Thoughts on Inspections and Sampling

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Topics

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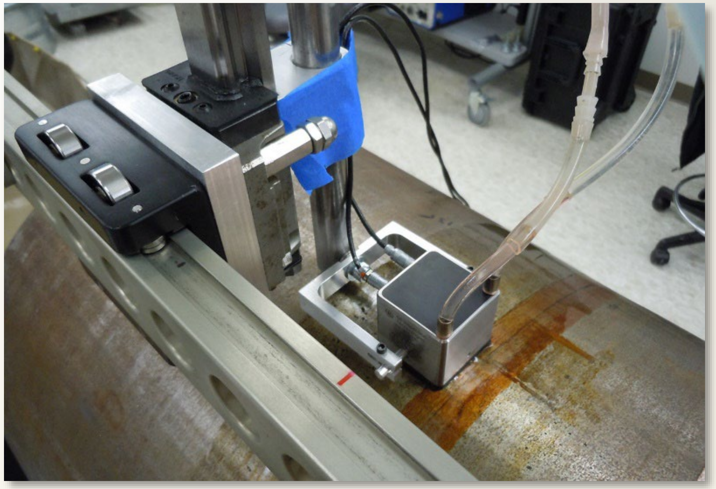
- What are inspections for?
- Inspections and Uncertainties
- Bathtub curve
- Inspection modeling
- Risk-informed decision making
- Examples

Motivation



NRC has noted an increase in ISI-related submittals that are explicitly or implicitly risk-informed; principally focused on ISI frequencies.

Many of these submittals contain novel applications of probabilistic modeling or other risk-based arguments– justifying adjustment of ISI.

Mixture of qualitative arguments regarding “state of knowledge” and (in some cases) probabilistic analysis requires staff to contextualize application in risk-informed decision making (RIDM) framework.

Motivation
Inspections in RIDM

Inspections are a key aspect of RIDM and necessary to reach regulatory conclusions.

Staff are seeking to bridge qualitative arguments, historical precedent, and historical thumb-rules to match inspection proposals with more quantitative insights.

Staff seek to answer, "how do we judge a proposed number of inspections versus the current practice?"

What are inspections for?

Inspections answer important questions through direct observation:

- Was a component fabricated to its design?
- Was a component installed properly?
- Etc.

What do we often use inspections for:

- Direct evidence of the state of SSC
- Data to feed/confirm models
- Diverse and timely assurance of SSC integrity/function/etc.

What are inspections for?
Utilizing results

Inspection results can support modeling. This requires:

- Sufficient data to model mean
- Additional data to model (or at least bound) variance

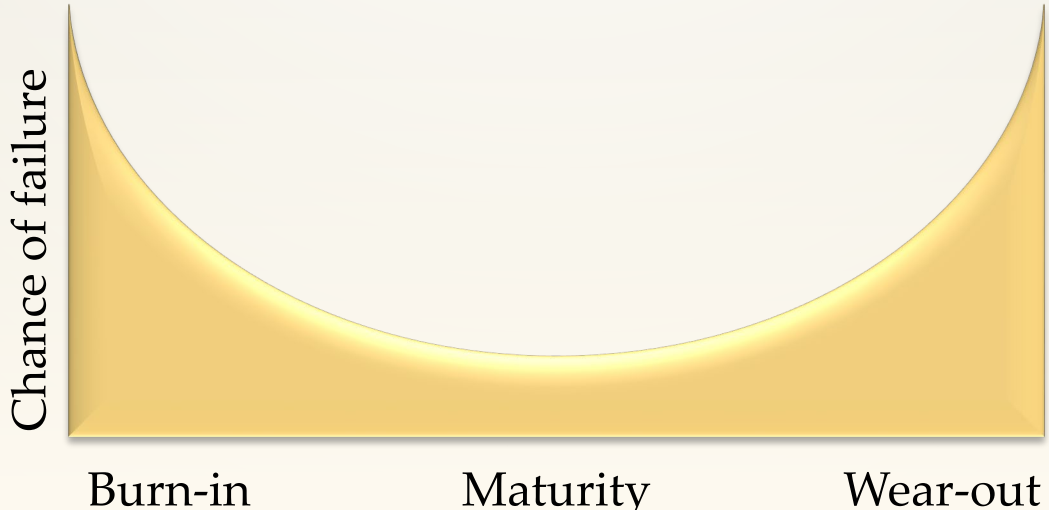
Inspection results can support follow-on actions:

- Confirm or negate presence of degradation
- Monitor integrity
- Detect potentially novel degradation

Bathtub curve
Framing inspection programs

How many inspections? Where? For how long?

What are the plausible degradation modes that may threaten operation? How can we detect them? When may they occur? How long may we have between detection and failure?



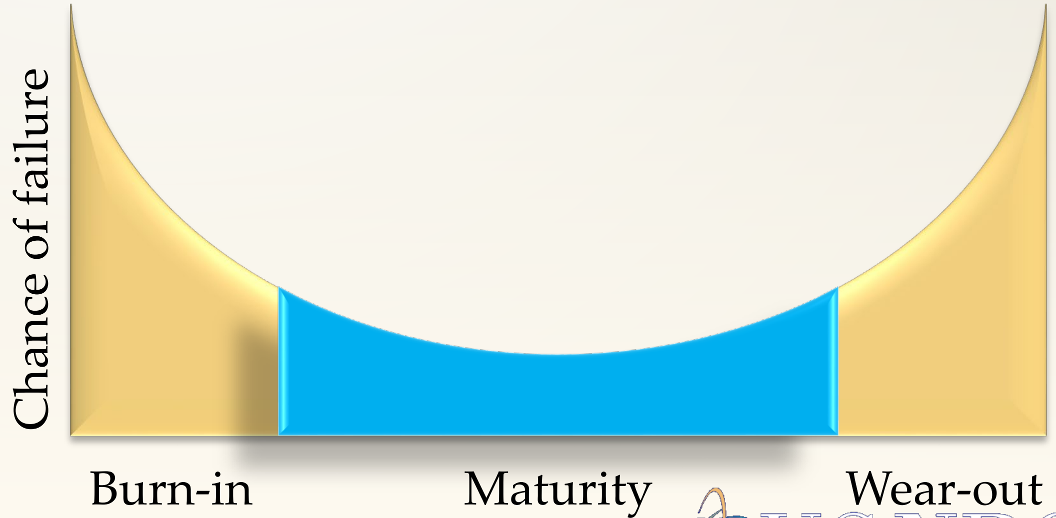
Bathtub curve

Shifting priorities

Burn-in - inspections are necessary to rapidly identify novel degradation and describe it (mean, variance, time-dependence)

Maturity – inspections are necessary to validate/confirm modeling and detect initiation of novel degradation (mean, trigger inspection program expansion)

Wear-out – inspections provide identification of entering wear-out period



Inspection Modeling

We will be presenting plots comparing inspection scenarios to illuminate program "sensitivity."

Can approximate using binomial distribution for quick results.

"Sensitivity" here is the mean of "at least one detection" for many simulations.

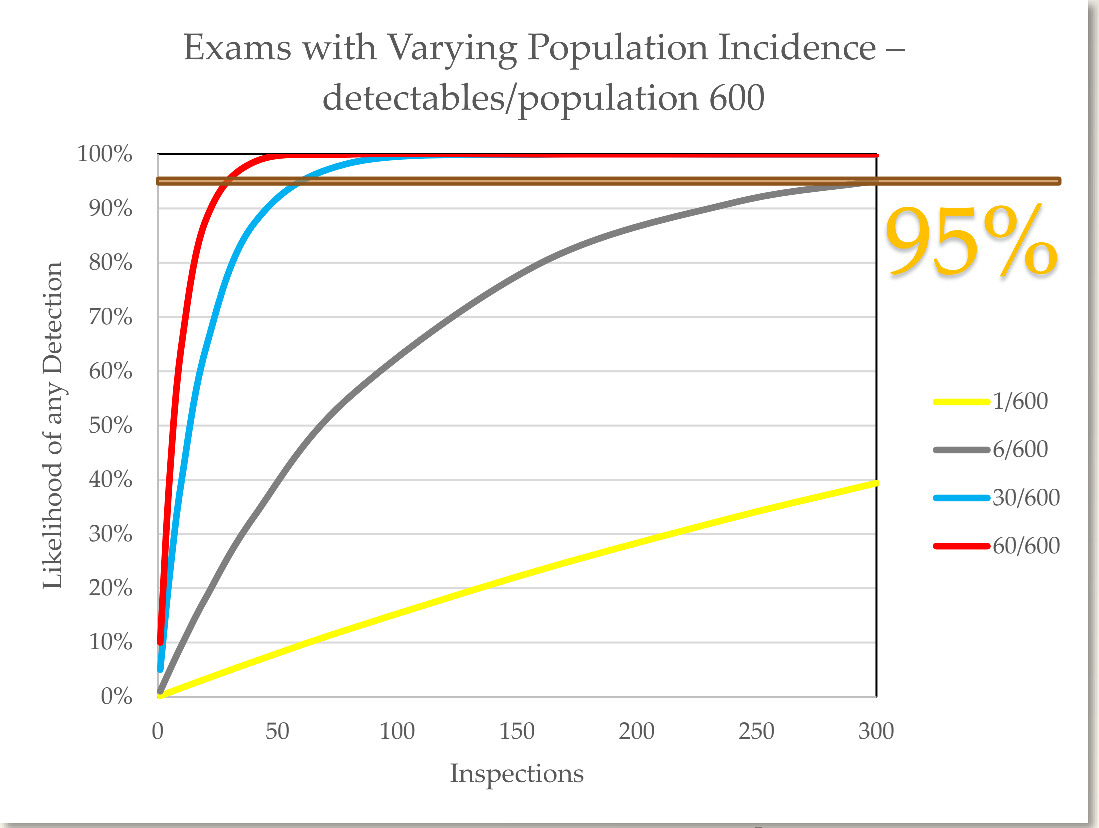
$$f(k,n,p) = \binom{n}{k} p^k (1-p)^{n-k}$$

Monte Carlo can be used to evaluate more complex scenarios (POD, time-effects, etc.)

Inspection Modeling
Inspections vs. Sensitivity

The ability to (on average) detect a level of detectable degradation in a population is a strong function of detectable incidence (% population with incidence) and number of examinations.

Sensitivity improves with increasing incidence or examinations.



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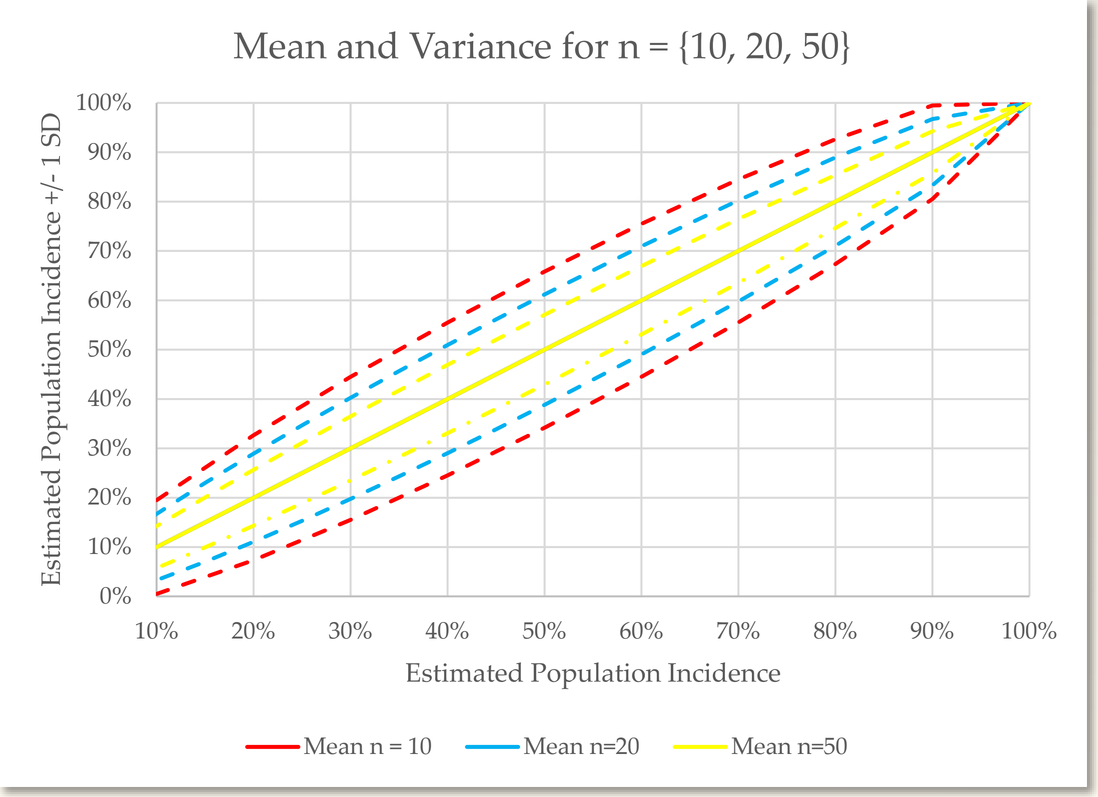
Inspection Modeling
Mean *and* Variance

Mean "sensitivity" or probability of detection is sample population independent.. but variance is not!

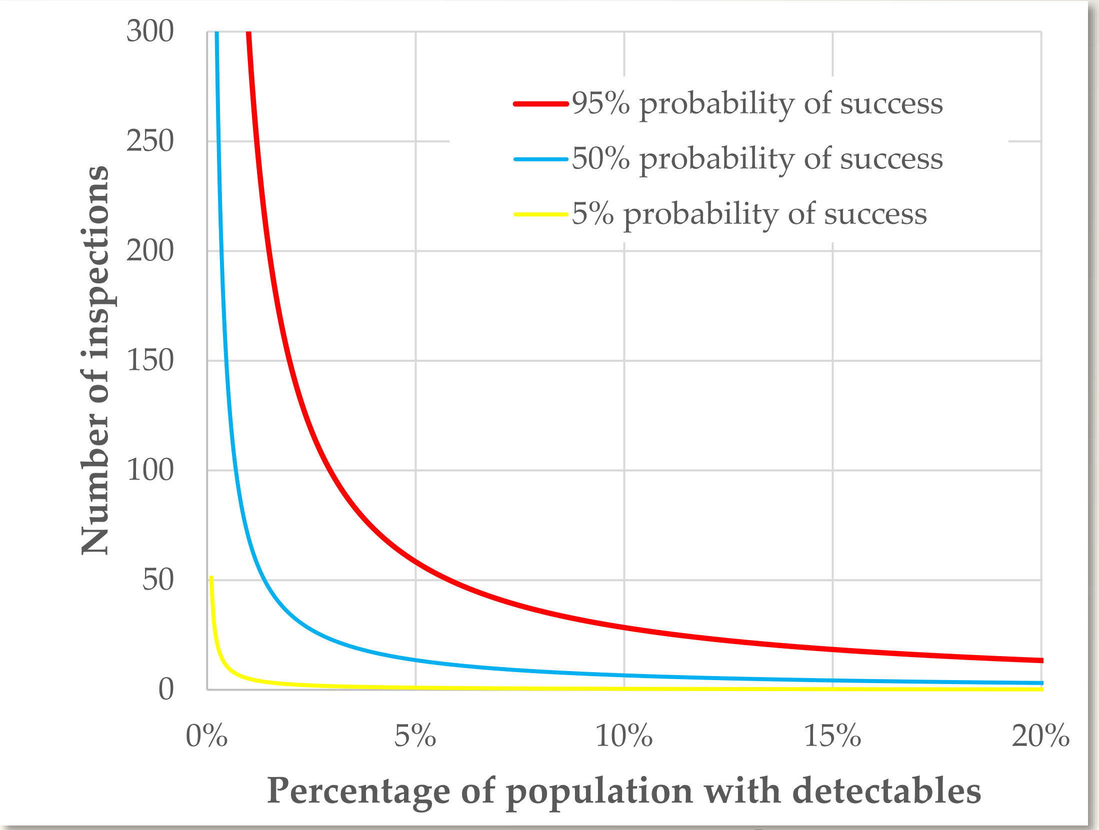
Confidence in mean value goes up with sampling (examination by percentage can help!)



Inspection Modeling
Incidence vs. Sensitivity

Finding rare occurrences requires many inspections.

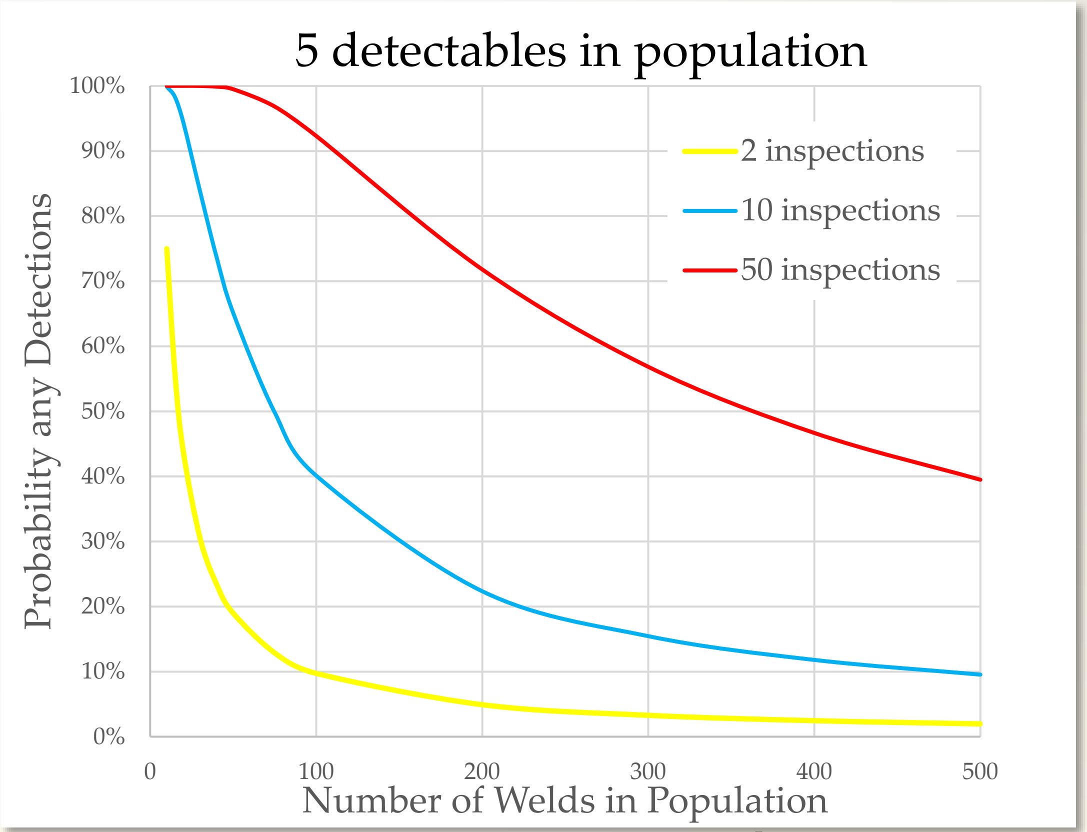
Approaches 100% inspections if rare occurrences are sufficiently important to detect as early as possible.



Inspection Modeling
Population vs. Sensitivity

Inspection schemes have different sensitivities. This relates to total population as well as number of inspections (Monte Carlo result).

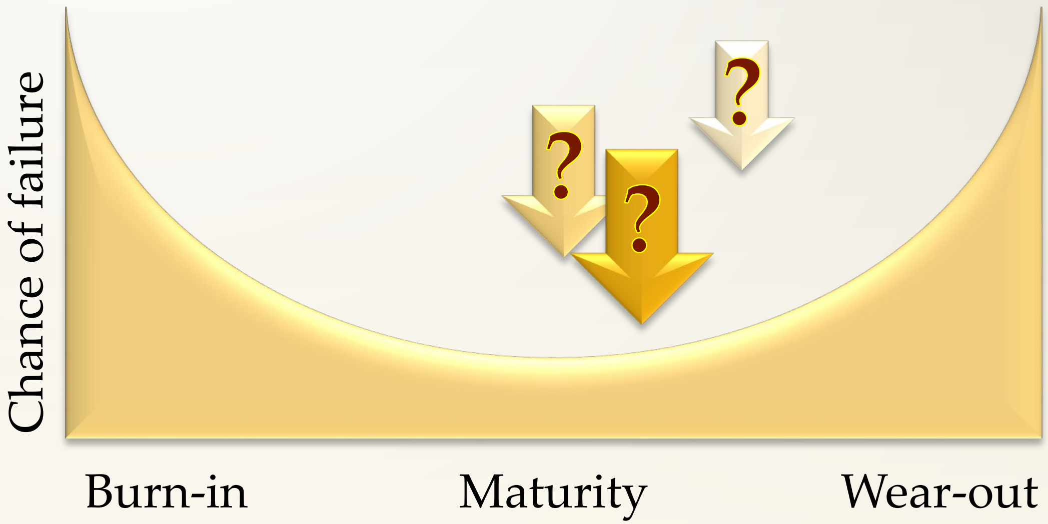
Fixing sampling (not as a percentage) has limits.



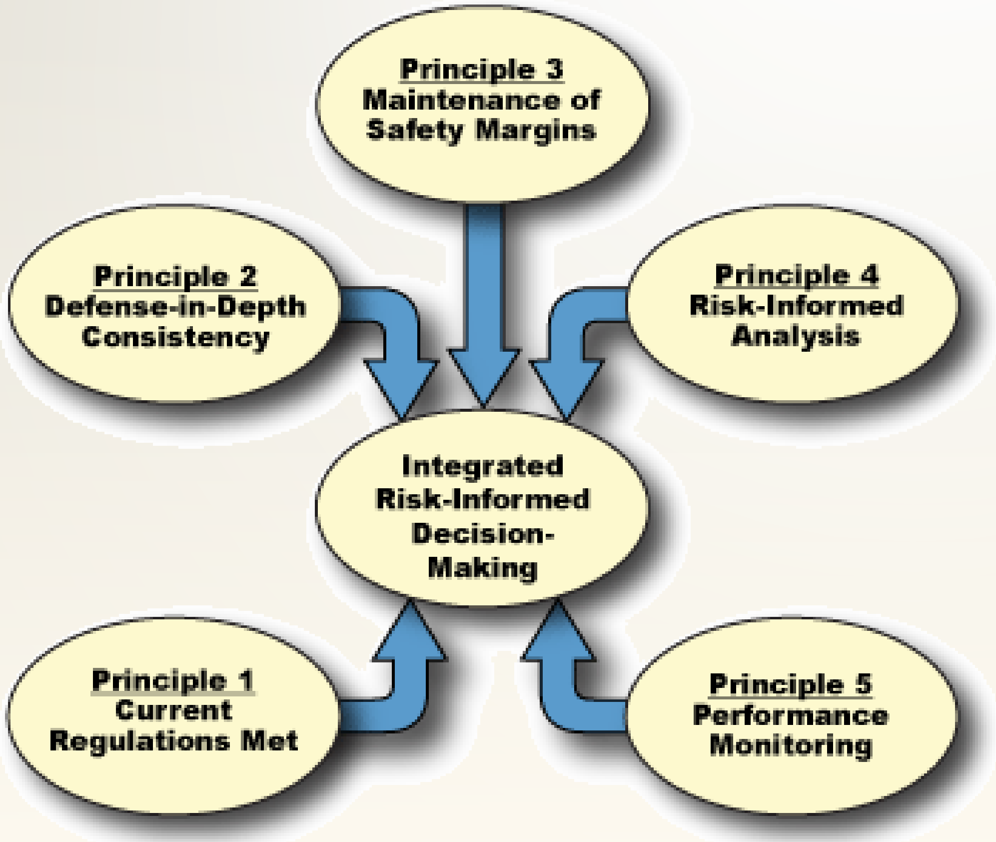
Other inspection factors

Other factors to be considered:

- Timeliness of detection
- Consequence of detection
- Consequence of “later” detection versus “earlier” detection
- Capabilities of monitoring technology



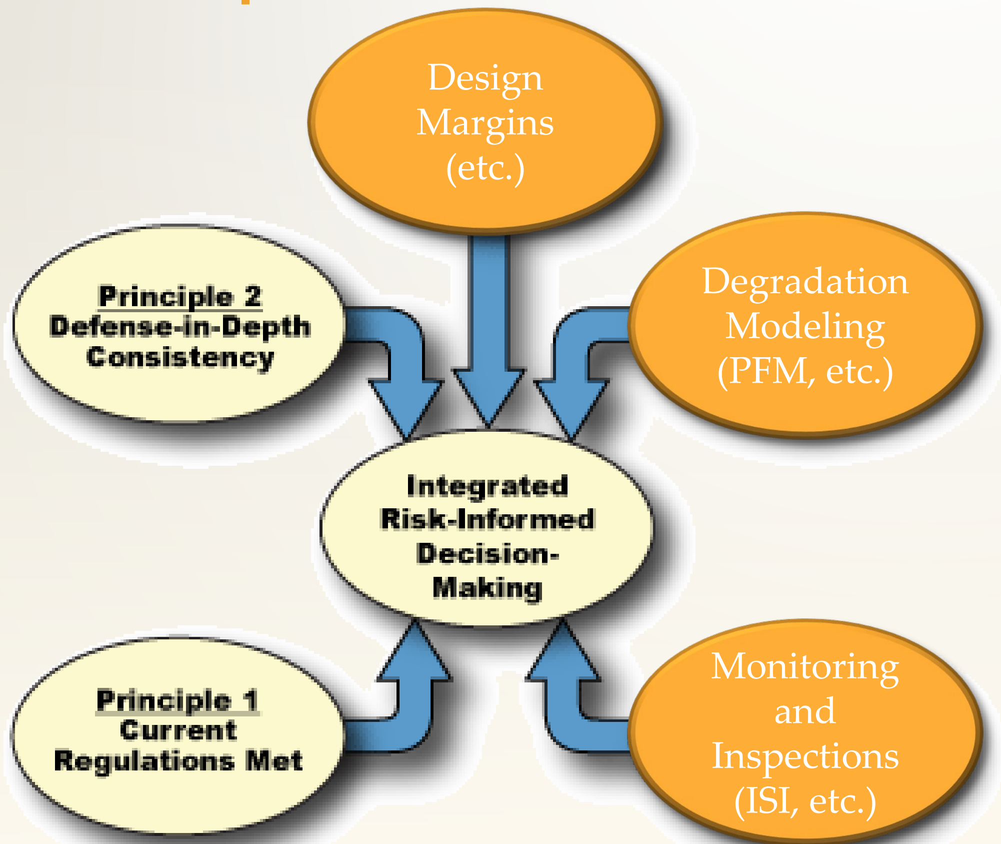
Principles of Risk-Informed Decision Making 1



The five principles of risk-informed decision form a holistic decision basis.

They are not separable – you cannot wholly replace Principle 5 with improvements to Principle 4

Principles of Risk-Informed Decision Making 2



In the materials engineering context, we often have safety margins defined through use of ASME BPV Code design requirements.

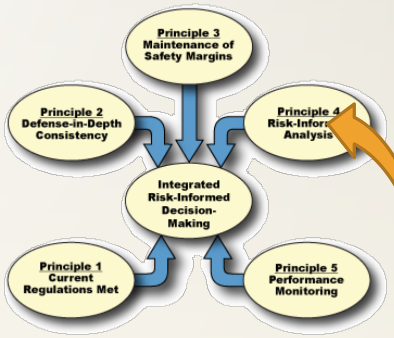
"Risk analysis" often takes the form of modeling, such as PFM.

"Performance monitoring" includes inspections, leak detection, etc.

Degradation Modeling: What is it for?

Degradation modeling allows the prediction of future degradation based on modeling assumptions (epistemic knowledge).

- Design optimization
- Inspection optimization
- Future planning (repair, replacement, etc.)



Reliability approaches rely on modeling and (often) Bayesian approaches to build maintenance and inspection programs. The *pure* use of this approach is considered Risk-Based by the NRC (Principle 4).

Performance Monitoring: What is it for? 1

Performance Monitoring, in the Principle 5 sense, provides:

- Direct evidence of presence and/or extent of degradation
- Validation/confirmation of continued adequacy of analyses
- Timely method to detect novel/unexpected degradation

Can inform regarding uncertainties:

- Epistemic uncertainties – model, parameter, and completeness uncertainties
- Aleatory uncertainties – stochastic randomness

Performance Monitoring: What is it for? 2

Performance monitoring works *together* with other approaches such as degradation modeling to provide assurance of integrity with a high degree of confidence.

Running to failure is *not* an adequate program.

Significant systems must be maintained with a high degree of confidence in the assurance of their function – uncertainties must be handled by *both* modeling investigation (sensitivity studies, etc.) and by on-going inspection (model and completeness uncertainties.)

Examples:
Thought Experiment

Licensee proposal: Component inspection requires high degree of "sensitivity," with a 95% mean detection probability. Proposal is for 50 inspections, will "rare" degradation be detected?

Assumptions: Binomial statistics are appropriate.

How rare is 95% likely to be detected? ~5.8% population incidence rate

How many inspections for 1% population incidence rate? ~300

Staff thoughts: ~1/17 incidence rate is not especially"rare." Binomial estimates are driven by number of inspections. Having a very high chance of finding rare occurrences requires very high numbers of inspections.

Examples:
Thought Experiment 2

Licensee proposal: Component has 10 inspections per ASME Code for each unit every 10 years; proposing 2 inspections every 20 years.

Assumptions: Population incidence of "detectable" indication of 5%

Per Unit Monte Carlo sensitivity: ~20%

"Fleet" Monte Carlo sensitivity (assuming 40 units): ~99%

Staff thoughts: Proposed inspection scheme would have very low ability to provide assurance regarding component and unit specific degradation, but very good sensitivity to fleetwide generic degradation. Expansion would be warranted if fleet detection occurred.

Examples:
PWR Weld Exams

WCAP-16168 TR Case

Analysis: Primarily PFM analysis addressing risk delta of conditional RV failure frequency due stress and different inspection scenarios.

Performance monitoring plan: Extension of ISI interval to a maximum of 20 years. Fleet inspections are coordinated to ensure regular data on population level (monitoring and trending).

One-time inspection for subsequent extensions to validate that generic flaw-distribution used in report bounds plant-specific per 10 CFR 50.61a(e) (model validation).

* For more details, see ADAMS Accession No. ML11306A084

QUESTIONS