

# Integrated Risk Informed Decision Making

## Uncertainties and their role in decision making

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# The Role of Uncertainty in IRIDM

- “Uncertainty” is just another term essentially focused on “how confident are we on our knowledge” or “what if we are incorrect in our assumptions”
- Underlying uncertainty exists whether we acknowledge this or not
- The capability to perform uncertainty analysis is a benefit of using PRA, not a detriment
- The key purpose of treating uncertainties in PRA is to identify important sources of uncertainty and ensure those sources are addressed appropriately
- When appropriately addressed, the uncertainty analysis adds technical support and value to risk-informed decisionmaking
- The analysis of uncertainty (i.e., sensitivity and parametric studies) allows consideration of the possible range of risk metric values as opposed to relying solely on a single value (e.g., the mean)

# Uncertainty and other “Monsters” – All about Confidence!

What do we mean when we say...

“Uncertainty”?

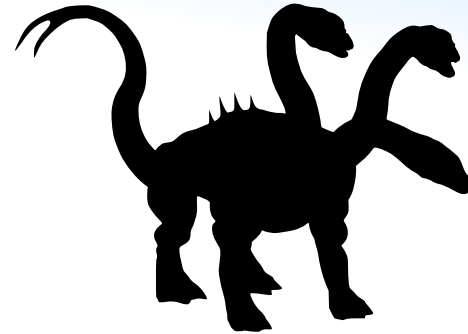
“Conservatism”?

“Margins”?

“Defense-in-Depth”?

“Realism”?

“Best Estimate”?, “Reasonable”?, “Bias”?...



More importantly, what are we asking for?

“What is the level of conservatism in your analysis?”

“Did you use an appropriate safety margin?”

“How did you address uncertainties in your model?”

“Was there an impact to the level of defense-in-depth?”



# These Words Matter...



“The program was operating too close to too many margins”  
— Report on Columbia Shuttle Disaster



“...margins need to be sufficiently large to address the high level of uncertainty...”

“...failure to provide sufficient means of protection at each level of defence in depth...”

“...site did not know how the accident would progress, which created significant uncertainty...” — Fukushima Daiichi Accident Report by the IAEA Director General

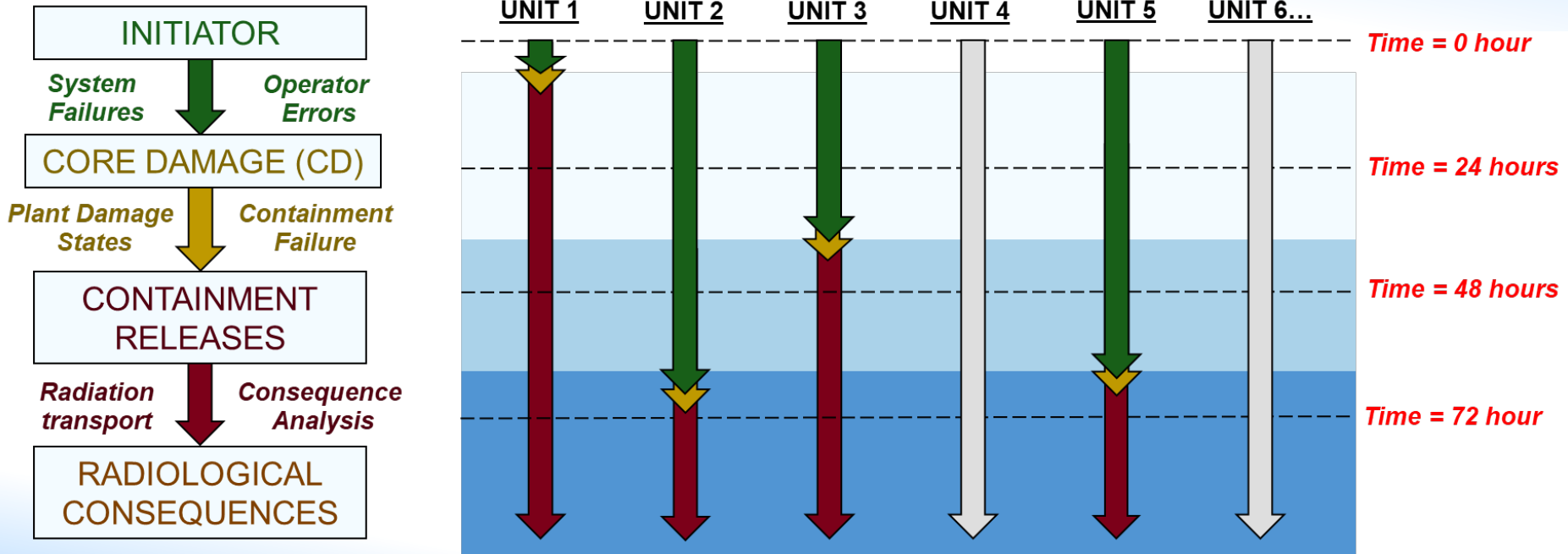


“It's not just as conservative as would have been the norm  
in the old Boeing.” — Former Boeing flight-controls engineer



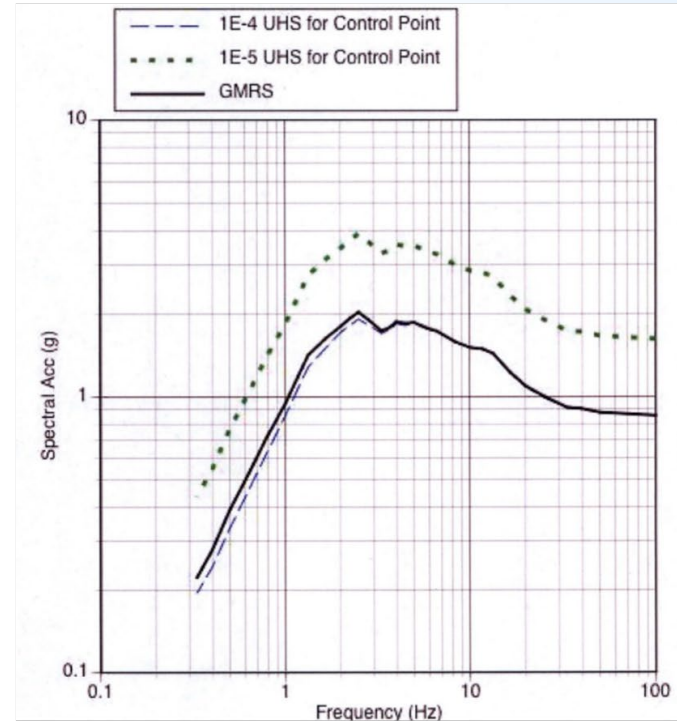
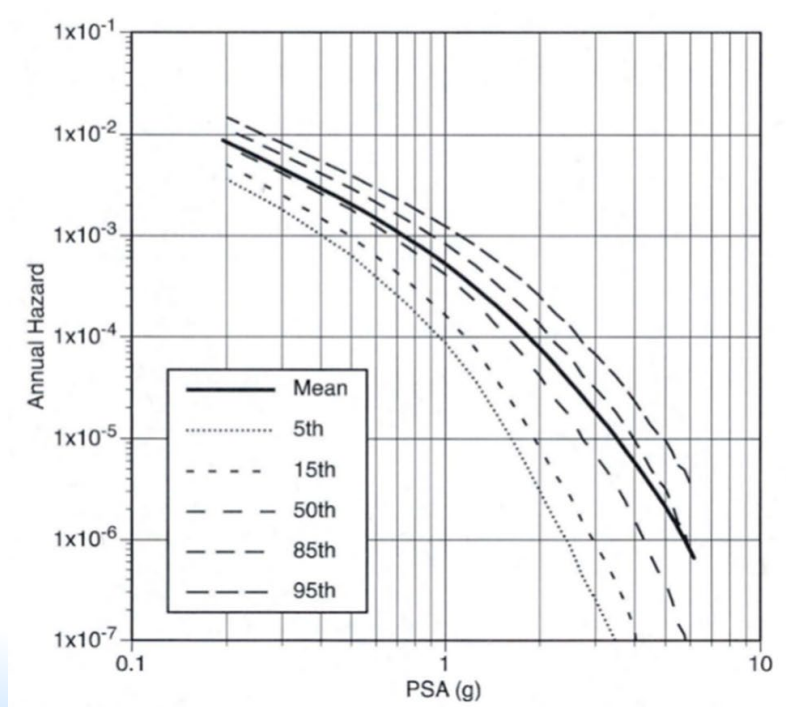
# There Will Always be Uncertainty

- In how a radiological event will unfold...



# There Will Always be Uncertainty

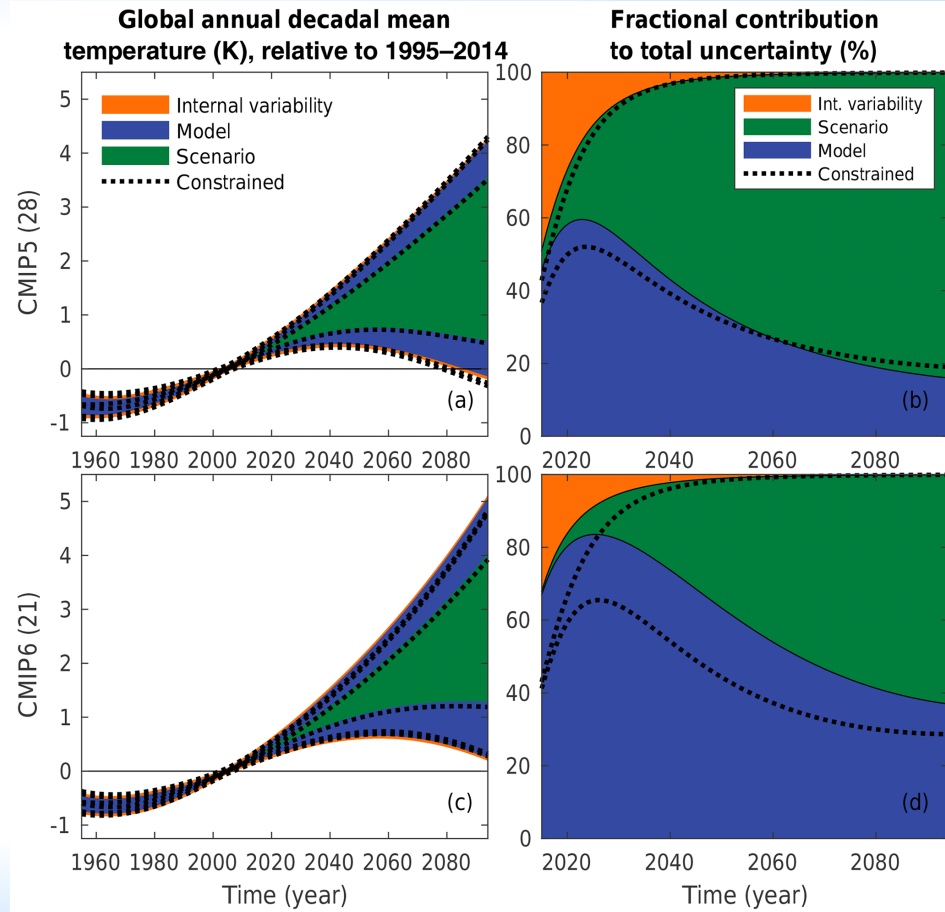
- In the likelihood and order of magnitude of a natural hazard



*\*Diablo Canyon Power Plant Units 1 and 2, Response to NRC Request for Information for Near-Term Task Force Review of Seismic Insights from the Fukushima Dai-Ichi Accident [ML18120A201](#)*

# There Will Always be Uncertainty

- In climate change...



# There Will Always be Uncertainty

Often, we are dealing with deep uncertainties for extremely unlikely events...

- We can not easily or even credibly quantify nor use probabilities
- We know there could be surprises
- We know neither the mechanisms, functional relationships nor statistical properties
- We do not agree on or do not know the (future) valuation of the outcomes



# There Will Always be Uncertainty

- Across multiple topics impacted by IRIDM and PSA



▪ Internal events



▪ Internal fire



▪ Internal flooding



▪ Seismic Events



▪ External Flooding



▪ Multi-unit accidents



▪ Spent Fuel Pool (SFP)



▪ Dry Cask Storage



▪ Digital Instrumentation & Control



▪ Shutdown Risk



▪ Periodic Safety Reviews



▪ Physical Security



▪ Portable Equipment

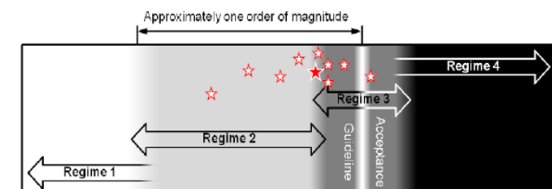
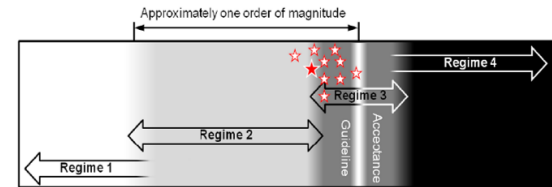
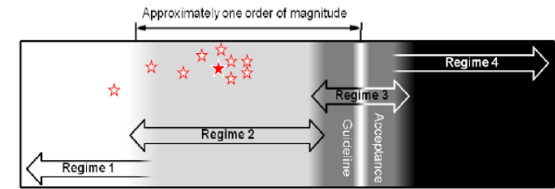
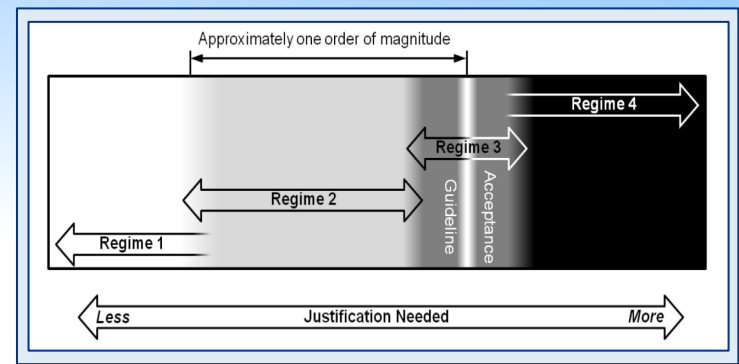


▪ Risk-Informed Applications

Again, knowing what we know and don't know is a very powerful exercise...

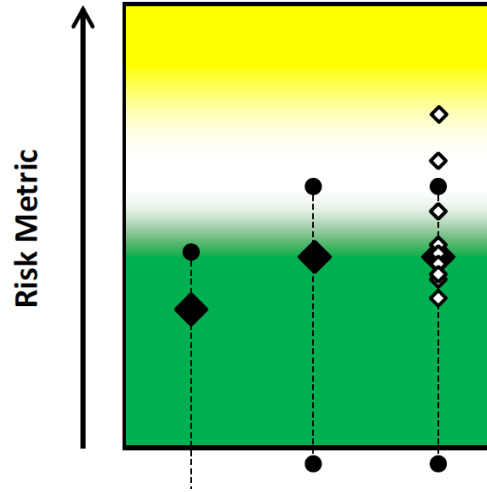
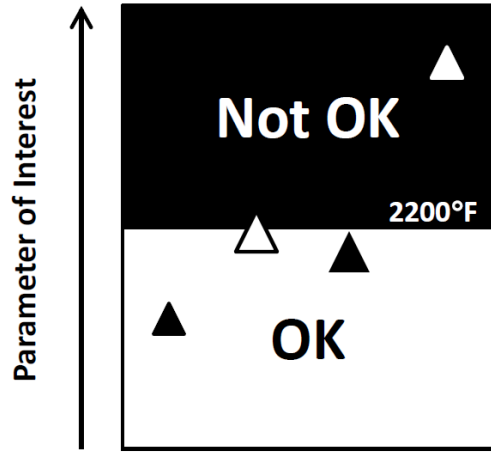
# There Will Always be Uncertainty

- Use of Quantitative Health Objectives (QHOs) presumes uncertainty is inherent in defining and ensuring acceptable risk, e.g.,
- Margin exists between QHO and risk acceptance guidelines, so:
  - Uncertainties need to be acknowledged, e.g.,
    - » How close are we to a threshold?!?
  - Uncertainties should not impede decision-making
  - Mean values to be used with confidence in risk-informed decision-making
  - No need for knife-edged treatment; treat as “guidelines”

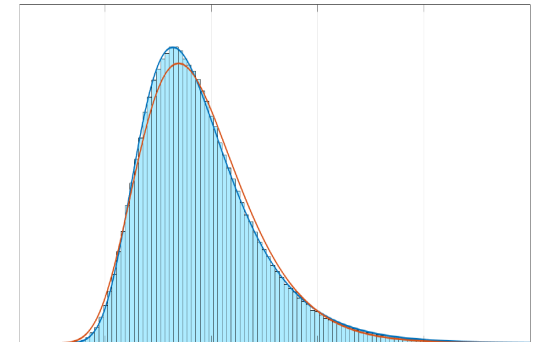


# The Struggle to Understand the Role of Uncertainty

Need to be careful when mixing deterministic/probabilistic “Uncertainty”

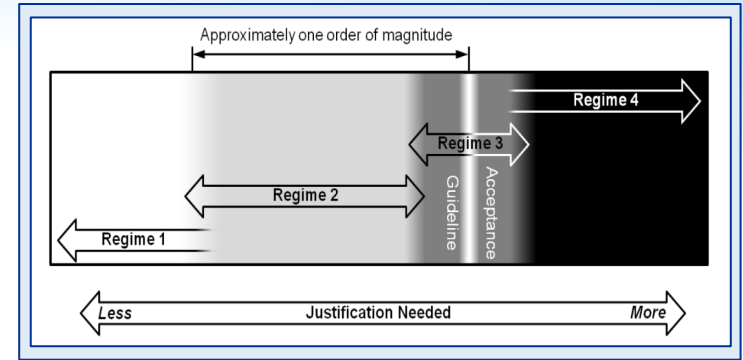


Too often, “Uncertainty” is viewed as a quantification exercise (can be part of it, but not the ultimate purpose)



# The Struggle to Understand the Role of Uncertainty

- A “perceived” challenge of risk, RIDM:  
*“But it has uncertainty (which I think means bad), so isn’t RIDM = bad?”*
- Uncertainty is everywhere, we can choose to address it or ignore it
  - Risk assessment & PRA can characterize it explicitly, implicitly in multiple ways
- Uncertainty is not just about “using probability distributions”, it is about:
  - Knowing where we have more/less confidence is critical
  - Being able to ask, “but what if we are wrong” and inform the decision-making



**It needs a structured approach to assessing it; avoid making it analyst-specific (where each person sees something different)**

# How to Deal with Uncertainty in IRIDM

- Develop a structured approach to deal with uncertainty in IRIDM, PSA implementation
- Use a PSA (as appropriate) to address uncertainty to support IRIDM (uncertainty in PSA)
- Development of the base PRA model and modeling the cause-effect relationship
  - Nature of a PRA model
    - Basic modeling assumptions
    - Uncertainties in the results obtained from this model
- Ensure an understanding of the types of uncertainty
  - How do we define them?
  - How do we characterize them?
  - How do we deal with them?

# How to Deal with Uncertainty in IRIDM – Detail/Realism



## LEVEL OF DETAIL

- Conservative Bias
  - Grouping of information – if using a less refined modeling approach, this could lead to additional uncertainty (which may or may not be reducible)
  - Choice of representative scenarios – using fewer, bounding (in terms of required response) accident scenarios is generally considered to be conservative
- Undetermined bias
  - Modeling all failures as complete – no partial failures
- Non-conservative Bias
  - Truncation of low frequency scenarios
  - Omission of specific failure modes or failure causes, e.g.,
    - Failure modes screened out on the basis of probability relative to others
    - Failures omitted because there are no accepted methods

## DEGREE OF REALISM

- Some modeling assumptions are generally considered realistic
- Some may be considered to be slightly non-conservative, but demonstrated to have minimal impact on the results
- Others are believed to be conservative

# How to Deal with Uncertainty in IRIDM – Biases

- Biases are inherently unquantifiable without repeating analysis using different basic assumptions
- However, their existence is generally an acceptable aspect of PSA models
  - Some of the assumptions made when constructing the model can be demonstrated to not significantly affect the results, e.g.,
    - Screening of low probability failure modes
  - If they are recognized as being significant to a decision some biases may be partially removed by more detailed modeling
    - May be done for a specific application where the less detailed model does not support the decision
- However, biases resulting from known conservative assumptions in the base PRA need to be recognized when using the PRA results (discussed later) because, depending on the application:
  - Can lead to overestimation or underestimation of risk impact
  - Can lead to masking or exaggeration of significant risk aspects
    - For example, assumption a component always fail in specific scenarios (if partial failure is possible)

# How to Deal with Uncertainty in IRIDM – Categories

Fundamentally there are two major categories of uncertainty

- ALEATORY UNCERTAINTY
  - That associated with randomness in occurrence of initiating events, component failures, etc.
  - This is captured in the probabilistic modeling of those events and characterized in the PSA results for CDF, LERF, etc.
- EPISTEMIC UNCERTAINTY
  - Uncertainty resulting from limitations in our state-of-knowledge on how to create those probabilistic models
  - Leads to uncertainty in the results of the PRA

# How to Deal with Uncertainty in IRIDM – Types

- Use consistent definitions/descriptions on types of uncertainty
  - PARAMETRIC
    - Uncertainty in input data (affects quantification)
  - MODEL
    - Can affect either the logic structure or quantification or both
  - COMPLETENESS
    - Refers to issues not explicitly modeled in PSA, known or unknown, e.g.,
      - Specific human actions
      - The effects of unknown failure mechanisms
- Identifying the types of uncertainties helps focus on the sources of different types, their potential implications, and what can be done about them
- Consider specific requirements that may be applicable to the use of PRA in RIDM with respect to uncertainties (for example, in standard requirements on uncertainties or regulatory guidance for a specific application)
- Focus should be on issues that may impact RIDM, not necessarily as an exercise on burdensome, never-ending analysis

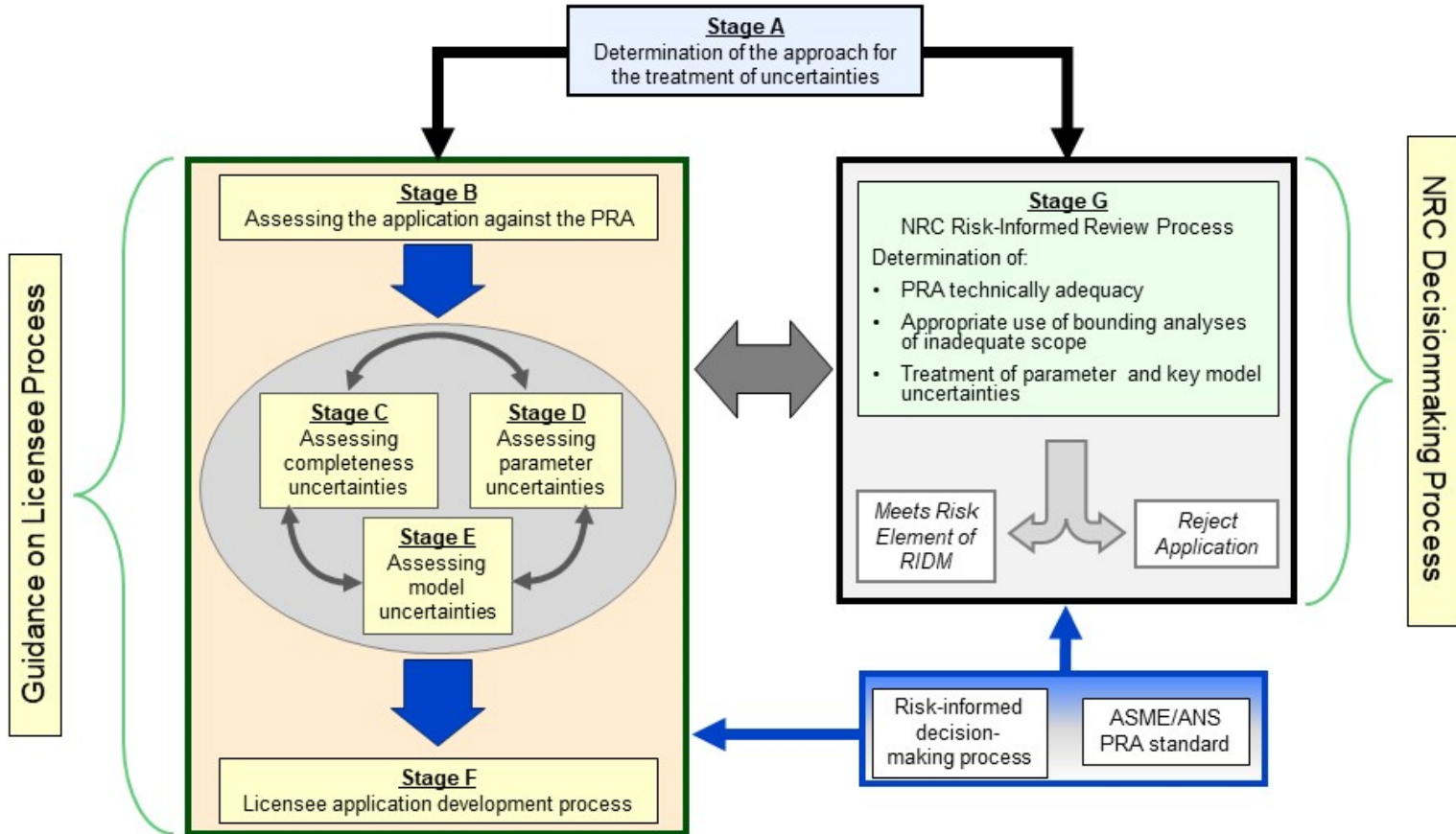
# How to Deal with Uncertainty in IRIDM – Guidance



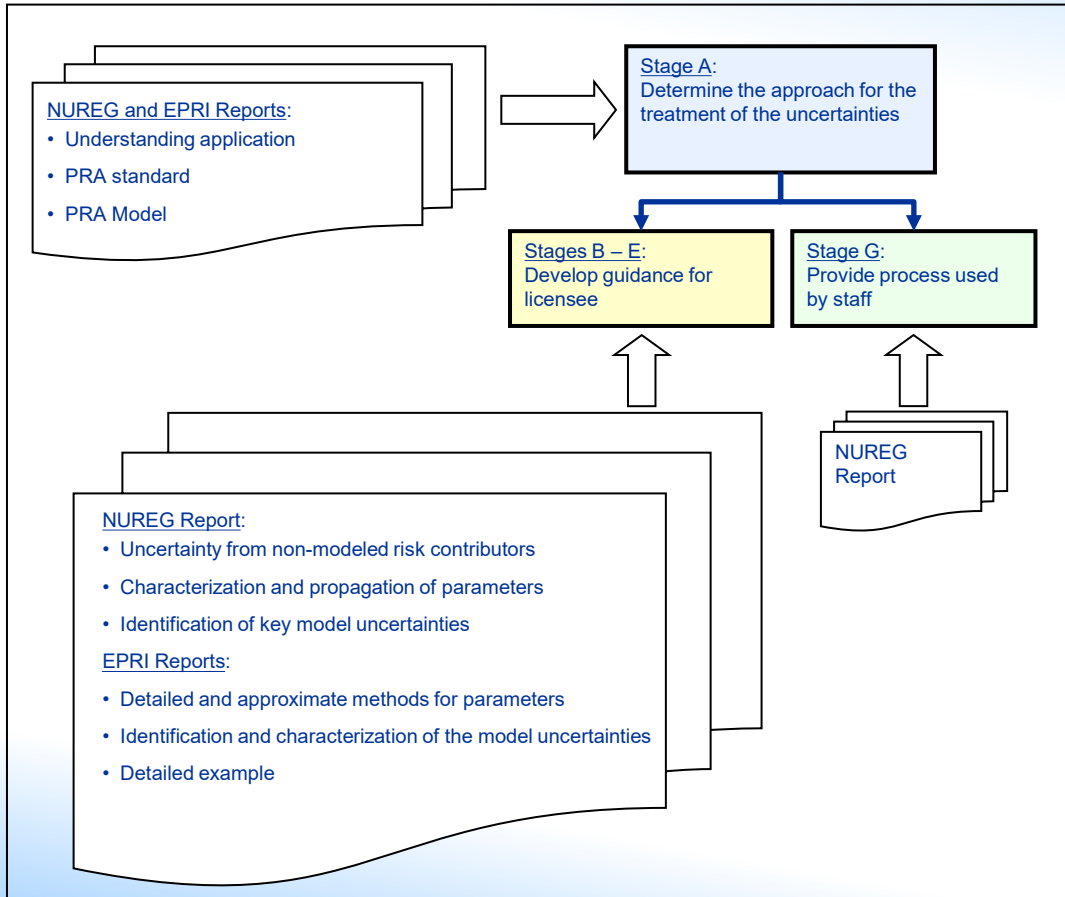
- In the U.S., specific guidance has been provided for the treatment of uncertainty in RIDM when using PSA as inputs (can be used by industry to assess its own information or by the regulator to review the information):
  - NUREG-1855: “Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decision Making”
- Specifically, guidance is provided with regard to:
  - identifying and characterizing the uncertainties associated with a PSA
  - performing uncertainty analyses to understand the impact of the uncertainties on the results of the PSA
  - how the results of the uncertainty analyses are considered in the regulatory decisionmaking process

**Fundamental Guidance on the Topic Already Exists**

# How to Deal with Uncertainty in IRIDM – Guidance



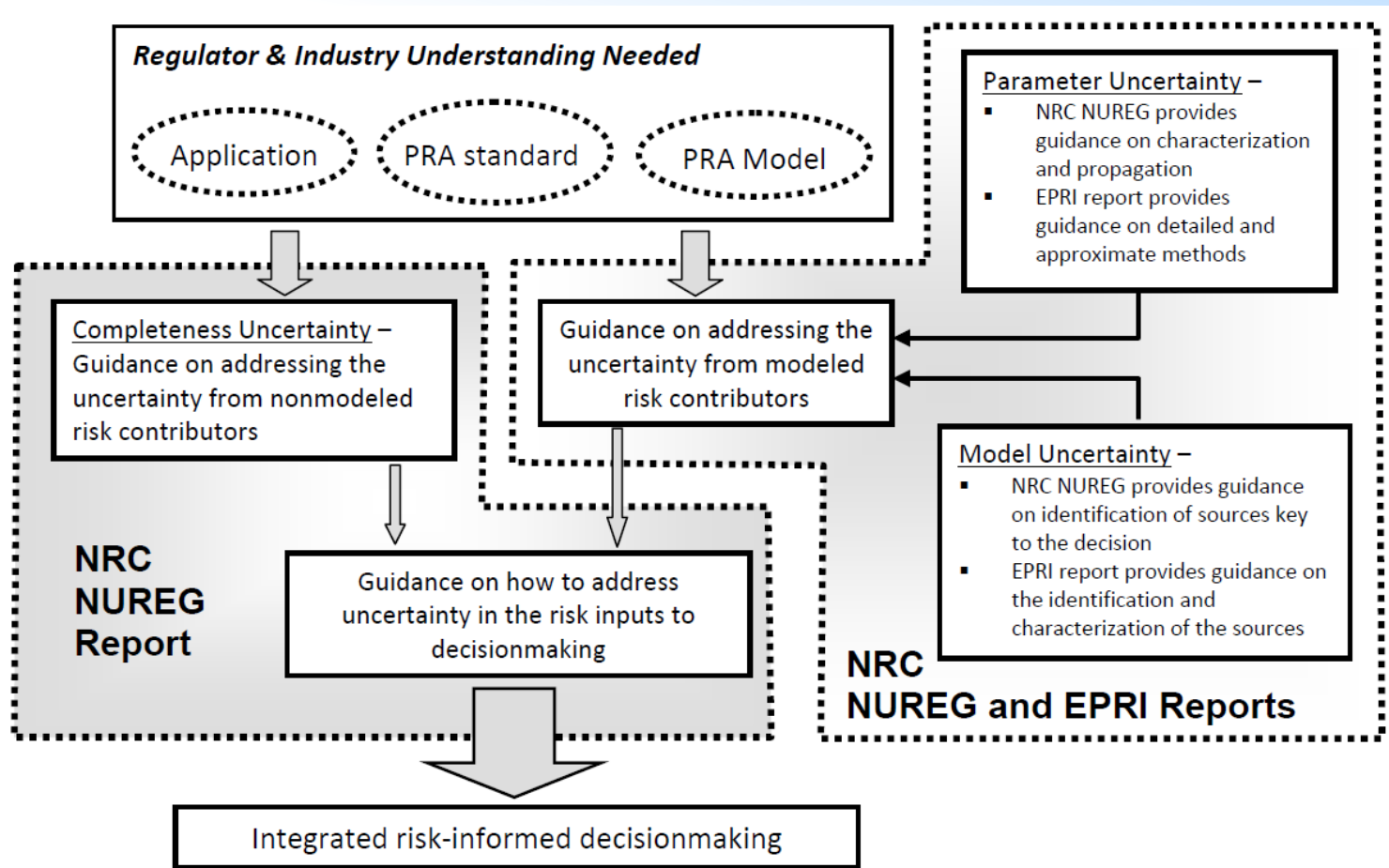
# How to Deal with Uncertainty in IRIDM – Guidance



As part of the U.S. regulatory effort to deal with uncertainty in IRIDM and use of PSA for decision-making, practical guidance was created in tandem with NUREG-1855:

- [EPRI 1016737](#) provides guidance on determining the importance of the modeling aspects and identifying and characterizing sources of model uncertainty for internal events and internal flood hazards
- [EPRI 1026511](#) provides supplemental guidance to EPRI 1016737 and NUREG-1855, Revision 1, related to identifying and characterizing sources of model uncertainty for internal fire, seismic, low-power and shutdown, and Level 2 PRA

# How to Deal with Uncertainty in IRIDM – Guidance



# How to Deal with Uncertainty in IRIDM – Parameter



Many parameter estimates, e.g., component failure probabilities or failure rates, component unavailabilities, the more common initiating event frequencies, are based on data using statistical methods

These statistical methods rely on assuming an underlying probabilistic model, e.g.,

- For failures to run and for initiating events, the Poisson model (failures occur randomly in time) is assumed
- For failures to start, it is assumed that there is a constant probability of failure on demand

These assumptions are consensus modeling assumptions

- **Caution:** some modeling assumptions may be challenged for specific applications
  - For example, use of constant failure rate models for long time frames where degradation may be an issue

Use of these models and statistical approaches to parameter estimation allows the uncertainty in the parameter to be expressed by a probability distribution:

- **Caution:** This is not aleatory uncertainty; it is the epistemic uncertainty in the parameter that characterizes the aleatory nature of the event being addressed

# How to Deal with Uncertainty in IRIDM – Parameter

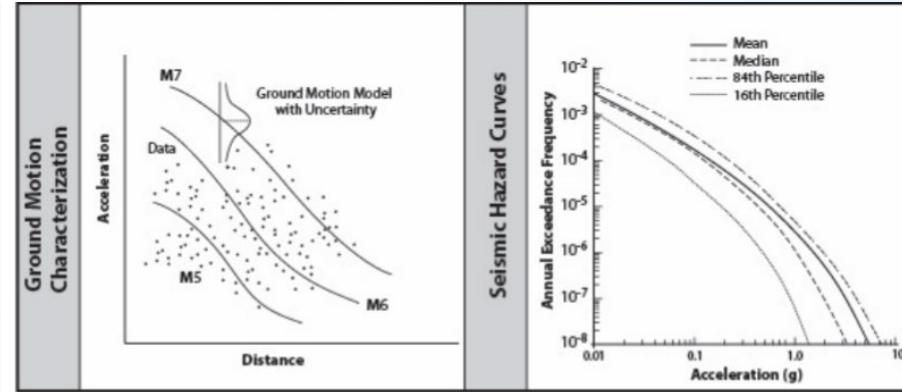
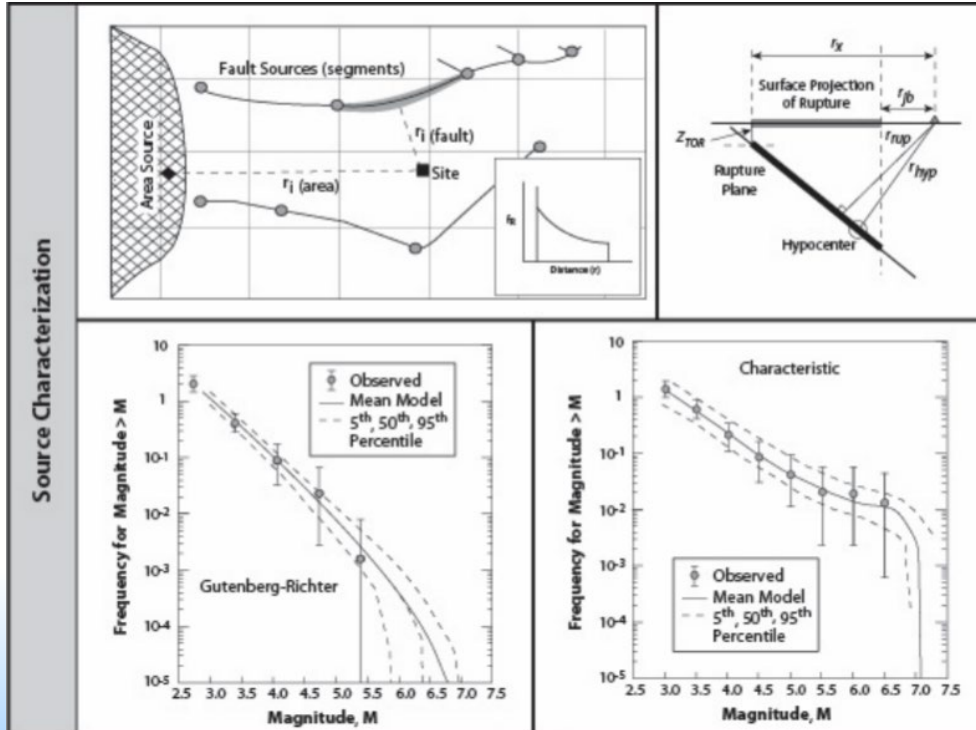


Some parameters relate to events for which there is no plant-specific or even generic data with which to estimate them. For example:

- Probabilities for human failure events
  - Accident sequences that challenge operators are rare, so statistical data on operator performance under such circumstances is not available
  - Probabilities are derived from a specific approach to model the human failure (there are multiple methods within Human Reliability Analysis to do this)
  - For most of these models the uncertainty characterization is chosen simply by specifying an error factor that varies with the determined point estimate
- Rare initiating events, such as large pipe break events
  - Derived on the basis of an expert elicitation (different experts may use different models to derive their estimates, which may or may not be weighted)
  - The expert elicitation produces a characterization of the uncertainty on the frequency of a pipe break as a function of size
  - The uncertainty characterization captures the variability in the experts' assessments

# How to Deal with Uncertainty in IRIDM – Modeling

- For example, consider how seismic impacts are addressed via Probabilistic Seismic Hazard Assessment (PSHA) approaches



- Fully characterizing uncertainty can be complex, resource-intensive
- State-of-art will continually change
- Focus is NOT on eliminating uncertainty, but in having confidence in its characterization

# How to Deal with Uncertainty in IRIDM – Modeling



- A decision or judgment that is made in the development of the PRA model
  - 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
- Hence, a source of model uncertainty occurs with an issue where there is no consensus approach or model and where the choice of approach or model is known to have an effect on the PRA model, for example:
  - Introduction of a new failure mode, 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.

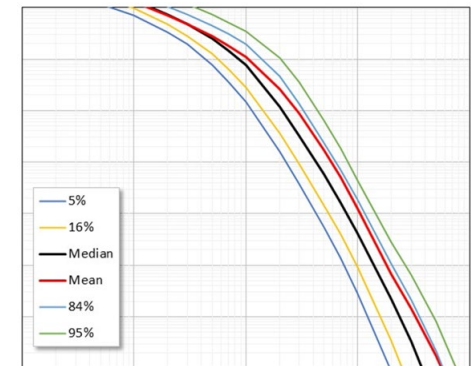
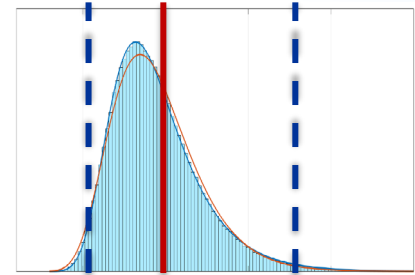
# How to Deal with Uncertainty in IRIDM – Modeling

- As discussed previously the construction of a PRA involves making many modeling choices, including:
  - Level of detail in modeling accident sequences and in the development of system fault trees
  - What hazard groups to include in the model
  - Which thermal hydraulic code to use to develop success criteria
  - Which fire growth or propagation model to use
- All modeling choices have an effect on the results, but they are not all sources of model uncertainty
- The majority of the modeling choices that have been made to develop the base PRA and model the cause-effect relationship have been demonstrated to be acceptable consistent with the state-of practice
- It is still important to assess situations where there is a viable alternative to constructing the PRA model that affects the significant contributors to the risk metrics important to the decision

**Often, a consensus model is established during state-of-art evaluations, which may change with additional research or new information (key issue is to identify possible alternatives for key modeling issues, not necessarily challenge every modeling assumption in PSA, IRIDM).**

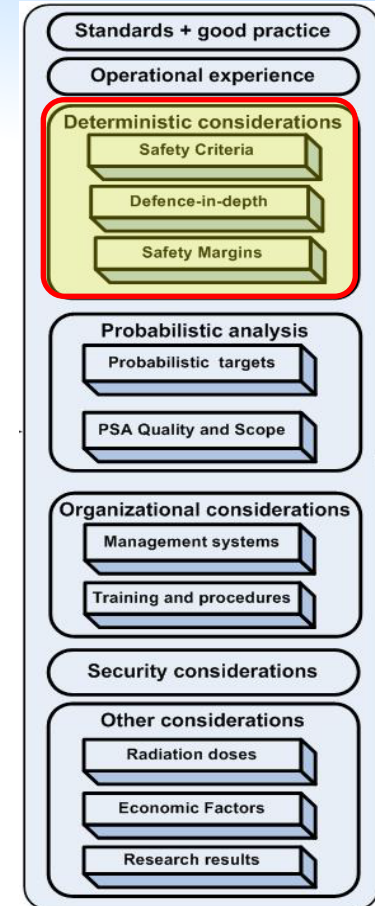
# How to Deal with Uncertainty in IRIDM – Modeling

- Sensitivity studies are also an important part of justifying the adequacy of the PSA model:
  - Used to determine whether a potentially conservative treatment is justified because it doesn't have a significant effect on the risk metrics
  - Used to screen specific contributors, etc.
- Types of sensitivity studies to address model uncertainty
  - Changes to the logic model, e.g., change success criterion, add new failures, delete option for response
  - Results in a discrete new characterization of the mean and its associated uncertainty characterization
  - Change parameter values as a surrogate for addressing model uncertainty (use percentiles instead of mean value)



# How to Deal with Uncertainty in IRIDM – Completeness

- When contributors are known to be missing from the model, the onus is on the analyst to:
  - Demonstrate that they are not significant contributors, or
  - Demonstrate that protective measures are in place to compensate
- The unknown unknowns are assumed to be addressed via the other principles of IRIDM
  - Defense-in-depth
  - Safety margins
  - Performance monitoring

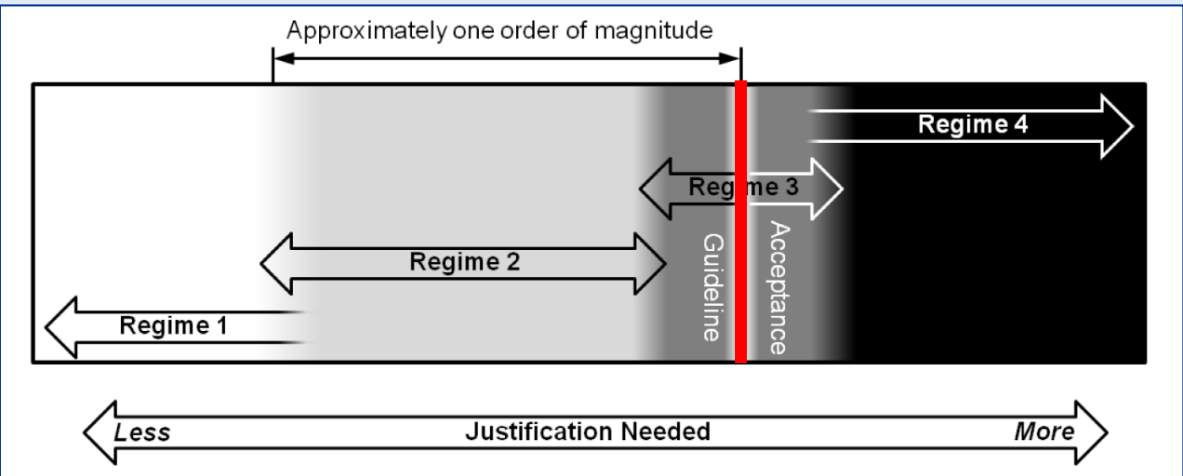
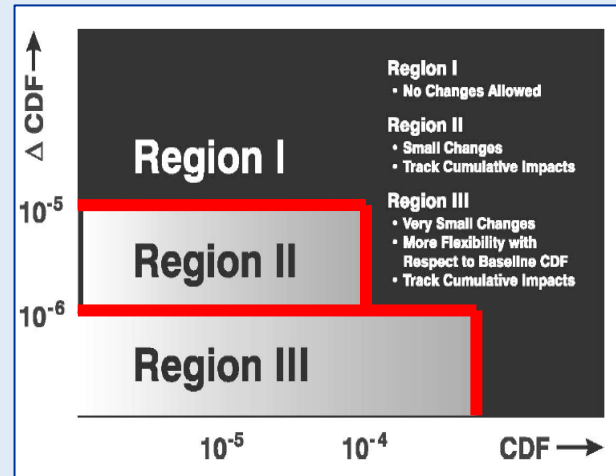


# How to Deal with Uncertainty in IRIDM – IRIDM (Example)

Regulator & Industry Understanding Needed

Parameter Uncertainty –

▪ Treatment of



Report

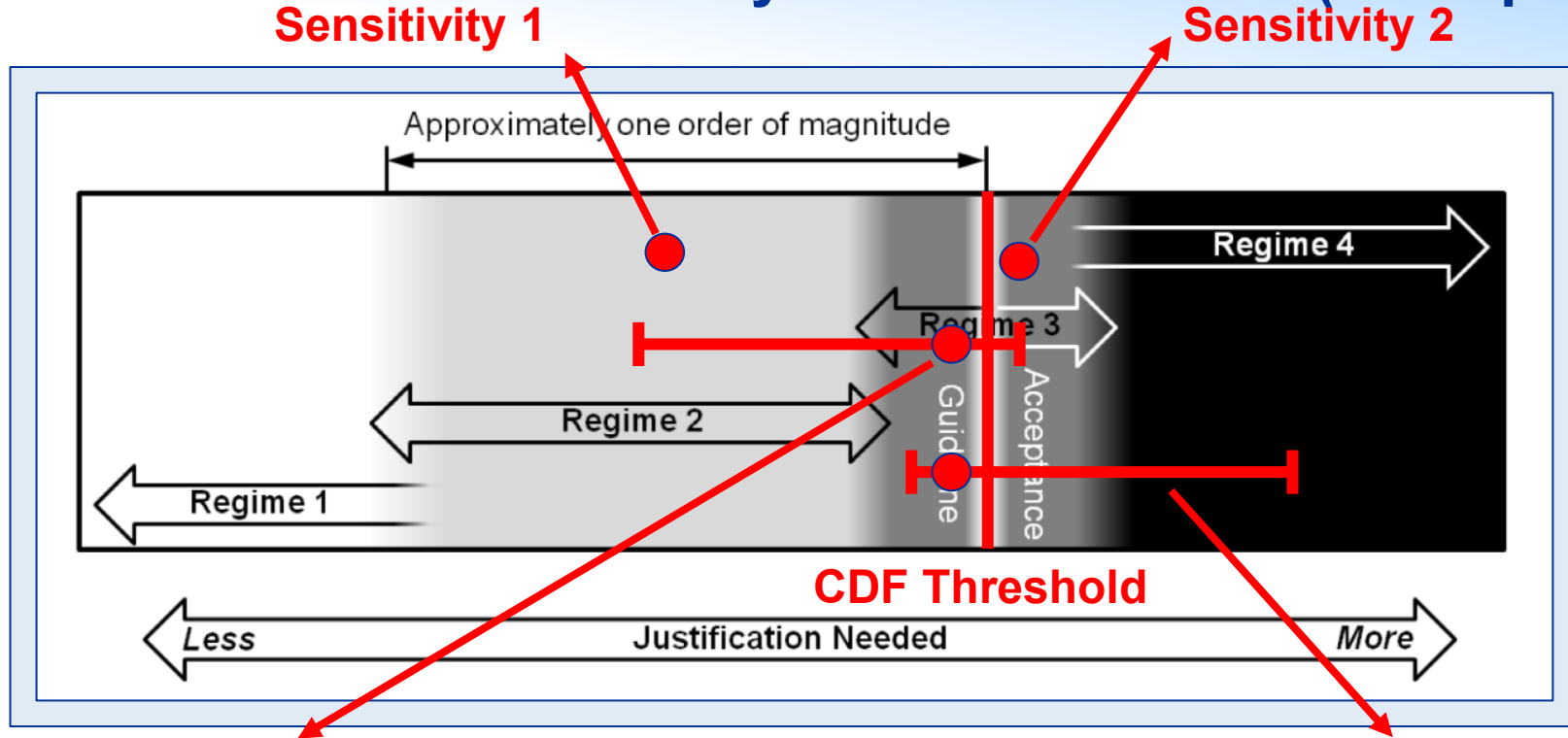
decisionmaking

NRC  
NUREG and EPRI Reports

Integrated risk-informed decisionmaking

how to address it and ultimately provide as input to decision-makers exist

# How to Deal with Uncertainty in IRIDM – IRIDM (Example)



What if CDF mean and uncertainty interval are like this? Or like this?

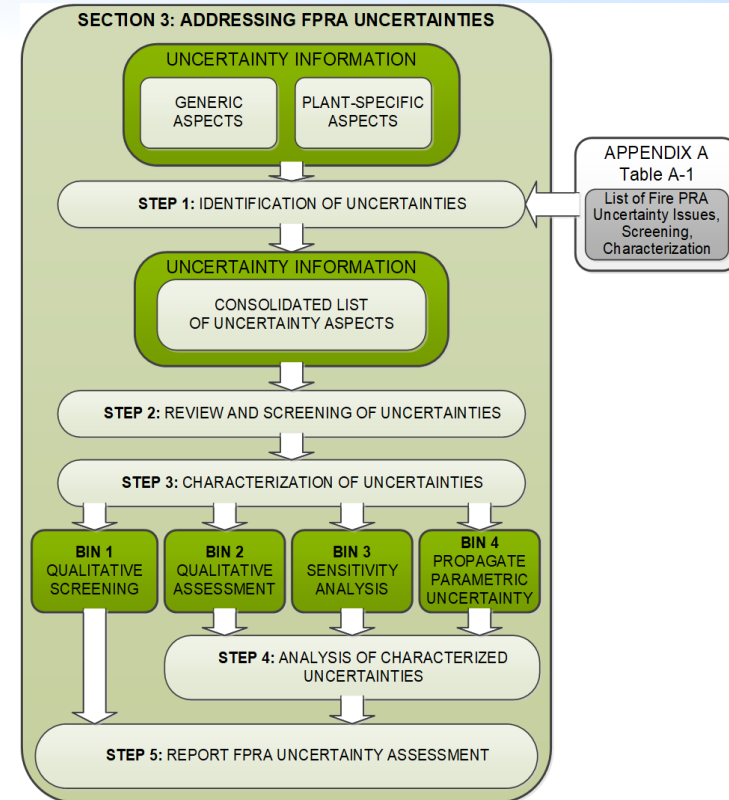
Ultimately, the decision-maker must deal with the uncertainty (make a decision)

# How to Deal with Uncertainty in IRIDM – IRIDM (Example)

As a practical example, consider a more recent effort to address uncertainties in fire PSA (a key risk contributor):



- See EPRI Fire Uncertainty Report ([3002018268](https://www.epri.com/~/media/724971main1/3002018268.pdf)), intended to be used as an implementation of previously mentioned guidance (e.g., NUREG-1855)
- Includes an overall graded approach
  - Identify (based on a large listing)
  - Review and screen identified sources
  - Characterize (focus on significant sources)
  - Disposition (screen, qualitative assessment, sensitivity analysis, practical quantification)
- Not focused on quantification for the sake of adding more complexity



# How to Deal with Uncertainty in IRIDM – IRIDM (Example)

Includes tabular list of fire PRA uncertainty issues for practical use with more than 150+ entries include the following descriptive entries

## Source of Uncertainty –

general, high-level binning

## Description –

succinct description of uncertainty issue

## Fire PRA Modeling Aspect –

e.g., human aspect, fire modeling

## Type of Uncertainty (Bias) –

e.g., “Level of Detail” (“Conservative”)

## Potential Impact on Fire PRA model –

succinct description

## Assessment –

description of potential solution, impact, mitigation

## Reference Document(s) –

documents with further guidance

## Uncertainty Treatment Bin –

e.g., “qualitatively screened” bin

Source of Uncertainty	Description	Source of Uncertainty	Type of Uncertainty (Bias)	Potential Impact on Fire PRA	Assessment	Reference Document(s)	Treatment of Uncertainty
Impact of Fire on Cables in Conduit	Cables in conduit do not contribute to fire growth and spread.	Fire Model; Cable	Modeling Choice (Realistic)	Cables in conduit are considered as potential damage targets, but not as ignition targets.	This is considered to be realistic and therefore does not introduce a significant degree of conservatism or uncertainty.	NUREG/CR-6850 [Chapter 8]	Qualitatively Screened
Modeling Junction Boxes	Junction boxes that are robustly secured are screened as non-propagating ignition sources. Note: The definition and treatment of junction boxes should be consistent with FAQ 13-0006.	Fire Model	Modeling Choice (Realistic)	This assumption is considered to be realistic and does not therefore introduce a significant degree of uncertainty.	N/A	NUREG/CR-6850 [Task 8 calculation]	Qualitatively Screened

# How to Deal with Uncertainty in IRIDM – IRIDM (Example)

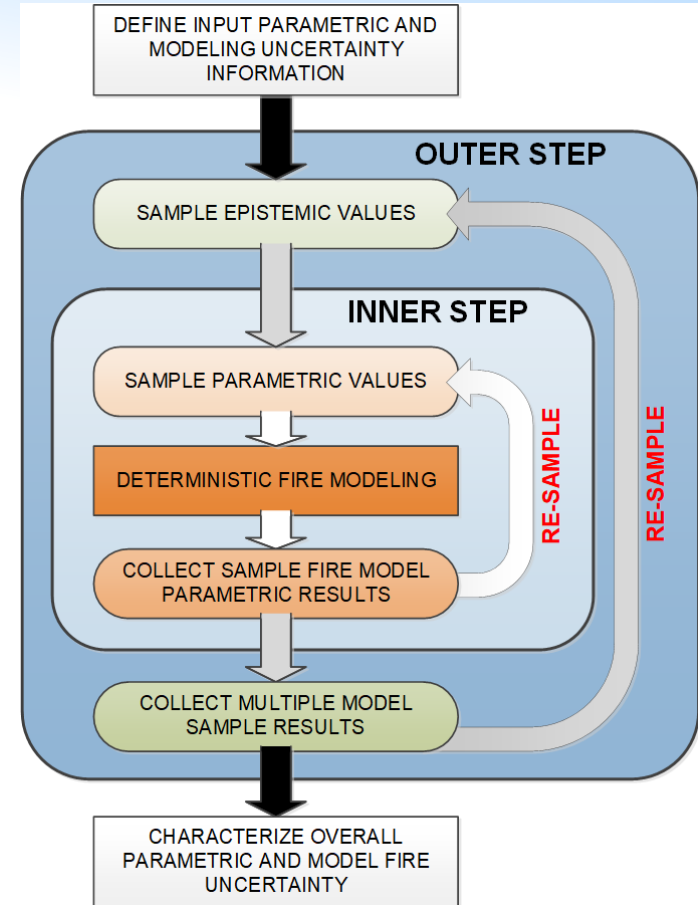
For specific cases fire propagation cases where quantification may support realism, a simulation approach is suggested:

**Epistemic uncertainties** (lack of knowledge) sampled in outer step. Some parameters include:

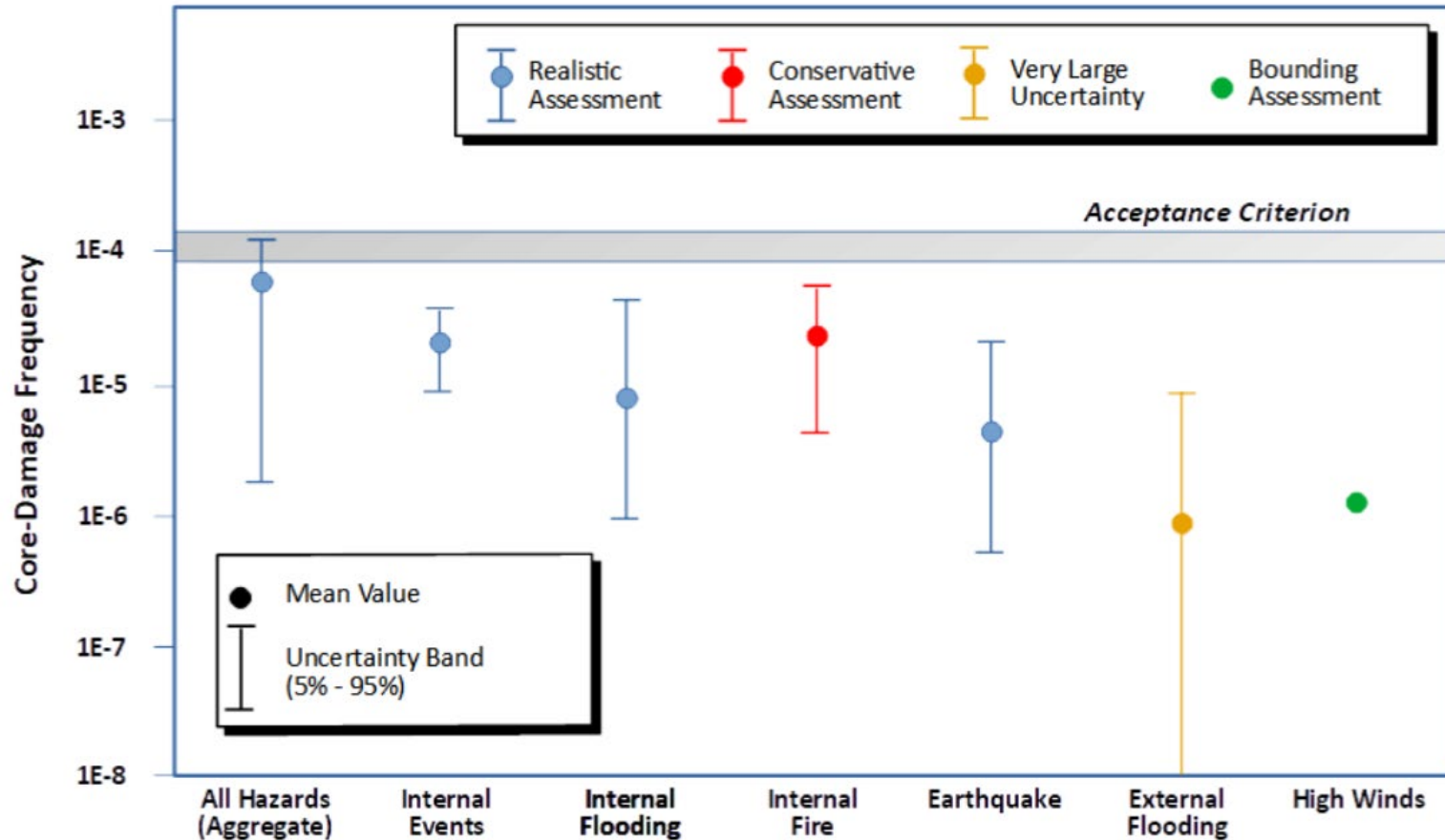
- Fire diameter
- Fire elevation
- Convective fraction
- Model uncertainty in fire modeling equations

**Aleatory uncertainties** (randomness) sampled in inner step. Some parameters include:

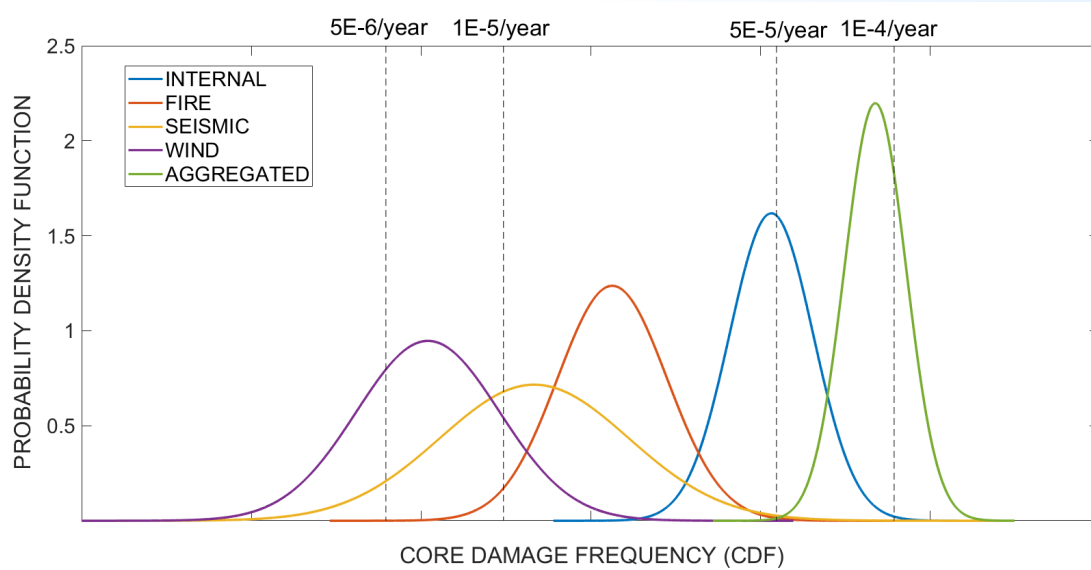
- Peak heat release rate
- Fire timing (time to peak, steady burning, decay)
- Manual suppression time



# How to Deal with Uncertainty in IRIDM – Quantification



# How to Deal with Uncertainty in IRIDM – Quantification



Hazard	Mean CDF	CDF 95th Percentile	CDF 5th Percentile	Median CDF	CDF Error Factor
Internal	5.0E-05	7.3E-05	3.2E-05	4.8E-05	1.50
Fire	2.0E-05	3.2E-05	1.1E-05	1.9E-05	1.70
Seismic	1.4E-05	3.0E-05	4.8E-06	1.2E-05	2.50
Wind	7.0E-06	1.3E-05	3.2E-06	6.4E-06	2.00
Aggregated	9.1E-05	1.2E-04	6.7E-05	8.9E-05	1.35

Propagating specific types of uncertainty is possible using PSA models (a requirement for meeting technical adequacy of the PSA).

- However, again, this reflects the uncertainty that is explicitly included (there are others...)
- For decision-making, the mean value is the most significant metric
  - Does the percentiles provide additional insights?
- Understanding the most important sources of uncertainty (and what has been done/could be done about it) is ultimately more important than simple quantification of results

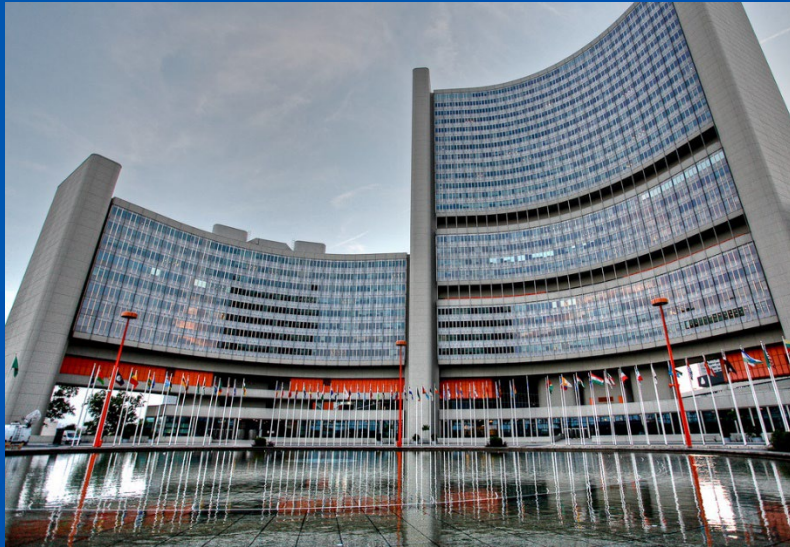
# Summary

- Underlying uncertainty exists whether we acknowledge this or not
- The capability to perform uncertainty analysis is a benefit of using PSA, not a detriment
- The key purpose of treating uncertainties in PSA is to identify important sources of uncertainty and ensure those sources are addressed appropriately
- Guidance exists on treatment of uncertainty, even if implementation details may differ for specific topics, applications
- Addressing uncertainty should be a benefit of PSA (not undue burden)



**IAEA**

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*Atoms for Peace and Development*



*Thank you!*

