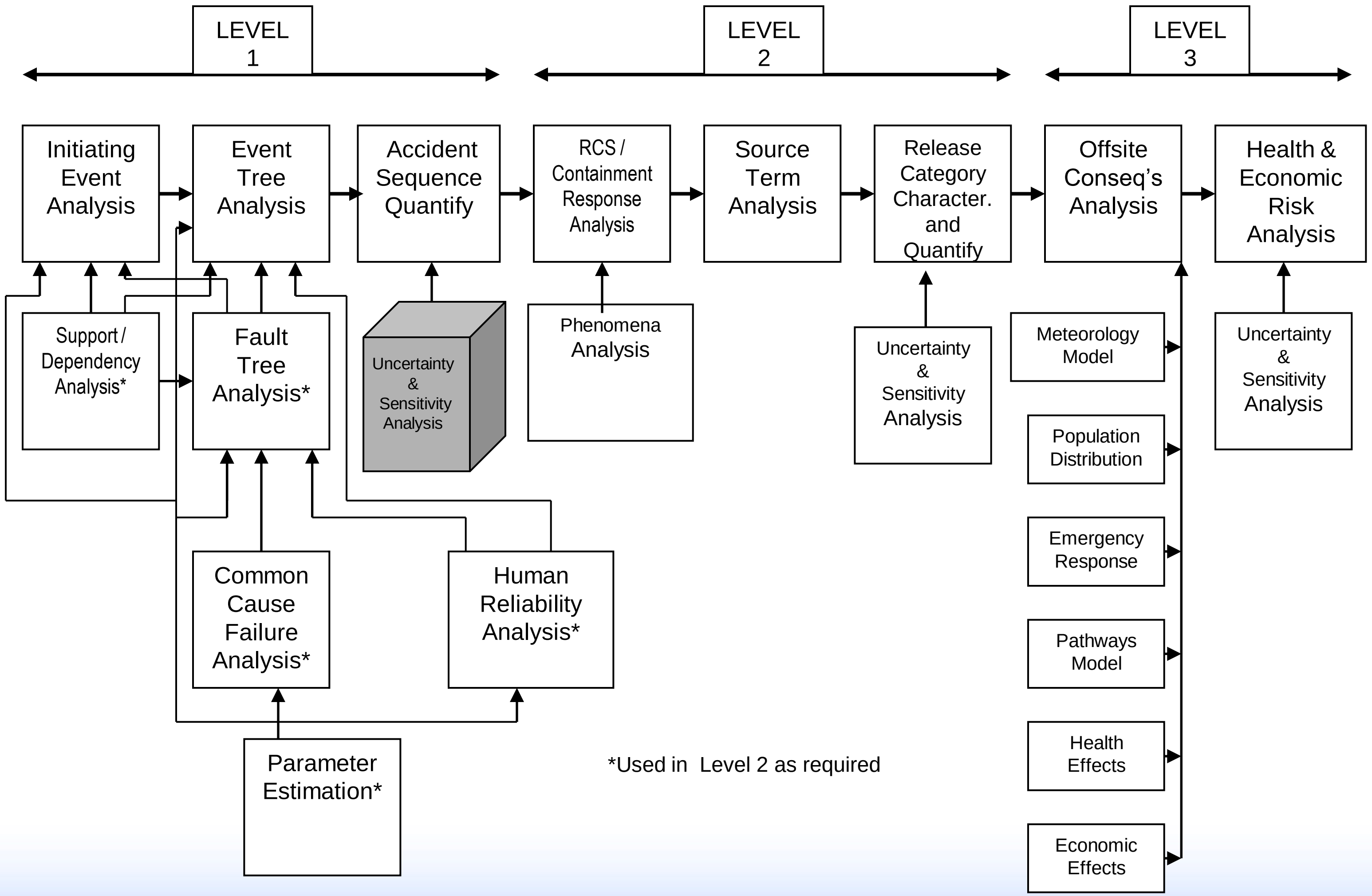
MODULE N

IMPORTANCE MEASURES

Importance Measures

- **Purpose: Students will be introduced to concepts of quantitative importance measures. Several different types of importance measures and their meanings are presented.**
- **Objectives:**
  - **Identify four common quantitative importance measures**
  - **Calculate values for four types of importance measures given Level 1 PRA results**
  - **Discuss how importance measures are influenced by the value of the associated basic event, the values of other basic events, and modeling assumptions**
  - **Understand implications of each importance measure for plant safety & inspection activities**
  - **Explain why use of importance measures is considered valid for Maintenance Rule applications (i.e., binning SSCs into risk and non-risk categories)**
- **References:**
  - **NUREG-1489, App. C**
  - **NRC Inspection Manual Part 9900: Technical Guidance-Operations; Use of Probabilistic Risk Ranking Information**
  - **The Use of Risk Importances for Risk Based Applications and Regulation; W.E. Vesely, PSA-96**
  - **Some Perspectives on Risk Importance Measures, I. Wall, D. Worledge, PSA-96**
  - **Developing Useful Insights and Avoiding Misleading Conclusions from Risk Importance Measures in PSA Applications, K. Fleming, PSA-96**

Principal Steps in PRA



What are Importance Measures

- **A means of utilizing a PRA model to measure impact of model inputs on total risk**
  - **An effective way to separate, identify, & quantify values of individual factors which affect risk**
    - **Design features**
    - **Plant operations**
    - **Test & maintenance**
    - **Human reliability**
    - **System & component failures**

Importance Measures

- Provide quantitative perspective on dominant contributors to risk and sensitivity of risk to changes in input values
- Usually calculated at core damage frequency level
- Common importance measures include:
  - Fussell-Vesely
  - Risk Reduction
  - Risk Increase or Risk Achievement Worth (RAW)
  - Birnbaum

Fussell-Vesely (FV)

- Measures the overall percent contribution of cut sets containing a basic event of interest to the total risk
- Calculated by finding the value of cut sets that contain the basic event of interest (x_i) and dividing by the value of all cut sets representing the total risk (baseline risk)

  $FV_{xi} = F(i) / F(x)$

  where,

  F(i) is risk from just those cut sets that contain event x_i

  F(x) is the total risk from all cut sets
- The FV range is from 0 to 1 (0% to 100%)

Fussell-Vesely Importance Measure Calculation Example

- **Consider these minimal cut sets:**

T * A	= 1/year * 6×10^{-4}	= 6×10^{-4}
T * B * C	= 1/year * 1×10^{-2} * 3×10^{-3}	= 3×10^{-5}
T * C * D	= 1/year * 3×10^{-3} * 1×10^{-3}	= 3×10^{-6}
	F(x)	= 6.33×10^{-4}

where:

T = 1/year
A = 6×10^{-4}
B = 1×10^{-2}
C = 3×10^{-3}
D = 1×10^{-3}

- **Fussell-Vesely Importance**

FV_T = $6.33 \times 10^{-4} / 6.33 \times 10^{-4}$ = 1.0
FV_A = $6.00 \times 10^{-4} / 6.33 \times 10^{-4}$ = 0.948
FV_B = $3.00 \times 10^{-5} / 6.33 \times 10^{-4}$ = 0.047
FV_C = $3.30 \times 10^{-5} / 6.33 \times 10^{-4}$ = 0.052
FV_D = $3.00 \times 10^{-6} / 6.33 \times 10^{-4}$ = 0.005

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Risk Reduction Importance (Risk Reduction Worth)

- Measures the amount that the total risk would decrease if a basic event's failure probability were 0 (i.e., never fails)
- Calculated as either ratio or difference between the value of all cut sets representing the total risk (baseline risk) and the value of the total risk with the failure probability for the basic event of interest (x_i) set to 0

  Ratio: $RRR_{xi} = RRW_{xi} = F(x) / F(0)$

  Difference (or Interval): $RRI_{xi} = F(x) - F(0)$

  where:

  F(x) is the total risk from all cut sets and all basic events are at their nominal failure probability

  F(0) is the total risk with basic event x_i probability set to 0
- The Risk Reduction Ratio range is from 1 to ∞
- Risk Reduction gives the same ranking as Fussell-Vesely
- For Maintenance Rule (10 CFR 50.65), NUMARC Guide 93-01 (endorsed by NRC) uses a RRR significance criterion of 1.005
  - Equivalent to Fussell-Vesely importance of 0.005

Risk Reduction Importance Measure Calculation Example

- **Consider these minimal cut sets:**

T * A = 1/year * 6 x 10^{-4} = 6 x 10^{-4}
T * B * C = 1/year * 1 x 10^{-2} * 3 x 10^{-3} = 3 x 10^{-5}
T * C * D = 1/year * 3 x 10^{-3} * 1 x 10^{-3} = 3 x 10^{-6}
F(x) = 6.33 x 10^{-4}

where:
T = 1/year
A = 6 x 10^{-4}
B = 1 x 10^{-2}
C = 3 x 10^{-3}
D = 1 x 10^{-3}

- **Risk Reduction Ratio Importance**

RRR_T = 6.33 x 10^{-4} / 0.0 = ∞
RRR_A = 6.33 x 10^{-4} / 3.3 x 10^{-5} = 19.18
RRR_B = 6.33 x 10^{-4} / 6.03 x 10^{-4} = 1.05
RRR_C = 6.33 x 10^{-4} / 6.00 x 10^{-4} = 1.06
RRR_D = 6.33 x 10^{-4} / 6.30 x 10^{-4} = 1.00

Risk Increase Importance (Risk Achievement Worth)

- **Measures the amount that the total risk would increase if a basic event's failure probability were 1 (e.g., component taken out of service or is failed)**
- **Calculated as either ratio or difference between the value of the total risk with the failure probability for the basic event of interest (x_i) set to 1 and the total risk (baseline risk)**

  Ratio: $RIR_{xi} = RAW_{xi} = F(1) / F(x)$

  Difference (or Interval): $RII_{xi} = F(1) - F(x)$

  where,

  F(x) is the total risk from all cut sets and all basic events are at their nominal failure probability

  F(1) is the total risk with basic event x_i probability set to 1

- **Ratio measure referred to as Risk Achievement Worth (RAW)**
- **The RAW range is ≥ 1**
  - **Caution when interpreting RAW for initiating events, recall initiating events are typically input as a frequency rather than a probability**
- **For Maintenance Rule (10 CFR 50.65), NUMARC Guide 93-01 (endorsed by NRC) uses a RAW significance criterion of 2**

Risk Increase Importance Measure Calculation Example

- **Consider these minimal cut sets:**

  $T * A = 1/\text{year} * 6 \times 10^{-4} = 6 \times 10^{-4}$
  $T * B * C = 1/\text{year} * 1 \times 10^{-2} * 3 \times 10^{-3} = 3 \times 10^{-5}$
  $T * C * D = 1/\text{year} * 3 \times 10^{-3} * 1 \times 10^{-3} = 3 \times 10^{-6}$
  $F(x) = 6.33 \times 10^{-4}$

  where:
  T = 1/year
  $A = 6 \times 10^{-4}$
  $B = 1 \times 10^{-2}$
  $C = 3 \times 10^{-3}$
  $D = 1 \times 10^{-3}$

- **Risk Achievement Worth Importance**

  $RAW_T = 6.33 \times 10^{-4} / 6.33 \times 10^{-4}$ = 1.0 (caution interpreting RAW for IE)
  $RAW_A = 1.0 / 6.33 \times 10^{-4}$ = 1579.78
  $RAW_B = 3.603 \times 10^{-3} / 6.33 \times 10^{-4}$ = 5.69
  $RAW_C = 1.16 \times 10^{-2} / 6.33 \times 10^{-4}$ = 18.33
  $RAW_D = 3.63 \times 10^{-3} / 6.33 \times 10^{-4}$ = 5.73

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Birnbaum (Bi)

- **Measures the rate of *change* in total risk as a result of changes to the probability of an individual basic event**
- **Ranks events according to the effect they produce on the risk level when they are modified from their nominal values**

  $$Bi_x = \partial F(x) / \partial x$$

  where:

  F(x) is the total risk from all cut sets and all basic events are at their nominal failure probability

  $\partial/\partial x$ is the first derivative of the risk expression with respect to the basic event of interest (x_i)

- **When the risk expression has a linear form**

  $$Bi_{xi} = F(1) - F(0)$$

- **The Bi range is between 0 and the cumulative initiating event frequency**
  - **That is, a Bi = 0 indicates little risk sensitivity and a Bi = cumulative initiating event frequency indicates large risk sensitivity**

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Birnbaum Importance Measure Calculation Example

- **Consider these minimal cut sets:**

  T * A = 1/year * 6×10^{-4} = 6×10^{-4}
  T * B * C = 1/year * 1×10^{-2} * 3×10^{-3} = 3×10^{-5}
  T * C * D = 1/year * 3×10^{-3} * 1×10^{-3} = 3×10^{-6}
  F(x) = 6.33×10^{-4}

  where:
  T = 1/year
  A = 6×10^{-4}
  B = 1×10^{-2}
  C = 3×10^{-3}
  D = 1×10^{-3}

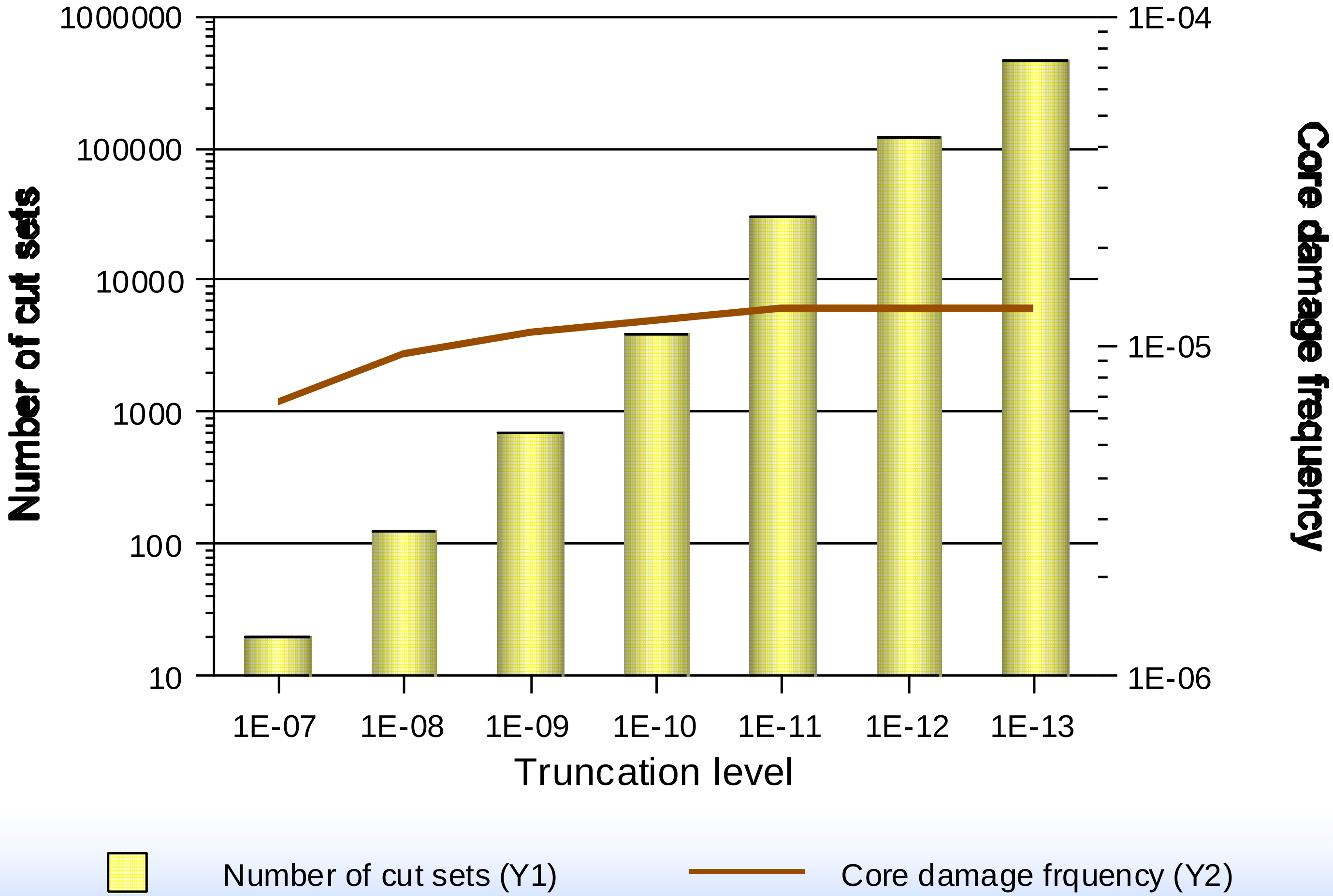
- **Birnbaum Importance**

Bi_T = $(6.33 \times 10^{-4}) - (0)$ = 6.33×10^{-4} (caution interpreting Bi for IEs)
Bi_A = $(1.0) - (3.3 \times 10^{-5})$ = 1.0
Bi_B = $(3.603 \times 10^{-3}) - (6.03 \times 10^{-4})$ = 3.0×10^{-3}
Bi_C = $(1.16 \times 10^{-2}) - (6.00 \times 10^{-4})$ = 1.1×10^{-2}
Bi_D = $(3.63 \times 10^{-3}) - (6.30 \times 10^{-4})$ = 3.0×10^{-3}

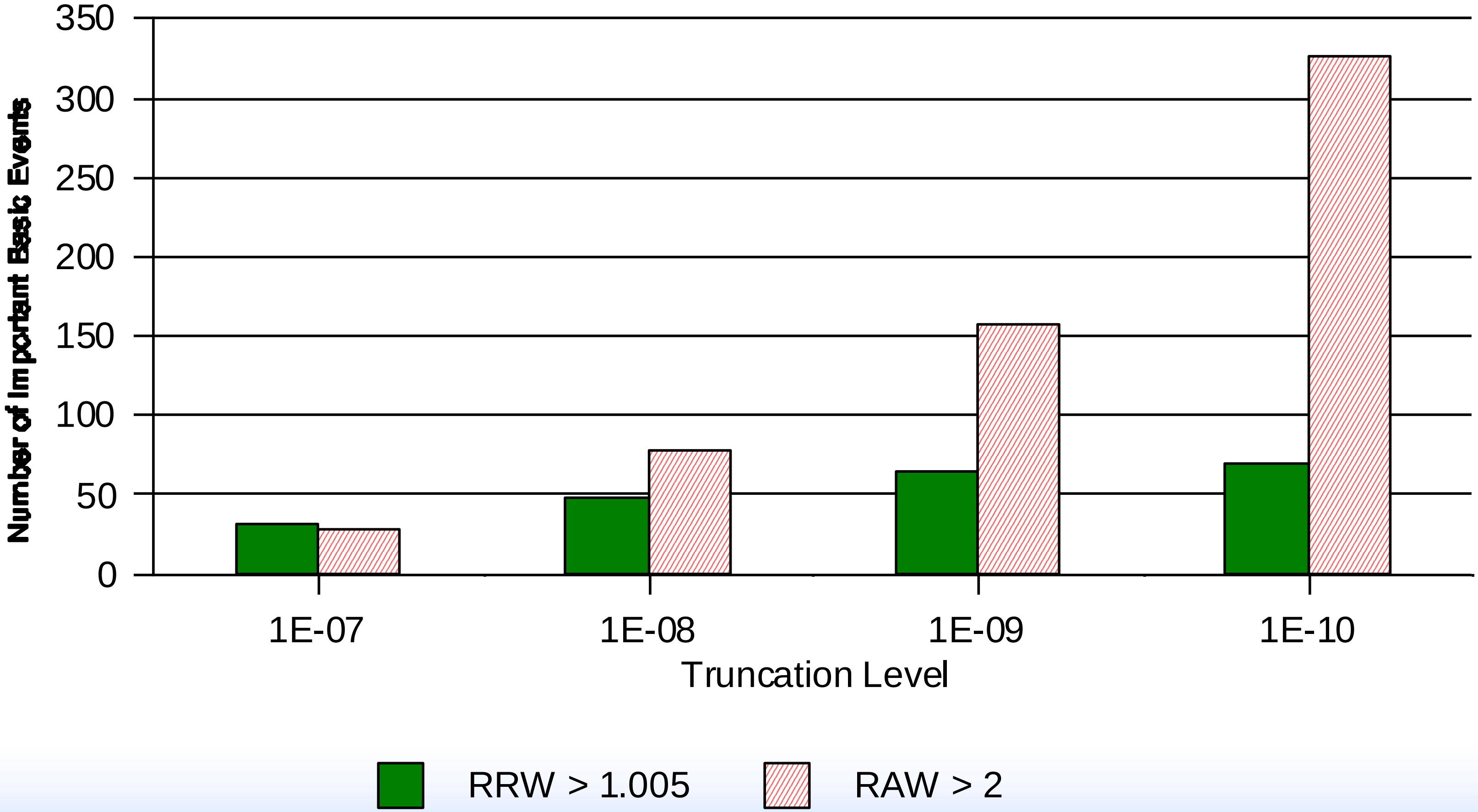
Limitations of Risk Importance Measures

- **Numerical values can be in error due to:**
  - **Exclusion of equipment from PRA model**
  - **Parameter values used for other events in model**
  - **Present configuration of plant (equipment that is already out for test/maintenance)**
  - **Model truncation during quantification**

Core Damage Frequency and Number of Cut Sets Sensitive to Truncation Limits



Truncation Limits Affect Importance Rankings



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Limitations of Risk Importance Measures (cont.)

- Risk rankings are not always well-understood in terms of their issues and engineering interpretations
  - That is, high importance does not necessarily mean dominant contributor to CDF
- RAW provides indication of risk impact of taking equipment out of service but full impact may not be captured
  - That is, taking component out of service for test and maintenance may increase likelihood of initiating event due to human error

Other Considerations When Using Importance Measures

- **F-V and RAW rankings can differ significantly when using different risk metrics**
  - **Such as, core damage frequency due to internal events versus external events, shutdown risk, etc.**
- **Individual F-V or RAW measures cannot be combined to obtain risk importance for combinations of events**
  - **Critical combinations can be extremely important due to failure of redundant components whereas individual components in one train may have low rankings (i.e., importance measure values do not add)**

NRC Technical Guidance for Inspection Programs

- **NRC Inspection Manual, Part 9900 provides technical guidance on use of Probabilistic Risk Ranking Information**
  - **Some key points to consider:**
    - **Use of PRA is effective in identifying and ranking risk-significant SSCs to prioritize inspection activities**
    - **SSCs with highest rankings normally warrant greater concentration of inspection resources**
    - **Risk reduction/F-V and risk increase measures convey fundamentally different information regarding a given SSC's importance to plant risk; therefore, no single importance measure should be used as the sole indicator**
      - **Risk reduction/F-V measures overall contribution of SSC to risk**
      - **RAW can be particularly informative in assessing risk impact of single out-of-service component**

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NRC Technical Guidance for Inspection Programs (Cont.)

- **Be aware that risk ranking results will change when plant configuration and/or system lineup is not the same as that assumed during original ranking**
- **Assumptions should not be made that non-modeled SSCs, initiators, or plant operating modes are not important to risk**
- **Importance of the adequacy of the analysis used as basis for decision-making cannot be overstated:**
- **Scope of analysis should be sufficient to incorporate all necessary SSCs to be considered, e.g., Level 1 PRA would not include SSCs for preservation of containment integrity**
- **Level of detail must be sufficient to support decisions regarding safety determinations, e.g., modeling of SSCs with respect to component boundaries**

NRC Technical Guidance for Inspection Programs (Cont.)

- **Overall quality of the PRA must be adequate to support quantitative decisions, e.g., the PRA should be based on realistic, best estimate assumptions and data; conservative assumptions can elevate importance of certain SSCs and mask importance of others**
- **An appreciation of the uncertainty of PRA results provides a better understanding of the results including their precision and limitations**

Student Exercise

- **From your IPE:**
  - What are the most risk significant items (approximately top five) to risk from a Fussell-Vesely/Risk Reduction point of view?
  - What are the most risk significant items (approximately top five) to risk from a Risk Increase/Risk Achievement Worth (RAW) point of view?
- **If your IPE does not provide a ranking of importance measures, review the risk rankings in the North Anna IPE (provided in Volume 2 of course material):**
  - What are the most risk significant items (approximately top five) to risk from a Fussell-Vesely/Risk Reduction point of view?
  - What are the most risk significant items (approximately top five) to risk from a Risk Increase/Risk Achievement Worth (RAW) point of view?