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

SESSION 1-3

OVERVIEW:
Risk-Informed Decision Making
NRC Experience

Donnie Harrison
U.S. Nuclear Regulatory Commission
Donnie.Harrison@nrc.gov
301-415-2470

RISK-INFORMED REGULATION SEMINAR
Mexico City, Mexico August 27-31, 2012

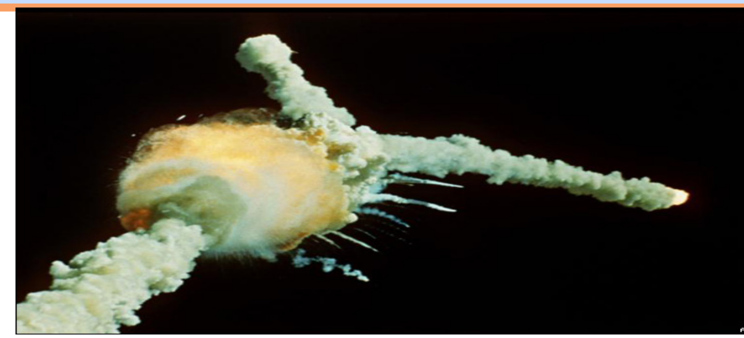
Presentation Outline

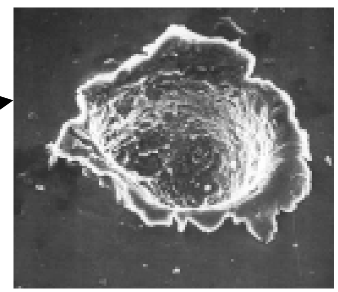
- Making Good Decisions
  - The Decision Making Process
  - Importance of Critical Thinking
- Use of Risk Information in Making Decisions
- Decision Example

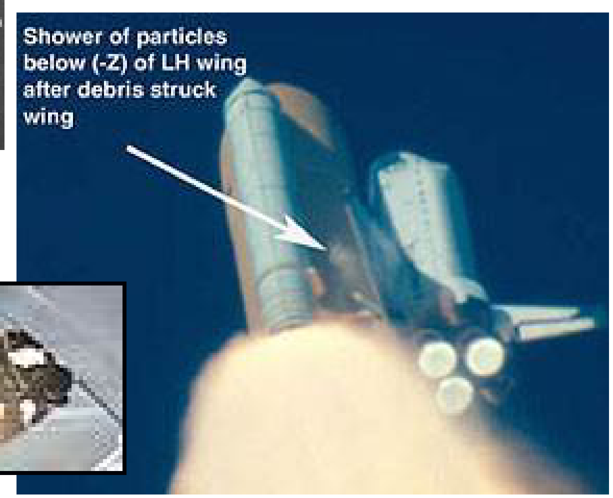
MAKING GOOD DECISIONS

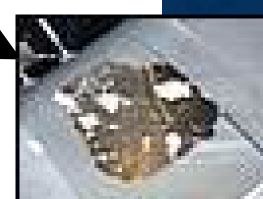
Poor Decisions may be Disastrous

- NASA Challenger
  - Data interpreted without seeing temperature relationship
- Davis-Besse
  - Numerous issues and failures in the process
- NASA Columbia
  - Believed foam not an issue
  - Focused on other impacts

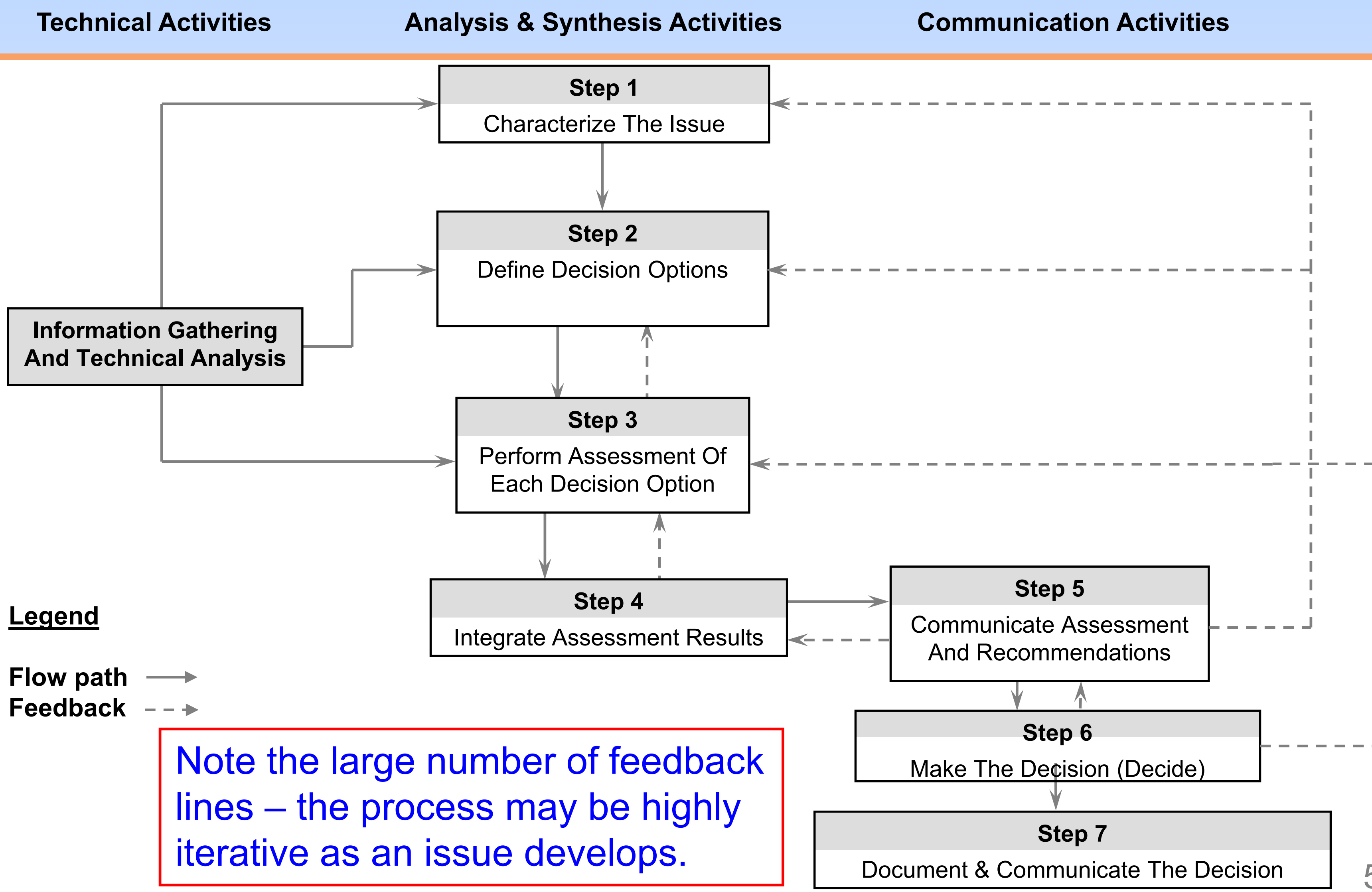








Sample Decision Making Process



Note the large number of feedback lines – the process may be highly iterative as an issue develops.

Critical Thinking

- Essential to making quality decisions

- Three aspects to consider:
  - Approaching the issue
  - Getting good input
  - Asking questions

Approaching an Issue

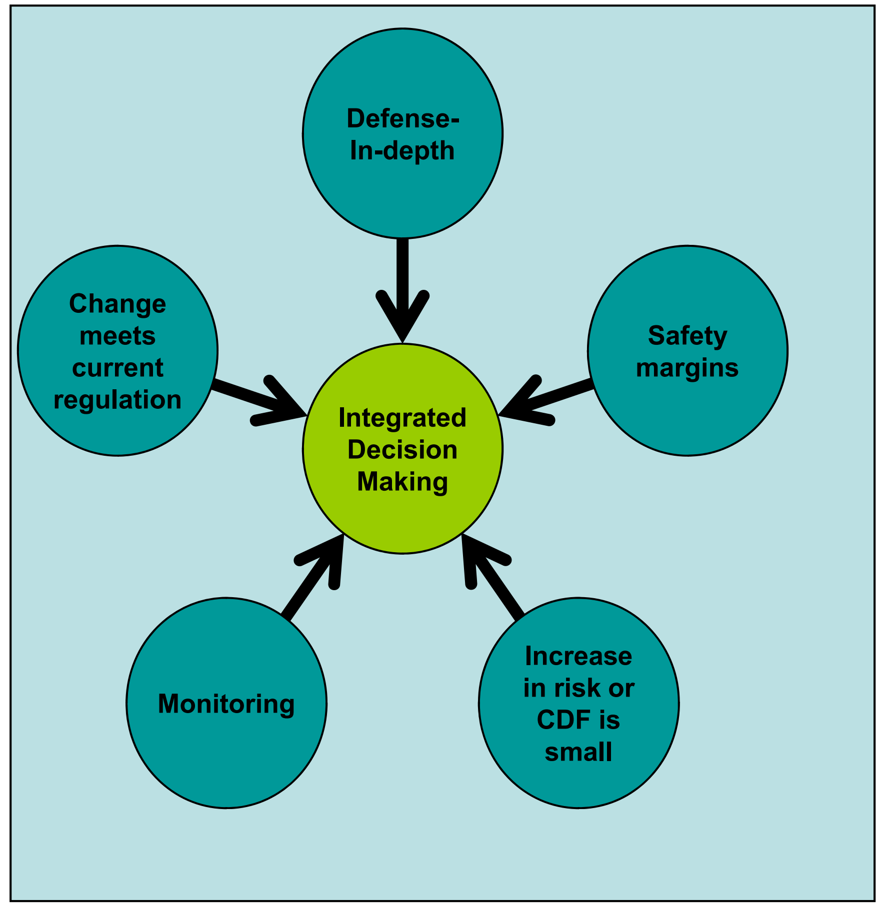
- Attributes of critical thinker:
  - Is open-minded and mindful of alternatives
  - Tries to be well-informed
  - Judges well the credibility of sources
  - Identifies conclusions, reasons, and assumptions
  - Judges well the quality of an argument, including the acceptability of its reasons, assumptions, and evidence
  - Can well develop and defend a reasonable position
  - Asks appropriate clarifying questions
  - Formulates plausible hypotheses; plans experiments well
  - Defines terms in a way appropriate for the context
  - Draws conclusions when warranted, but with caution
  - Integrates all items in this list when deciding what to believe or do

Source: "A Super-Streamlined Conception of Critical Thinking," Robert H. Ennis, 6/20/02

Good Decisions Require Good Input

- Analyses need to provide bases for concluding that…
  - Regulatory position provides reasonable assurance of adequate protection of public health and safety

- All five principles of risk-informed regulation are potentially contributing support for a conclusion
  - Integrated approach to decision making



Good Decisions Require Good Input

- Analysis results
  - Need to be relevant to issue being decided
  - Need to be clearly understood by decision-maker
  - Need to include information on uncertainties
  - Need to provide assessment of confidence in results

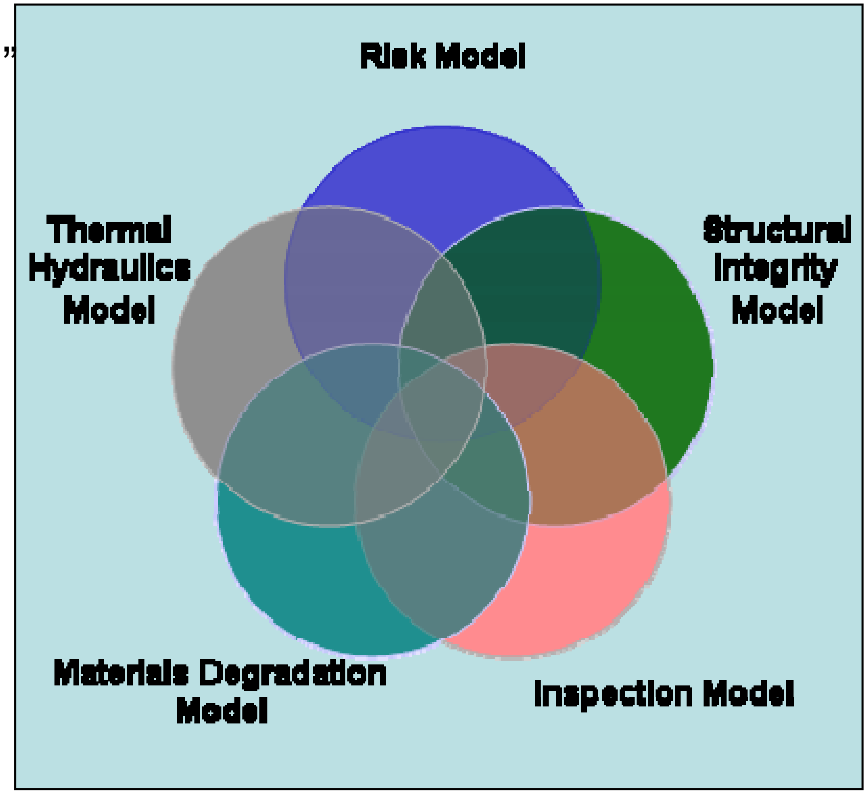
- Communication is key ~ expect well-defined …
  - Characterization of problem
  - Identification of options
  - Analysis of options, including uncertainty
  - Recommendation and basis/rationale

Good Decisions Require Good Input

- Decision-makers need to be "educated" about analyses
  - Assumptions
  - Boundary conditions
  - Limitations
  - Uncertainties
  - Confidence in results

- Inadequate communication/ education leads to less-than-ideal decisions
- Gather the information to make a good decision

  Ask for it ~ Demand it
  (have a questioning attitude)
- Practice critical thinking

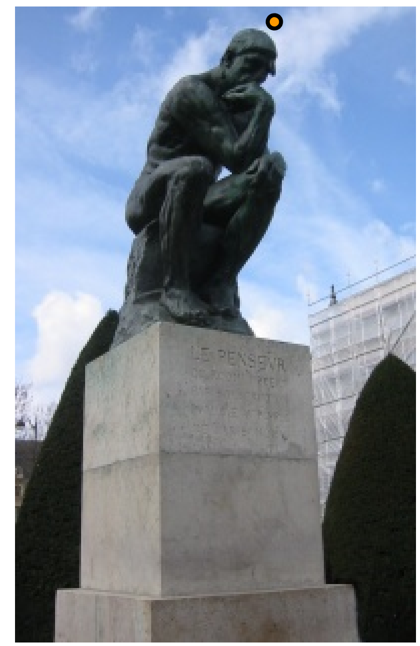


Effective decision making requires integration of information from many sources

Questioning Attitude

I have some Questions

- Understand possible implications of internalized information
- Suspend early judgment or expectations
  - Don't ask: How does this support my beliefs?
- Sample questions
  - Why? How do we know?
  - Have we validated that?
  - What might this mean?
  - How did you come to that conclusion?
  - Why do you think that is correct?
  - What are your sources?
  - What assumptions drive that conclusion?
  - What happens if this is incorrect?
  - What is an alternate explanation?

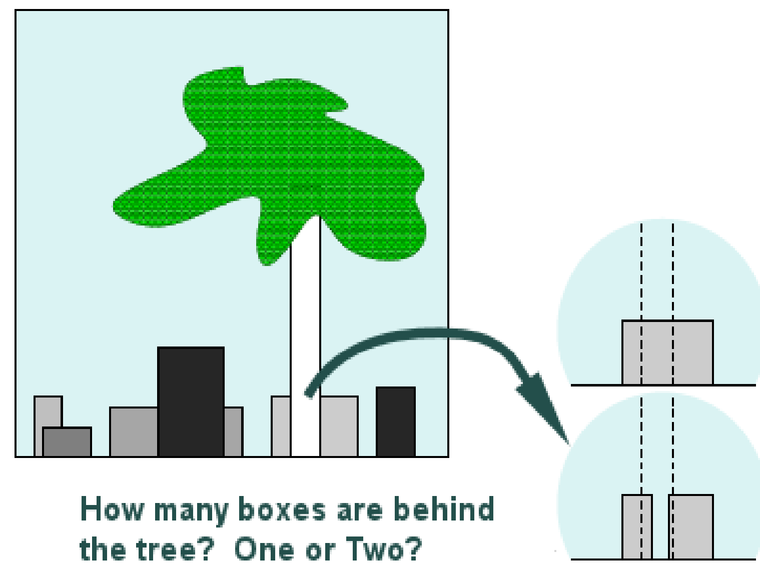


Decision Makers Need to Question

- Questioning attitude helps
  - Understand assumptions, limitations, boundary conditions
  - Ensure results make logical sense (“sanity check”)
  - Identify/understand uncertainties
  - Engender confidence in the decision

- All aspects of the process “fair game” for thoughtful questions

e.g., Separating “knowns” from assumptions



“Information Theory, Inference, and Learning Algorithms” D. MacKay

Questioning Attitude

- What are some questions one may ask to identify significant uncertainties?
  - Does current in-service inspection explicitly verify extent of degradation?
  - Does laboratory or test data cover range of parameters/boundary conditions found in the plant?
  - Was expert elicitation used to compensate for lack of relevant data?
  - Were the modeling assumptions only partially satisfied in practice?
  - Is complex or poorly understood phenomena a part of the process?

Can you think of any others?

Causes of Bad Decisions

- Pressure to get the “right” answer
- Taking the “easy way out”
  - Easier option to implement
  - Easier follow-on actions
- Rush to judgment
  - Schedule/cost pressure
- Competing priorities
  - Safety vs. economics
  - Missing a milestone may affect others
- Convenient explanations
  - New characteristics/issues attributed to existing or known causes
- Failure to perceive a problem once it has occurred
- Correctly answering the wrong question
- Overgeneralization
- Illogical reasoning
  - Flawed thought process
  - Incorrect consideration of causal mechanisms
- Lack of information distribution
  - Analysis insights and recommendations do not get distributed or are ignored
- Failure to anticipate a problem
  - Failure to attempt to solve it after it has been perceived
- Groupthink

Common Fallacies

- Ad Hominem ~ attacking a person's character instead of the content of the argument
- Anecdotal Evidence ~ using one observation to prove the general case
- Appeal to Authority ~ rely on person's position or popularity rather than on subject matter expertise
- Argument from Ignorance ~ assuming that the inability to prove something is true implies it is false and vice versa
- Begging the Question ~ using dubious statement to prove a dubious conclusion
- Circular Reasoning ~ the conclusion (often re-stated) is also assumed as a premise

Source: NRC Course, "Critical Thinking & Decision Making (873)"

Common Fallacies (continued)

- Non-Sequitur ~ drawing a conclusion that does not follow from the evidence
- Red Herring ~ diversion from the main argument by introducing irrelevant material
- Slippery Slope ~ argument that a specific relaxation in a requirement implies widespread, dire consequences
- Straw Man ~ creates a false scenario (straw man) and then attacks it. Argument concludes that the original idea has been defeated based on defeating the false scenario
- Sweeping Generalization ~ a general rule is applied to a situation where it does not apply

Source: NRC Course, "Critical Thinking & Decision Making (873)"

Critical Thinking & Management Decisions

- Practicing the critical thinking techniques supports NRC's principles of good regulation

- As stated in NUREG/CR-6840:*

Management should be committed to an open and objective process that recognizes validity of multiple perspectives in keeping with NRC's principles of good regulation — independent, open, efficient, clear, and reliable

* "The Technical Basis for the NRC's Guidelines for External Risk Communication"

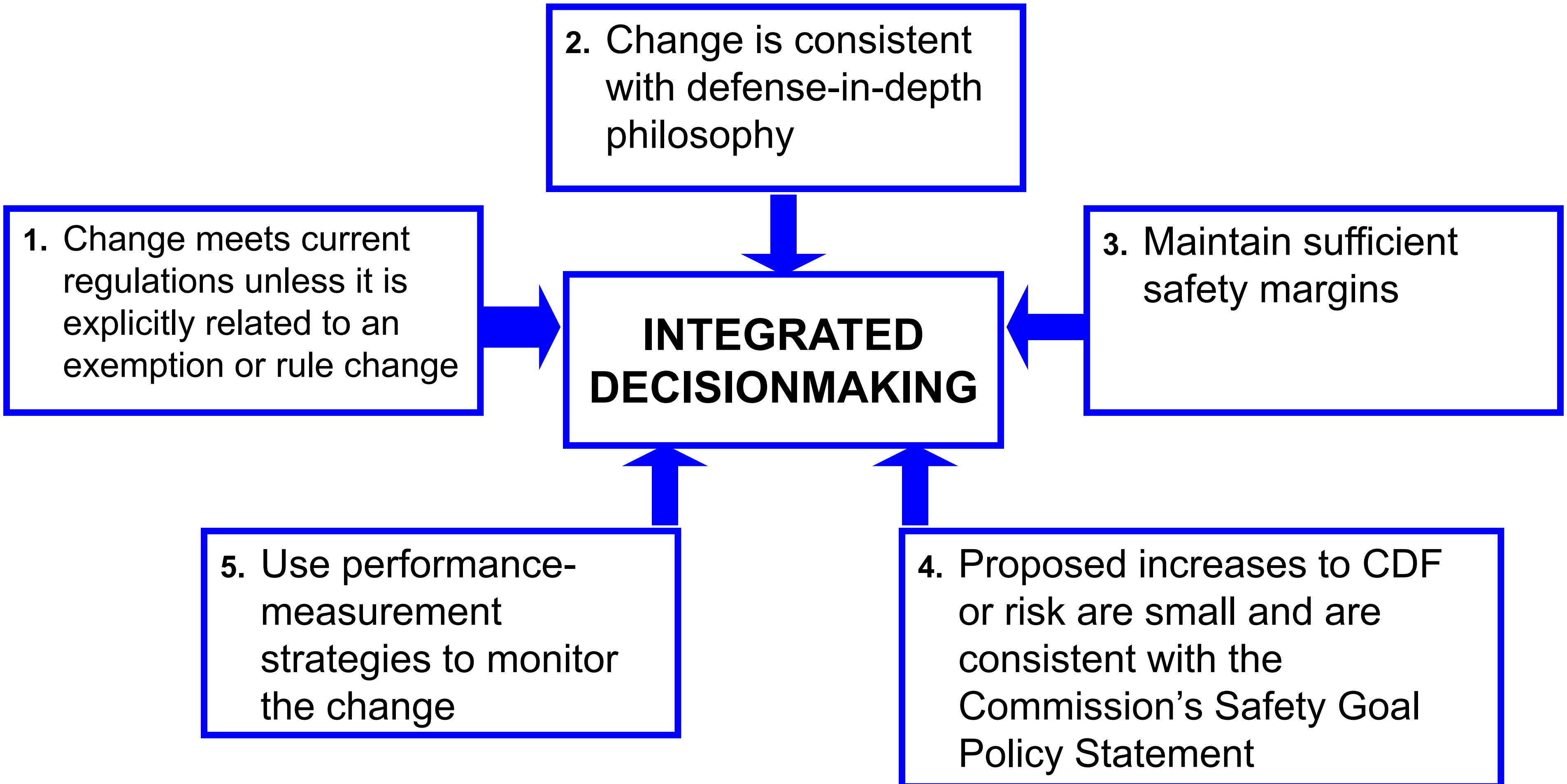
USE OF RISK INFORMATION IN DECISIONMAKING

What is risk-informed regulation?

- A philosophy whereby risk insights are considered together with other factors to establish requirements that better focus licensee and regulatory attention on design and operational issues commensurate with their importance to health and safety.*

**** Source: SRM on SECY-98-144, 3/1/99***

Five Key Principles of Risk-Informed Regulation



*** Source: RG 1.174, 11/2002***

Defense-in-Depth

- Consistency with defense-in-depth philosophy is maintained if:
  - A reasonable balance is preserved among prevention of core damage, prevention of containment failure, and consequence mitigation
  - Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided
  - System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers)
  - Defenses against potential common cause failures are preserved, and the potential for the introduction of new common cause failure mechanisms is assessed
  - Independence of barriers is not degraded
  - Defenses against human errors are preserved
  - The intent of the General Design Criteria in Appendix A to 10 CFR Part 50 is maintained

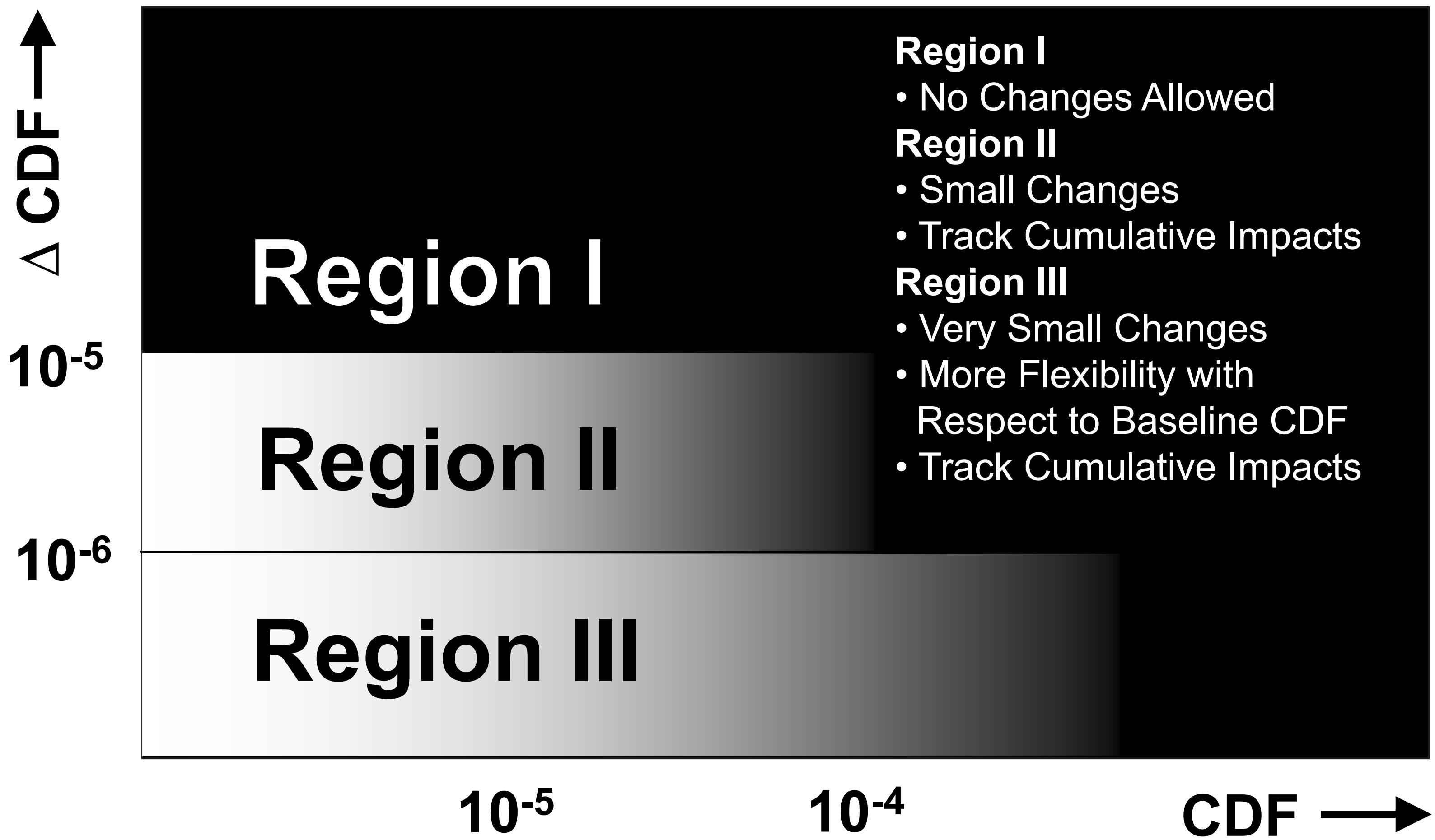
Source: RG 1.174, 11/2002

Safety Margins

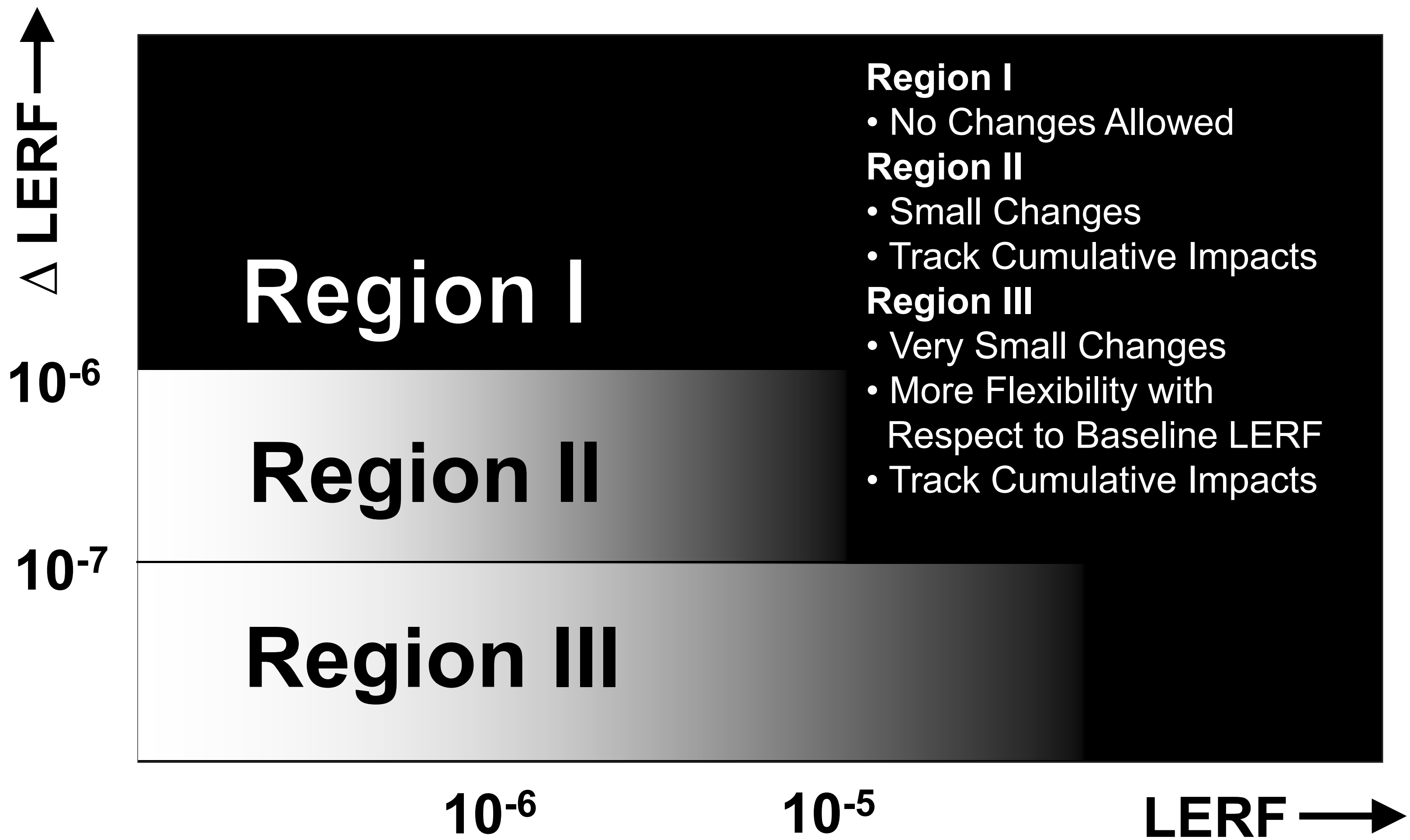
- Sufficient safety margins are maintained:
  - Codes and standards or their alternatives approved for use by the NRC are met
  - Safety analysis acceptance criteria in the Licensing Basis (e.g., FSAR, supporting analyses) are met, or proposed revisions provide sufficient margin to account for analysis and data uncertainty

Source: RG 1.174, 11/2002

Risk Increases



Risk Increases



Performance Measurement

- Primary goal for performance monitoring strategies is to ensure that no adverse safety degradation occurs because of changes to the licensing basis
  - Possibility that the aggregate impact of changes affecting a large class of SSCs could lead to an unacceptable increase in the number of failures from unanticipated degradation, including possible increases in common cause failure mechanisms
  - Implementation and monitoring plan to ensure that the conclusions drawn from the engineering evaluation remain valid (i.e., continues to reflect the actual reliability and availability of SSCs that were evaluated)

Source: RG 1.174, 11/2002

Why regulatory decisions are NOT risk-based?

- “Risk-based” would mean using only the numerical results and insights of a risk assessment
  - Risk cannot be measured ~ need to evaluate risk using models
    - The models should address all contributors but do so with varying degrees of rigor and realism
    - Data on many failures or initiating events are sparse
    - Uncertainties may be large, but can be dealt with
  - No complete knowledge ~ therefore, risk models are incomplete (e.g., previously unknown failure mechanisms)
- Need to consider traditional “deterministic” concepts such as defense-in-depth and safety margins, as well as performance monitoring, to accommodate lack of complete knowledge

How do we make decisions given the uncertainty?

- The results obtained from the PRA are compared with acceptance criteria relevant to the application
- Acceptability of the risk associated with the application takes into account the uncertainties in the results of the risk analysis
- The uncertainty analysis provides the decision maker with confidence in the assessment of the risk input
- Decision makers should be provided with:
  - Risk metrics expressed as the mean of a distribution, where possible
  - A discussion of key assumptions and sensitivity studies performed
  - Information on defense in depth, safety margins, and performance monitoring, as applicable

Thoughts on Uncertainty – Takeaways

- When faced with a decision, a decision maker may ask:
  - What are the limitations of the model that was used to evaluate the various options?
  - What assumptions went into the recommendation from the technical staff?
  - How confident are we of the input variables? The output results?
  - What is the “downside risk” of the various options? What if one of our assumptions is wrong, what could happen?
  - Do we have adequate defense-in-depth and margin to help compensate for uncertain knowledge?

Risk-Informed Regulation – Takeaways

- When faced with a decision, a decision maker may ask:
  - How do the options compare in terms of:
    - Compliance with regulations?
    - Maintaining adequate defense-in-depth?
    - Maintaining adequate safety margins?
  - Are any risk increases small and consistent with the NRC's Safety Goal Policy Statement (i.e., are risk increases in Region II or III of the RG 1.174 figures?)
  - Which option provides the smallest risk increase or the greatest risk reduction?
  - Are there performance measurement strategies or compensatory measures that will mitigate the risk?

DECISION EXAMPLE

Issue Description

- Nuclear Power Plant (NPP) X is a hypothetical light-water reactor plant
- The NRC resident inspector was walking around the facility and noticed water spraying from a small hole in an emergency service water (ESW) pipe
- The licensee subsequently determined that portions of the ESW piping were severely corroded (wall thickness degraded from 0.4” to less than 0.1” in some cases)
- A major rupture of these pipes would cause loss of ESW, which cools safety-related equipment credited to mitigate design basis accidents

What NRC Inspector Saw

Background Information

- NPP X licensee inspects portions of this piping every refueling outage (RFO)
  - NPP X is on a nominal 2-year RFO cycle
  - Last RFO (15 months ago), corroded portions of ESW were inspected but the corrosion was not noted as a severe problem
  - Next RFO is in 8 months
- The extent of the corrosion, both in amount of material corroded away and the portion of the system affected, indicates that the degradation took place over a number of years (i.e., with a number of discovery opportunities)

Risk Information

- NPP X has an at-power, internal events CDF of 3.3E-5 per year
- The NPP X PRA has Loss of Essential Service Water (LOESW) as an initiating event
  - LOESW frequency ~ 4E-4 per year
  - CDF from LOESW ~ 1.4E-7 per year
  - Importance measures of LOESW initiating event
    - Fussell-Vesely ~ 4.2E-3
    - Risk Achievement Worth ~ 11.4
    - Risk Reduction Worth ~ 1.004
- NPP X does not have PRA models for
  - Internal flooding
  - Seismic events
  - Shutdown operating states

Risk Assessment #1

- The licensee PRA engineer estimated the risk increase as a result of one loss of ESW train in the year as follows:
  - Total annual CDF is 3.3E-5
  - RAW for LOESW is 11.4
  - If the LOESW initiating event likelihood was set to 1.0, the CDF value would be (11.4 * 3.3E-5) = 3.7E-4
  - The increase over base CDF value would be (3.7E-4 – 3.3E-5) = 3.4E-4

- PRA engineer concluded that a LOESW event was fairly risky!

- However, the engineer noted that a LOESW had not occurred, and the leak would have been discovered in time to take action before a pipe rupture resulted in loss of function

Risk Assessment #2

- A new NRC manager at the Regional Office decided to apply his acquired knowledge from a basic PRA training course (P-105)
- Using the NPP X SPAR model, he calculated:
  - Total annual CDF value is 3.3E-5 per year
  - LOESW event contributes 1.4E-7 to the total CDF value
  - The LOESW frequency value is 4E-4 per year
  - Given the LOESW event, the CDP value would be (1.4E-7 / 4E-4) = 3.5E-4
- The NRC manager agreed that leak-before-break would provide opportunity to detect and react to the leak
  - He estimated 50% of the piping was in locations where leak would not be seen
  - CCDP was estimated as (0.5 * 3.5E-4) = 1.7E-4

Risk Assessment #3

- Licensee's management argued as follows:
  - Inspection next outage would find the degradation (98% chance)
  - Likelihood of an ESW piping rupture in next 8 months is very small
    - Leak would be detected before rupture ~ 50% of locations
    - Margin to failure exists ~ use 1% as a bounding probability of rupture in 8 months in remaining 50% locations
  - Increase in risk from degraded ESW piping is estimated:
    - Likelihood of rupture in next 8 months * conditional CDF given rupture, minus the baseline LOESW risk, times the exposure period
    - [(0.5) * (0.01) * (3.5E-4) – 1.4E-7] * 8 / 12 = 1.1E-6
  - The 50% of piping locations is "grossly conservative," so the management concluded that the ICCDP is < 1E-6

What are the Assumptions?

- Explicit
  - Leak-before-break allows detection before rupture
  - For 50% of the piping, the leak will be seen in time
  - Inspection next RFO identifies degradation (98%)
  - Likelihood of rupture in next 8 months is 1%
  - …?
- Implicit
  - 100% likelihood of identifying degradation in next RFO (risk of degradation not identified was ignored)
  - Sufficient time between leak and rupture to act
  - …?

What are Sources of Uncertainty?

- Parameter Uncertainty
  - No basis for 1% rupture probability next 8 months
  - …?
- Model Uncertainty
  - If probabilistic fracture mechanics were used, huge uncertainties in any resulting probabilities for rupture
  - Extent of condition/common cause failure
  - Did not consider impact on ESW as mitigating system
  - …?
- Completeness Uncertainty
  - Seismic risk not considered – pipe could fail at low ground peak acceleration
  - Internal flooding from ESW pipe rupture not considered
  - Is ESW a contributor to shutdown risk?
  - …?

How Sensitive are the Results?

- Sensitivity to percent of ESW piping that could rupture without leakage noticed (assessment #2)
  - 50% ~ 1.7E-4 CCDP
  - 10% ~ 3.5E-5 CCDP
  - 1% ~ 3.5E-6 CCDP
- Sensitivity to assumed likelihood of rupture in next 8 months (assessment #3)
  - 10% ~ 1.2E-5
  - 1% ~ 1.1E-6
  - 0.1% ~ 2.3E-8
- What other sensitivities might be important?

Questions a Decision Maker May Ask

- What is the decision? What are the options? How do the options compare in terms of the 5 key principles of risk-informed regulation?
- Is this a performance deficiency related to a system or initiating event with high risk importance?
- What are the assumptions and limitations of the model that was used to evaluate the options?
- How confident are we of the input variables? The output results? What is the "downside risk" of each option?
- Do we have adequate defense-in-depth and safety margin to help compensate for uncertain knowledge?

What is the “Decision?”

- Example 1: Significance Determination Process
  - Assessment of significance of the performance deficiency
  - “Decision” is what significance to assign
  - May need to use qualitative assessment and judgment
- Example 2: Licensee wants to continue to operate until next RFO (8 months)
  - Decision is to pick one option from those available:
    - Require plant to shut down until piping repaired
    - Allow operation until next RFO with suitable compensatory measures
    - Allow operation for some intermediate time pending additional inspection, analysis, etc.
  - The “5 key principles” are useful in this case (next slides)

5 Key Principles of Risk-Informed Regulation

- Compliance with Regulations
  - Not very helpful for violations, but a consideration for licensing actions
- Defense-in-Depth
  - Impact on fission product barriers?
    - ESW indirectly cools RCP seals at many plants ~ RCS
    - ESW may cool containment fan coolers ~ 3rd barrier
  - Impact on equipment that supports barriers?
    - Common cause failure (corrosion) of both ESW trains
    - Heat sink for EDGs, RHR heat exchangers, etc.
  - Could have significant impact on defense-in-depth?

5 Key Principles of Risk-Informed Regulation (contd.)

- Safety Margins
  - Must meet applicable codes and standards
  - Significant degradation observed in this case (wall thicknesses much less than design)
- Risk
  - Very difficult to get realistic estimate of probability of pipe failure over given time period
  - Core damage probability value, given LOESW event, is relatively high
- Performance Measurement
  - May not be informative for after-the-fact conditions
  - Could be a factor (if desired) to justify continued operation for some period of time
    - Frequent walking down of ESW piping to monitor leakage
    - Other compensatory measures

Sample Decision - SDP

- Decision maker asks questions and receives the following information
  - Upper bound value of pipe rupture probability during exposure period estimated at 7E-4
  - A small earthquake could break the degraded piping; probability 1E-2 (leak before break not applicable)
  - Internal transients (LOSP, turbine trip, etc.) could stress the ESW piping (change in flows; pump stop and restart) and result in rupture ~ unknown rupture fraction
- Concludes that significance of this finding is “white”
  - The internal events analysis yields upper bound CCDP of 2.5E-7
  - Seismic-induced CCDP is 3.5E-6
  - Other risks exist that cannot be quantified

Sample Decision – Justify Continued Operation for 8 Months

- Decision maker asks same questions and receives the information on the previous slide
- Considers the “driving factors” for the options
  - Defense-in-Depth ~ RCP seals and containment systems compromised if ESW system is lost
  - Safety Margins ~ ESW severely degraded ; does not meet code requirements
  - Risk ~ mid E-6 range is “very small” increase, but very high level of uncertainty
  - Performance Measurement ~ most of risk comes from minor seismic event → no chance to detect leak before rupture
- Concludes that the plant will be ordered to remain shut down until ESW piping integrity is restored

CONCLUSION

Conclusion

- Decision Maker's role – not only to make the decision, but to …
  - Insist on the best input available/practicable
  - Foster an open atmosphere for analysis & communication
  - Practice critical thinking
  - Ask the hard questions

The End

Questions and Answers…..