED RISK ASSESSMENT OUTPUT VALUES

Output Parameter	Internal Events and Internal Floods	Internal Fires	Total
CDF_{NEW}	3.79E-06/yr	1.27E-05/yr	1.65E-05/yr
ΔCDF	6.30E-08/yr	2.10E-07/yr	2.73E-07/yr
$ICCDP_A$	5.37E-08	6.14E-08	1.15E-07
$ICCDP_B$	6.71E-08	3.41E-07	4.08E-07

- The refinement included the removal of demonstrated conservatisms in the fire model and credit for compensatory measures in reducing the risk for the analyzed configurations

Summary of Base Case Results

COMPARISON OF RESULTS TO ACCEPTANCE GUIDELINES

Figure of Merit	Total Value	Acceptance Guideline	Below Acceptance Guideline
CDF_{NEW}	1.65E-05/yr	<1.0E-04/yr	Yes
ΔCDF	2.73E-07/yr	<1.0E-06/yr	Yes
$ICCDP_A$	1.15E-07	<5.0E-07	Yes
$ICCDP_B$	4.08E-07	<5.0E-07	Yes
$LERF_{NEW}$	<1.0E-05/yr	<1.0E-05/yr	Yes
ΔLERF	<1.0E-07/yr	<1.0E-07/yr	Yes
$ICLERP_A$	<5.0E-08	<5.0E-08	Yes
$ICLERP_B$	<5.0E-08	<5.0E-08	Yes

- The total value is the sum of the contributions from the internal events, internal floods, and internal fire PRAs

Interpretation of Results

COMPARISON OF INDIVIDUAL HAZARD GROUP RESULTS TO ACCEPTANCE GUIDELINES

Figure of Merit	Value	Acceptance Guideline	Below Acceptance Guideline
Internal Events and Internal Floods			
ΔCDF	6.30E-08/yr	<1.0E-06/yr	Yes
$ICCDP_A$	5.37E-08	<5.0E-07	Yes
$ICCDP_B$	6.71E-08	<5.0E-07	Yes
Internal Fires			
ΔCDF	2.10E-07/yr	<1.0E-06/yr	Yes
$ICCDP_A$	6.14E-08	<5.0E-07	Yes
$ICCDP_B$	3.41E-07	<5.0E-07	Yes

- For purposes of this example, the focus will be on the core damage risk metrics since the large early risk metrics were determined to not be significant contributors

Decomposition of Results

SIGNIFICANT ACCIDENT CLASSES FOR INTERNAL EVENTS AND INTERNAL FLOODS EVALUATIONS

Figure of Merit	RHR "A" Loop Case	RHR "B" Loop Case
CDF_X	6.53E-06/yr	7.23E-06/yr
$\Delta CDF = CDF_X - CDF_{BASE}$	2.80E-06/yr	3.50E-06/yr
Percent Contribution to ΔCDF		
Class I (Transient w/ Loss of Injection) from ΔCDF	18.6%	37.2%
Class II (Loss of Containment Heat Removal) from ΔCDF	80.6%	61.0%
Class III (LOCAs w/ Loss of Injection) from ΔCDF	<0.1%	0.5%
Class IV (ATWS) from ΔCDF	0.8%	0.6%
Class V (ISLOCA) from ΔCDF	0.0%	0.8%

- These results indicate that the loss of containment heat removal scenarios are the most important contributor to the delta CDF contributed by internal events

Decomposition of Results

SIGNIFICANT INITIATOR CONTRIBUTIONS FOR THE INTERNAL EVENTS AND INTERNAL FLOODS EVALUATIONS

Figure of Merit	RHR "A" Loop Case	RHR "B" Loop Case
CDF_X	6.53E-06/yr	7.23E-06/yr
$\Delta CDF = CDF_X - CDF_{BASE}$	2.80E-06/yr	3.50E-06/yr
Percent Contribution to ΔCDF		
LOSS OF OFFSITE POWER	20.5%	22.1%
MEDIUM LOCA	28.8%	22.0%
LARGE LOCA	17.7%	13.6%
TURBINE TRIP TRANSIENTS	8.5%	7.5%
LOSS OF AC BUS DIV. I	0.0%	12.8%
LOSS OF AC BUS DIV. II	6.3%	0.0%
SMALL LOCA	6.7%	4.8%
LOSS OF FEEDWATER TRANSIENTS	3.6%	2.9%
LOSS OF CONDENSER VACUUM TRANSIENTS	3.6%	4.2%
OTHER INITIATING EVENTS	4.4%	10.1%

Understanding the Results

- The detailed review provides a general understanding of the nature of the most important CDF contributors associated with the RHR Loops
  - Accident class
  - Initiating event
  - Accident sequence
  - Cut set review
  - Importance measure review
- In many cases, the basic events can either directly or indirectly assist in identifying the important risk drivers and potential sources of uncertainty

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Identifying Sources of Uncertainty

- Internal events and internal floods contributors that are potential sources of uncertainty
  - Viability of CRD injection post containment failure
  - Various Human Errors:
    - Failure to depressurize RPV
    - Failure to bypass containment isolation
    - Failure to cross-tie instrument air (IA) to primary containment instrument gas (PCIG)
    - Failure to utilize CRD for RPV Makeup

Identifying Sources of Uncertainty

- Potential sources of uncertainty (cont'd)
  - LOOP failure to recover probabilities
  - Credit for RHRSW pump repair
  - Medium LOCA partition factor
  - No credit for maintaining ECCS injection post-venting

Internal Fire Model Results

SIGNIFICANT FIRE SCENARIO CONTRIBUTORS FOR THE INTERNAL FIRE EVALUATIONS (RHR “A” LOOP CASE)

Figure of Merit	RHR “A” Loop Case
$FCDF_A$	1.57E-05/yr
$\Delta FCDF = FCDF_A - FCDF_{BASE}$	3.20E-06/yr
Percent Contribution to ΔFCDF	
IEFR-123-0 (Spray Pond Pump Structure – B Half)	23.8%
IEFR-024-V012 (Main Control Room – ECCS B Panel)	20.5%
IEFR-048E-0 (Division II MCC Fire)	8.6%
IEFR-044E-A (Division II MCC Fire)	8.4%
IEFR-039-0 (Sump Room and Passageway)	4.6%
IEFR-031-0 (RHR B Compartment)	3.8%
IEFR-015-A (Division II 4kV Switchgear)	2.5%
IEFR-024-C002 (Main Control Room – CRD Console)	2.3%
OTHER FIRE SCENARIOS	25.6%

Internal Fire Model Results

SIGNIFICANT FIRE SCENARIO CONTRIBUTORS FOR THE INTERNAL FIRE EVALUATIONS (RHR “B” LOOP CASE)

Figure of Merit	RHR “B” Loop Case
$FCDF_B$	3.03E-05/yr
$\Delta FCDF = FCDF_B - FCDF_{BASE}$	1.78E-05/yr
Percent Contribution to ΔFCDF	
IEFR-024-V011 (Main Control Room – ECCS A Panel)	41.5%
IEFR-025-T001C (Aux Equipment Room – Div I Cabinet)	15.3%
IEFR-122-0 (Spray Pond Pump Structure – A Half)	7.0%
IEFR-045W-D (Division III Load Center Severe Fire)	5.8%
IEFR-048W-C (Division I Load Center Severe Fire)	4.3%
IEFR-025-T003C (Aux Equipment Room – Div III Cabinet)	3.6%
IEFR-020-A (Electric Cabinet Division I Severe Fire)	3.1%
IEFR-044W-A (Division I MCC Fire)	2.5%
OTHER FIRE SCENARIOS	17.1%

Identifying Sources of Uncertainty

- Unique internal fire contributors that are potential sources of uncertainty
  - Scenario initiating event frequencies
  - General conservatism of fire scenario treatment
- The modeling of fire effects is generally considered to be a source of model uncertainty.
  - However, in this hypothetical case, the scenarios contributing to the increased fire risk due to the RHR loops being out of service did not rely on fire modeling

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  - Interpreting base case results
  - Identifying sources of uncertainty
  - **Assessment of uncertainty**
    - Parameter uncertainty
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Addressing Parameter Uncertainty

- Reviewed the cut sets for the four different delta-CDF assessments
  - Determined that the dominant contributor cut sets do not involve basic events with epistemic correlations
  - Per Guideline 2b from EPRI 1016737, then it is acceptable to use the point estimate directly in the risk assessment

Addressing Parameter Uncertainty

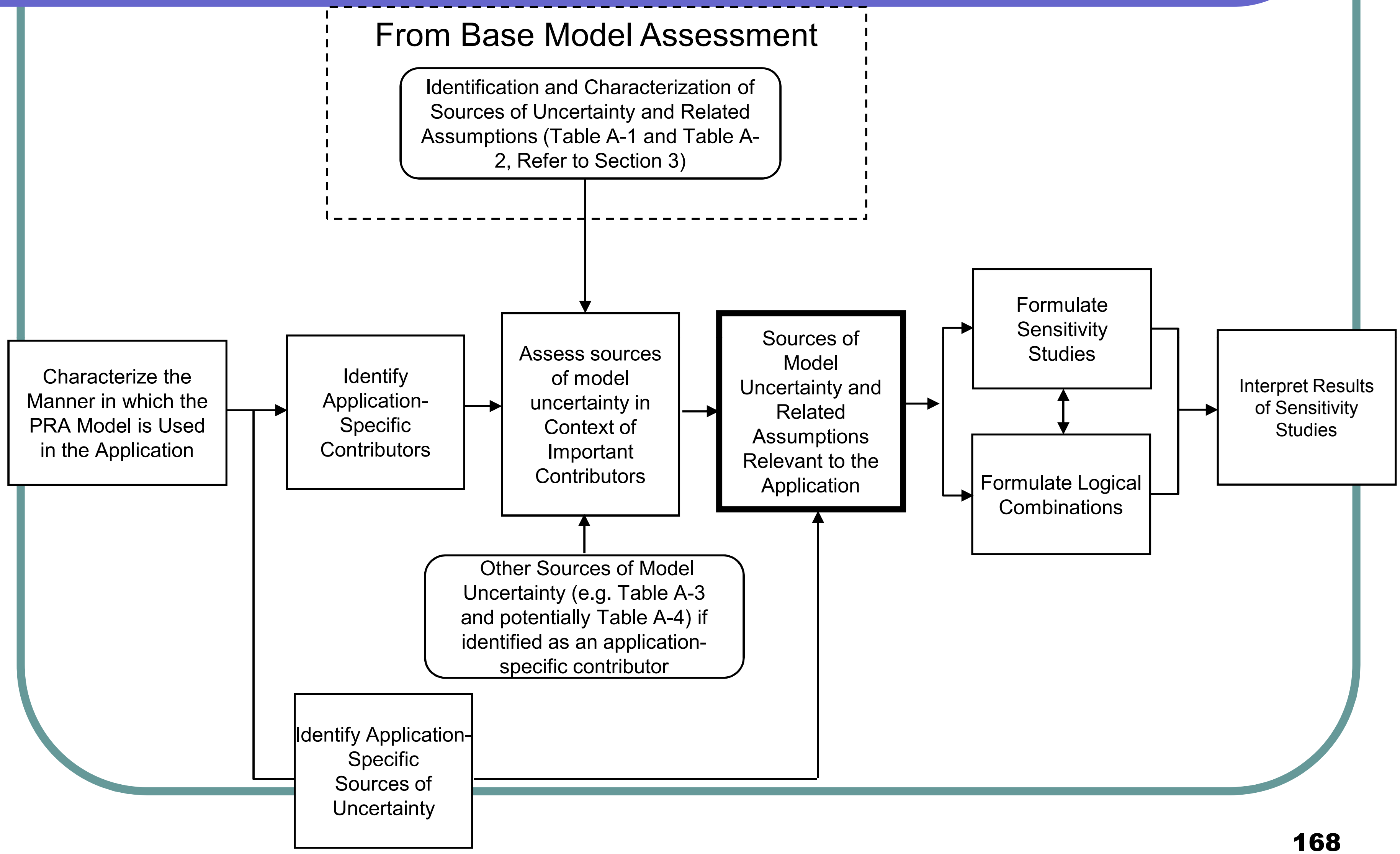
PARAMETRIC UNCERTAINTY EVALUATIONS AND COMPARISON TO POINT ESTIMATE RESULTS

Result	Internal Events and Internal Floods		Internal Fires	
	RHR "A" Case	RHR "B" Case	RHR "A" Case	RHR "B" Case
Propagated Mean Values[1]				
CDF_X[1]	6.56E-06/yr	7.31E-06/yr	1.57E-05/yr	3.05E-05/yr
CDF_{BASE}[1]	3.80E-06/yr		1.25E-05/yr	
$\Delta CDF^{(1)} = CDF_X - CDF_{BASE}$	**2.76E-06/yr**	**3.51E-06/yr**	**3.20E-06/yr**	**1.80E-05/yr**
Point Estimate Mean Values[2]				
CDF_X[2]	6.53E-06/yr	7.23E-06/yr	1.57E-05/yr	3.03E-05/yr
CDF_{BASE}[2]	3.73E-06/yr		1.25E-05/yr	
$\Delta CDF^{(2)} = CDF_X - CDF_{BASE}$	**2.80E-06/yr**	**3.50E-06/yr**	**3.20E-06/yr**	**1.78E-05/yr**

(1) Developed based on the parametric mean value for each case from a Monte Carlo simulation with 10,000 samples.

(2) Developed based on the point estimate value for each case.

Addressing Model Uncertainty



Addressing Model Uncertainty

- Screening of base PRA Sources of Model Uncertainty
- The complete PRA model is relevant to this application.
  - Therefore, none of the sources of uncertainty listed in Tables A-1 and A-2 of EPRI 1016737 can be a priori screened as not being relevant to this application

Addressing Model Uncertainty

- Identification Based on Consideration of Significant Contributors
- Internal Events Important Contributors
  - HEPs for utilizing CRD injection
  - HEP for failure to depressurize RPV
  - HEP for bypassing containment isolation
  - HEP for cross-tying instrument air to instrument gas
  - LOOP failure to recover probabilities
  - Credit for RHRSW pump repair
  - Medium LOCA partition factor
  - Viability of CRD injection post containment failure
  - No credit for maintaining ECCS injection post-venting

Addressing Model Uncertainty

- Issues which impact the internal events and internal fire portions of the quantified risk assessment
  - HEPs for utilizing CRD injection
  - HEP for bypassing containment isolation
  - HEP for cross-tying IA to PCIG
  - Viability of CRD injection post containment failure
- Additional sources of uncertainty unique to the internal fire PRA evaluation
  - Scenario initiating event frequencies
  - General conservatism of fire scenario treatment

Addressing Model Uncertainty

- Review of the identified sources of model uncertainty from the base model assessment
  - Determine which of those items are potentially applicable for this assessment
- Many of the items easily screened, except
  - ISLOCA Frequencies
  - Credit for recovery of instrument air in support of containment venting

Addressing Model Uncertainty

- Identification and characterization of sources of uncertainty associated with model changes
- The performance of this risk assessment did not require any model changes.
  - Therefore, there are no additional sources of uncertainty associated with this aspect of the process

Assessing Potential Sources of Model Uncertainty

- Perform a qualitative or semi-quantitative assessment to determine if sources of uncertainty affect the important contributors for the application
  - HEPs for utilizing CRD injection
  - HEP for failure to depressurize RPV
    - Only very bounding assumptions regarding the appropriate HEP values for these individual actions would lead to exceeding the risk metric acceptance guidelines
  - Retained as potential key sources of uncertainty for this application as part of the HEP development as a global source of uncertainty

Assessing Potential Sources of Model Uncertainty

- HEP for bypassing containment isolation
- HEP for cross-tying instrument air to instrument gas
  - Variations to these HEP values may lead to fairly substantial changes in the risk assessment results for all four of the risk assessment cases
  - Importance of these actions elevated by the assumption that all fire scenarios with credit for FW/PCS always require success of both of these actions
- Fire PRA model assumption is identified as a potential key source of uncertainty
- Also retained as potential key sources of uncertainty for this application as part of the HEP development as a global source of uncertainty

Assessing Potential Sources of Model Uncertainty

- LOOP recovery terms at various time intervals
  - Overall assessment is not limited to only LOOP events, and LOOP is not a significant contributor to the internal fire events results
  - Fail to recover values are fairly well accepted (based on NUREG-6890)
- LOOP recovery values are not retained as a potential key source of uncertainty

Assessing Potential Sources of Model Uncertainty

- RHRSW pump repair failure probabilities
  - No credit for repair is taken in the internal fires assessment
  - The maximum impact based on the risk achievement worth would not lead to exceeding the risk metric acceptance guidelines
- RHRSW pump repair failure probabilities are not retained as a potential key source of uncertainty

Assessing Potential Sources of Model Uncertainty

- Medium LOCA partition factor
  - Individually the maximum impact based on the Risk Achievement Worth would not lead to exceeding the risk metric acceptance guidelines
  - However, it is identified as a potential source of uncertainty combined with the medium LOCA frequency
- Total frequency of medium LOCAs that are too big for CRD makeup capabilities is retained as a potential key source of uncertainty

Assessing Potential Sources of Model Uncertainty

- Viability of CRD injection post containment failure
  - Could have a large enough impact to result in exceeding the ICCDP acceptance guidelines for both the RHR A and RHR B internal events and internal fires cases
- The basis for determining CRD survivability following containment failure scenarios is identified as a potential key source of uncertainty

Assessing Potential Sources of Model Uncertainty

- No credit for maintaining ECCS injection post-venting
  - The assumptions related to viability of non-CRD systems following containment venting or containment failure represent a potentially conservative bias treatment
- Retained as a potential source of model uncertainty
  - Removal of the conservative bias treatment associated with this assumption is likely to improve the margin compared to the acceptance guidelines

Assessing Potential Sources of Model Uncertainty

- Fire scenario initiating event frequencies
  - The fire scenario initiating event frequencies have a direct impact on all of the calculated risk metrics for the internal fire events assessment
- The fire scenario initiating event frequencies are identified as a potential key source of uncertainty

Assessing Potential Sources of Model Uncertainty

- General conservative treatment for fire scenario development
  - Limited credit for all available plant systems (i.e. those systems without explicit cable routing information)
  - No credit for short term ex-control room manual actions
  - No credit for equipment repair
  - General assumption that fire damage leads to plant trip or short term shutdown
- This issue is not identified as a potential key source of uncertainty
  - Identified on a case-by-case basis for those fire scenarios that are driving the risk metric results

Assessing Potential Sources of Model Uncertainty

- ISLOCA Frequencies
  - The ISLOCA frequencies are derived from a detailed ISLOCA analysis which includes the relevant considerations listed in IE-C12 of the ASME/ANS PRA Standard
  - Only a factor in the RHR B internal events case
- Due to the overall minor impact on the risk metric results, it is not identified as a potential key source of uncertainty for this application

Assessing Potential Sources of Model Uncertainty

- Credit for recovery of instrument air in support of containment venting
  - The average Risk Achievement Worth for this event is approximately 1.2 between the four different base case risk assessments
  - Only the very bounding assumption of no credit for IA recovery in support of venting would lead to exceeding the acceptance guidelines
- Credit for recovery of IA in support of containment venting is not retained a candidate source of model uncertainty for this application

Summary of Potential Sources of Model Uncertainty

- Human Error Probability (HEP) development as a class as discussed in Section 7.3.3.2
- Total frequency of medium LOCAs that are too big for CRD makeup capabilities (i.e. below TAF)
- The basis for determining CRD survivability following containment failure scenarios

Summary of Potential Sources of Model Uncertainty

- Assumptions related to viability of non-CRD systems following containment venting or containment failure
- Fire scenario initiating event frequencies
- Fire PRA model assumption that all scenarios with credit for FW/PCS always require bypass of the containment isolation signal and cross-tie of instrument air to instrument gas

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Summary of Base Case Results

COMPARISON OF RESULTS TO ACCEPTANCE GUIDELINES

Figure of Merit	Total Value	Acceptance Guideline	Below Acceptance Guideline
CDF_{NEW}	1.65E-05/yr	<1.0E-04/yr	Yes
ΔCDF	2.73E-07/yr	<1.0E-06/yr	Yes
$ICCDP_A$	1.15E-07	<5.0E-07	Yes
$ICCDP_B$	4.08E-07	<5.0E-07	Yes
$LERF_{NEW}$	<1.0E-05/yr	<1.0E-05/yr	Yes
$\Delta LERF$	<1.0E-07/yr	<1.0E-07/yr	Yes
$ICLERP_A$	<5.0E-08	<5.0E-08	Yes
$ICLERP_B$	<5.0E-08	<5.0E-08	Yes

- The total value is the sum of the contributions from the internal events, internal floods, and internal fire PRAs

Summary of Potential Sources of Model Uncertainty

- Human Error Probability (HEP) development as a class as discussed in Section 7.3.3.2
- Total frequency of medium LOCAs that are too big for CRD makeup capabilities (i.e. below TAF)
- The basis for determining CRD survivability following containment failure scenarios

Summary of Potential Sources of Model Uncertainty

- Assumptions related to viability of non-CRD systems following containment venting or containment failure
- Fire scenario initiating event frequencies
- Fire PRA model assumption that all scenarios with credit for FW/PCS always require bypass of the containment isolation signal and cross-tie of instrument air to instrument gas

Items to Explore

- Sensitivity Study Selection
  - HEP development as a class
  - Total frequency of medium LOCAs that are too big for CRD makeup capabilities (i.e. below TAF)
  - The basis for determining CRD survivability following containment failure scenarios
  - Fire scenario initiating event frequencies

Items Not to Explore

- Screened due to most likely reducing the relevant risk measures
  - Assumptions related to viability of non-CRD systems following containment venting or containment failure
  - Fire PRA model assumption that all scenarios with credit for FW/PCS always require bypass of the containment isolation signal and cross-tie of instrument air to instrument gas
  - There were no identified logical combination sensitivity cases to explore

Sensitivity Study Results

- HEP development
  - HRA was performed using a systematic approach that is consistent with the ASME PRA standard and has been peer reviewed
  - Nevertheless, in this example application, all HEP events are set to their 95th percentile values to search for new insights
- Results exceed all relevant acceptance guidelines
  - Cutset and importance measure review did not reveal any additional important contributors

Sensitivity Study Results

- HEP development (Cont'd)
- Potential Compensatory Measures
  - Perform pre-shift briefs on potentially important actions:
    - Maximize CRD flow for RPV injection
    - Depressurize RPV for low pressure injection
    - Bypass containment isolation for PCIG
    - Cross-tie IA to PCIG to maintain inboard MSIVs open for use of FW/PCS

Sensitivity Study Results

- Total frequency of medium LOCAs that are too big for CRD makeup capabilities
  - Current MLOCA frequency is greater than alternative hypothesis from NUREG/CR-6928
  - Sensitivity case provides a conservative screening assessment by setting all of the current MLOCA frequency to be greater than CRD makeup capability
- Results within all relevant acceptance guidelines
  - No additional compensatory measures identified

Sensitivity Study Results

- CRD survivability following containment failure
  - Current value is believed to represent the best estimate plant response
  - Sensitivity case increases the likelihood that CRD fails in containment failure scenarios based on an assessment of the uncertainty associated with the containment failure modes leading to failure of CRD
- Results exceed ICCDP acceptance guideline for the RHR B case
  - Establish actions to consider pre-alignment of alternate injection systems when containment pressures approach the primary containment pressure limit

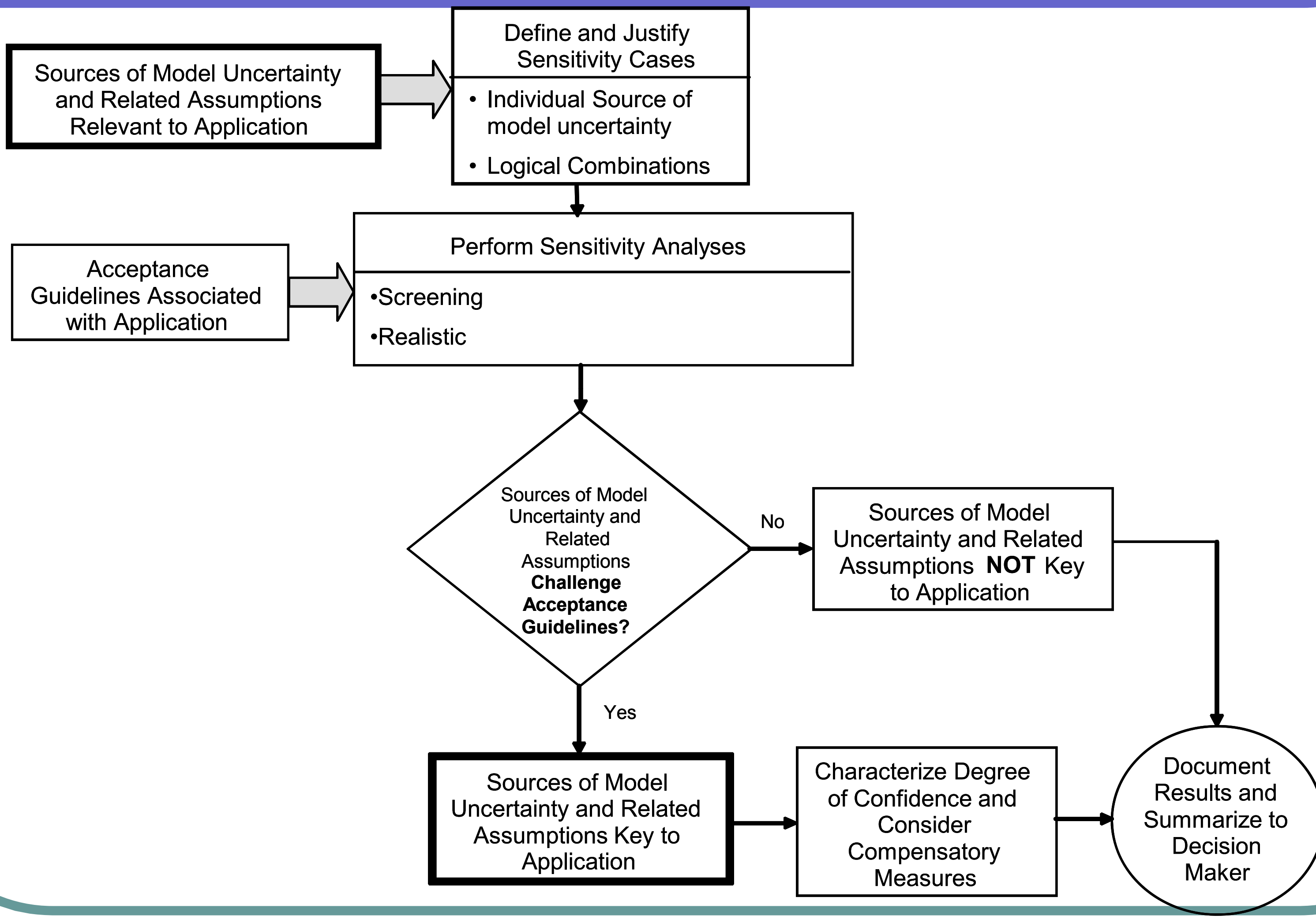
Sensitivity Study Results

- Fire scenario initiating event frequencies
  - New data indicates that the initiating event frequencies may be conservative
  - This sensitivity case reduces all of the scenario frequencies by a factor of two
- Results are well within the acceptance guidelines for all cases
  - Demonstrates the significance of this conservatism

Key Sources of Uncertainty

- The following two items are identified as ***key*** sources of uncertainty for this application:
  - HEP development as a class
  - The basis for determining CRD survivability following containment failure scenarios
- Compensatory measures identified for the key sources of uncertainty

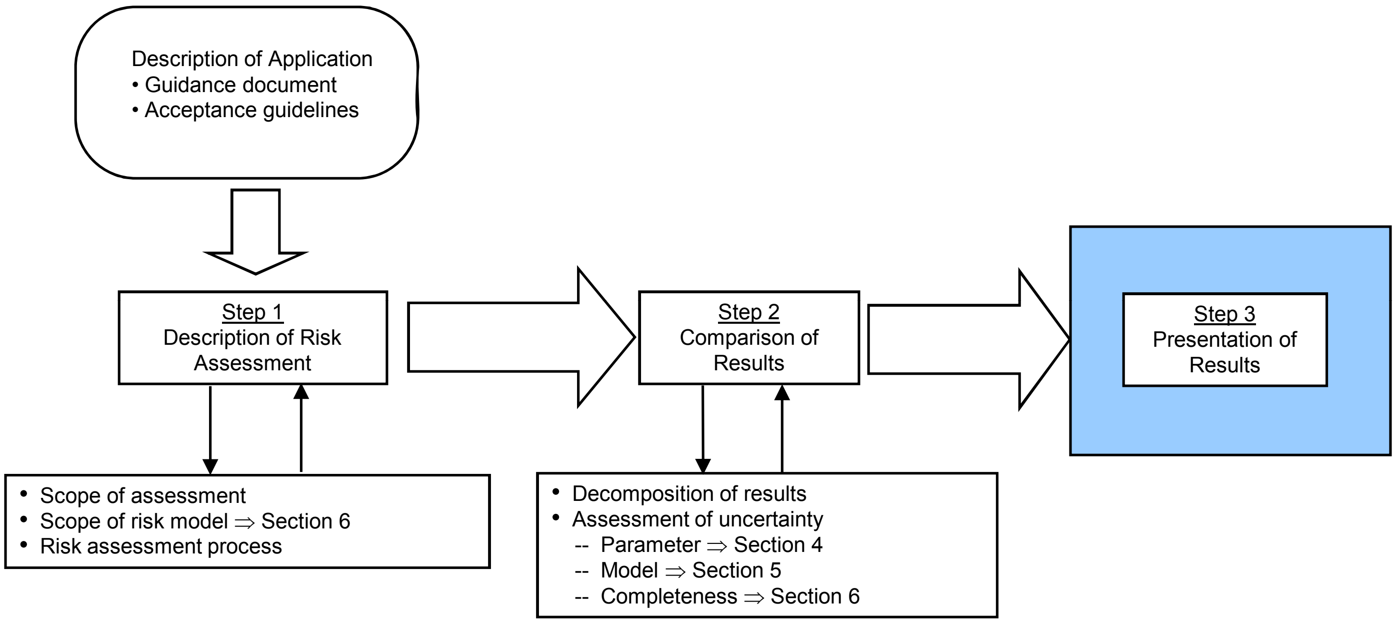
Evaluation of Sensitivity Study Impacts on Decision



Intent of Sensitivity Study Results

- The results of any one or more sensitivity case being above the acceptance guidelines should not automatically lead to a negative outcome by the decision maker
- The intent of the process is to clearly identify those sources of uncertainty that are key to the decision
  - Challenge the acceptance guidelines
  - Appropriate compensatory measures identified

Process for Evaluating the Results of the Risk Assessment



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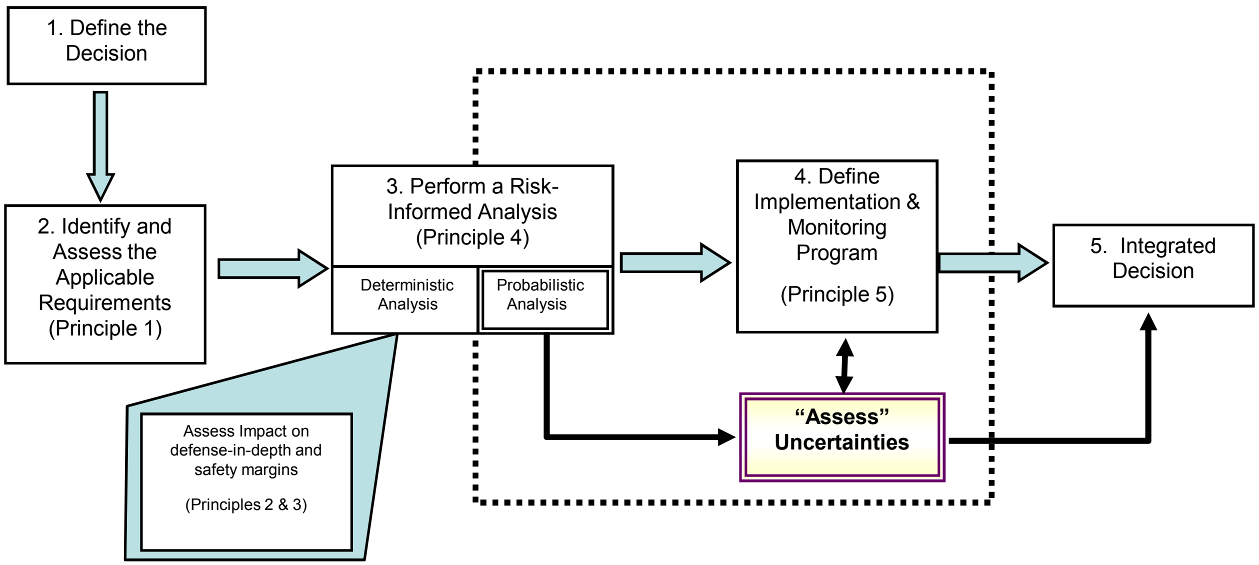
The Risk-informed Process



Presentation of Results: Description of the Risk Assessment (Step 1)

- Based on the application and the associated guidance
  - Defined scope of the risk assessment
  - Determined the adequacy of scope of the PRA model
    - Used insights from the existing PRA model (internal events, internal flood, internal fires)
    - Screened other relevant hazard groups based on significance to the decision
  - Defined how to use the PRA model to generate the required results

Presentation of Results: Comparison of Results with Acceptance Guidelines (Step 2)

- Performed initial analysis with the existing PRA model to identify the significant contributors to the results by:
  - Hazard groups
    - Internal events and internal flood
    - Internal fires
  - Accident classes/sequences
  - Basic events

Presentation of Results: Comparison of Results with Acceptance Guidelines (Step 2)

- Assessed impact of uncertainty
  - Parameter uncertainty
    - Compared formal propagation with point estimate (using mean values)
    - In this example very little difference as expected based on inspection of cut sets
  - Model uncertainty

Presentation of Results: Comparison of Results with Acceptance Guidelines (Step 2)

- Model uncertainty:
  - Identified those sources of model uncertainty relevant to the significant contributors
    - Tables A-1 and A-2 and Appendix B of EPRI 1016737
  - Dispositioned based on the specific PRA modeling approach to identify potentially key sources of uncertainty
  - Performed sensitivity studies to identify key sources of uncertainty

Presentation of Results

- Summarized results of comparison with acceptance guidelines
  - Two key sources of uncertainty
    - HRA results
    - CRD survivability following containment failure
  - Identified compensatory actions
    - Base case is presented as the best estimate
    - Compensatory measures provided as additional assurance

Conclusion

- Have presented an approach that exercises most parts of the guidance
- All conclusions are plant specific and cannot be interpreted generically

Regulatory and Industry Perspectives

Open Discussion

Items of Concern

1. Is the guidance easily understood to implement? If not, where could additional explanation (guidance) be provided?
2. Is it clear when and to what extent is this guidance to be used? If not clear, where and why not?
3. Is the example helpful? If not, why not and where? What improvement needed?
4. Would additional examples be helpful? If so, what examples would be most helpful?

Items of Concern

5. What missing scope should be addressed next? For example, internal fires, new LWRs?
6. Are there particular “issues” that need to be addressed separate from the NRC and EPRI guidance documents? If so, what are they?
7. Should guidance be developed for the quantification and integration of model uncertainties into the overall PRA results? If so, why is this guidance needed? What would be the benefit (e.g., where would it be used)? If not, why not?
8. Is the approach provided by NRC and EPRI a pragmatic approach to dealing with model uncertainties? If not, why not?

Summary – Wrap-up

Where do we go from here….

- Revise Appendix A as needed and publish
- Identify where guidance needs to be expanded for clarification
- Identify where scope will be expanded
- Determine need and benefit of any "pilots"