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Licensing Novel Designs on the Basis of Margin

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Disclaimer

Opinions expressed in this presentation are not necessarily those of INL.

Acknowledgments

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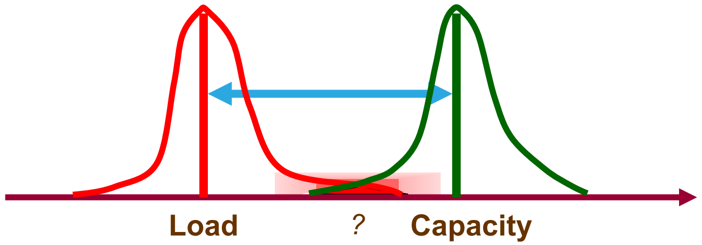
Outline

- Probabilistic Concept of "margin"
  - Basic modeling point: **P(failure from limits exceeded | hardware & operator success)** **<<** **P(hardware or operator failure)**
  - To nail the right-hand side, you need to sample within a carefully-formulated issue space
  - Summarize Gabor / Sherry / True EPRI Report
- Point to Stu Magruder's slide on 50.43(e), and the ANS Grand Challenge
- "License By Test"
  - Play EBR-II clip from "Pandora's Promise." How did they know it was OK to do those experiments?

    https://www.youtube.com/watch?v=Sp1Xja6HlIU Starting at 1:18 [Charles Till]
  - Summarize John Sackett's argument. My translation: We worked with EBR-II long enough to really understand its ***margin.***
  - *That's* how they knew it was OK to do those experiments.
- Allocation, Implementation, Performance-Based
- Summarize

Probabilistic Concept of Margin

"Margin" (1 of 2)

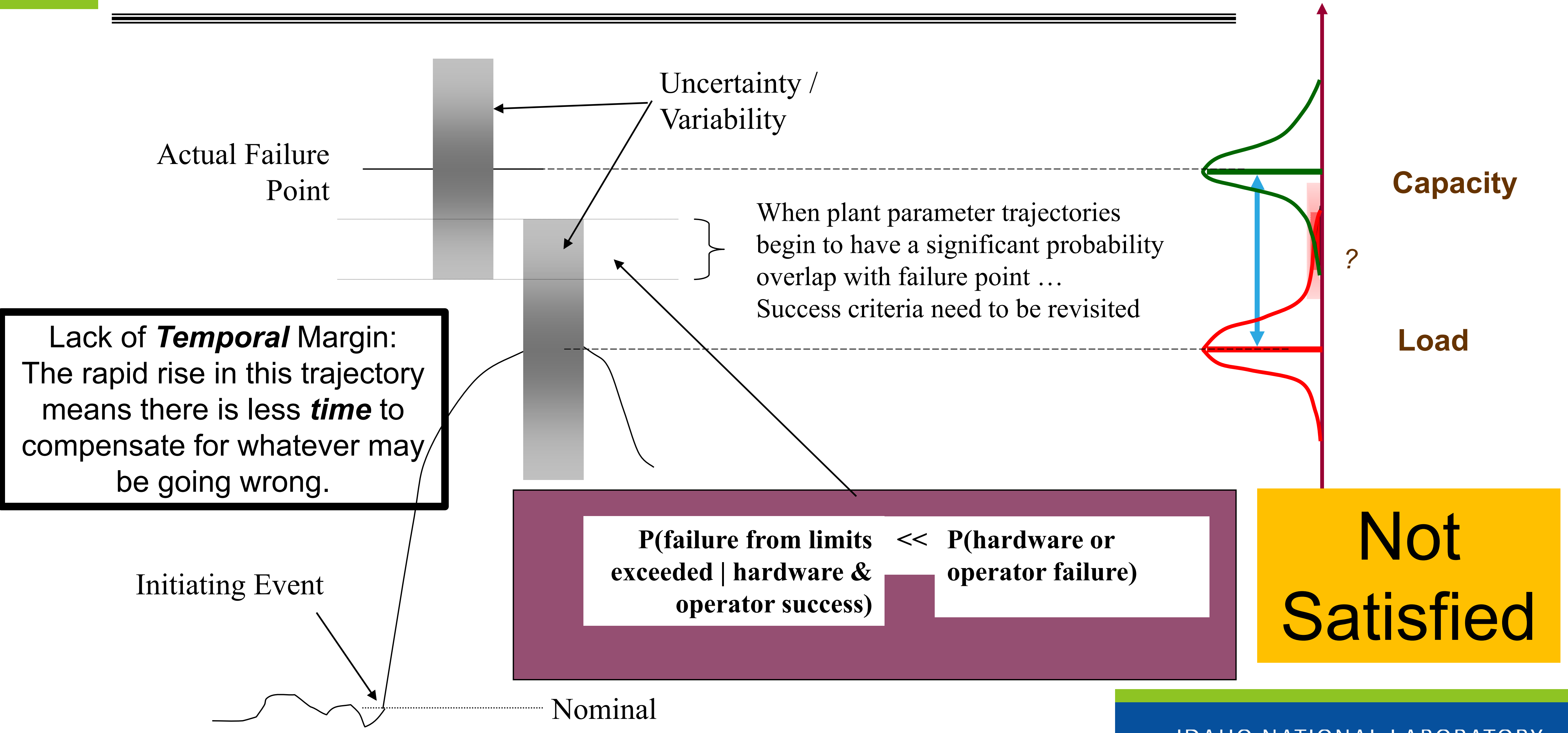


- "Margin" is not just a distance between a point on a "load" curve and a point on a "'capacity" curve: it must also consider uncertainties in load and capacity, since the actual use of the concept relates to reasoning about the probability that load exceeds capacity (P(L>C)).
- "Risk-informed" evaluations of margin need to condition the margin evaluation on a set of probabilistically significant scenarios, and not just the limiting cases addressed in design-basis accident analysis. "Risk-informed" assessment of the margin quantities traditionally assessed (such as margin to fuel failure) will therefore incorporate a notion of scenario frequency that entered traditional applications only indirectly (through the idea that the requirement on limiting-case margin could be less, if the challenge frequencies of related scenarios are much, much less).

“Margin” (2 of 2)

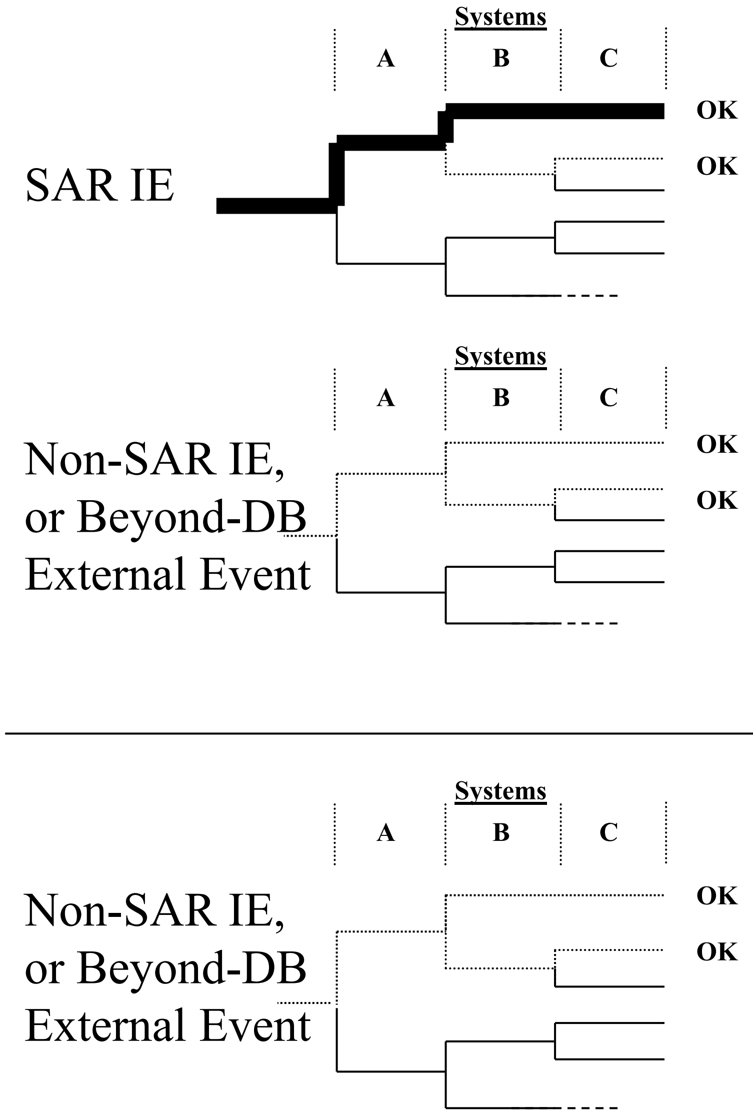
- Many of the elements whose performance reduces loads on other SSCs have low failure probabilities precisely because of SSC-specific “margins” that assure reliable performance of those elements. In other words, the “margin” idea is applicable more broadly than just to fuel failure and criticality.
- It has even been suggested that most, if not all, of the factors that make severe accidents remote are describable in terms of a “margin” concept: not just the physical margin in certain SSCs, but also the reliability of active components and their physical capacity (e.g., pump capacity).

Significant Uncertainty in Success Path Margin



“Safety Analysis Report” (SAR) Safety Case vs. Risk Model Safety Case

IE: Initiating Event
DB: Design Basis
PRA: Probabilistic Risk Assessment
PIRT: Phenomena Identification & Ranking Table



Bold: Licensing success path

Dotted: PRA success paths, which nominally succeed in PRA space, but in some cases with less margin than would be required in SAR analysis

Existing PIRT may not have carefully considered these

Full Power

Other Modes

Dotted: PRA success paths, which nominally succeed in PRA space, but in some cases with less margin than would be required in SAR analysis

Interesting Example

- This free EPRI report* analyzed margin in PWR feed and bleed, allowing for uncertainty and variability in a handful of variables:
  - Power Level at Start of Incident, Modeling of Steam Generator Levels (Masses), Time of Reactor Trip, Number PORVs Opened for F&B, Number of Trains of SI and CCP Available, HPSI Pump Flow Characteristics Near Shutoff Head, Pressurizer PORV Flow Characteristics, Time of AFW Failure, RCP Trip, Time Feed Initiated (SI Actuated), Temperature for Core Damage
- This issue space was sampled and the corresponding simulations were performed. Rick examined the runs manually and found out that some of the credited success paths only succeeded some of the time.
  - In the cases simulated, the charging pumps always succeeded if actuated, but the High Pressure Injection pumps did not always succeed, even if actuated

*EPRI Report 1023032, Technical Framework for Management of Safety Margins--Loss of Main Feedwater Pilot Application
Principal Investigators J. Gabor, R. Sherry, D. True
EPRI Project Manager S. Hess

Excerpt From Stu Magruder's Talk:

50.43(e) Applications for a design certification, combined license, manufacturing license, operating license or standard design approval that propose nuclear reactor designs which differ significantly from light-water reactor designs that were licensed before 1997. Or use simplified, inherent, passive, or other innovative means to accomplish their safety functions will be approved only if:

(1) …

or

(2) There has been acceptable testing of a prototype plant over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions. If a prototype plant is used to comply with the testing requirements, then the NRC may impose additional requirements on siting, safety features, or operational conditions for the prototype plant to protect the public and the plant staff from the possible consequences of accidents during the testing period.

MARGIN

Excerpt from
ANS Nuclear Grand Challenges / June 2017 | Special Report

EXPEDITE LICENSING

CHALLENGE: Expedite licensing and deployment of advanced reactor designs.

Institutional difficulties associated with obtaining design certification for novel reactor technologies could be avoided by **first constructing and operating a prototype plant that has sufficient extra margin and safety features to justify near-term Nuclear Regulatory Commission (NRC) approval for prototype construction and testing.** This process is explicitly contemplated in 10 CFR 50.43 e(2), but is seldom or never used. Such a process could be carried out with the expectation that the results of testing and operation of a prototype plant would support subsequent expeditious certification of a viable commercial (as opposed to prototype) design.

Play clip about the 1986 EBR-II Experiments

https://www.youtube.com/watch?v=Sp1Xja6HIIU

Starting at 1:18 [Charles Till]

Key points

- EBR-II had lots of margin, and proved it in a fairly dramatic fashion.
- A couple of key points from John Sackett, another key figure at EBR-II (not his exact words):
  - The key safety features were *passive.*
  - An approach to licensing a novel technology:
    - Build a prototype with a lot of margin,
    - Operate it and test it,
    - Use the knowledge gained to optimize a design for normal licensing.
  - John Sackett called this “license by test.”

See also SAFETY CHARACTERISTICS OF A SMALL MODULAR REACTOR, E. L. Gluekler, N. W. Brown, C. L. Cowan, A. Hunsbedt, R. A. Meyer, Proceedings of the International topical Meeting on FAST REACTOR SAFETY / Volume I / April 21 • 25, I985

Considerations in Formulating a Safety Case: Allocation and Implementation

Alternative Regulatory Approaches

(descended from long-ago NEI / NUMARC position papers)

What's Important?

(the "allocation")

What SSCs, operator actions, etc. do we care about, and what level of performance do we need from them?

What do we do about it?

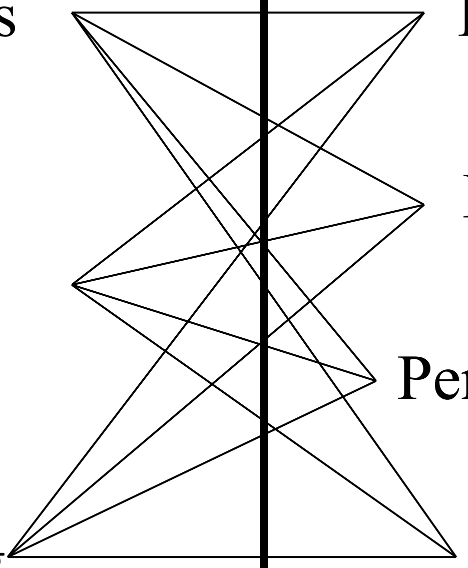
(the "implementation")

How do we make the allocated (planned, expected) performance come true? How do we ***know*** that it is coming true?

Design Basis

Risk Model

Engineering Judgment



Prescriptively Gold-Plate

Process-Based Approach

Performance-Based Approach

Penalties Following Accidents

Allocation

- Allocation:
  - Deciding what SSCs, operator actions, etc. we wish to rely on in our safety case, and
  - Deciding what level of performance we need from them, in order to satisfy safety objectives
  - ➢ Deciding how much credit to take, trading off the costs of taking that credit (capital, maintenance, monitoring, NRC inspection) against the benefit of having that credit (lower risk numbers, lower severe accident premiums?)
- In traditional licensing, the process of allocation is declaring to be “safety class” the complement of SSCs needed to satisfy safety analysis criteria, including single failure criterion, etc.

Different Ways to Allocate

- Design basis approach
  - Somehow choose DBAs
  - Require (e.g., single-failure-proof) mitigation capability (implies a certain complement of success paths)
  - “Good” performance is then implicitly allocated to all elements of these paths
  - The safety objectives being met...
    - are almost necessarily qualitative
    - are implied by the selection of DBAs and the stringency of the mitigation requirement and (arguably) the way in which “implementation” is being approached
- Possible use of a risk model
  - Develop a model that quantifies performance with respect to the metrics of interest
  - Exercise taste and discretion in what is credited in the risk model
  - Select a complement of success paths that collectively satisfy your performance target (e.g., using Top Event Prevention Analysis)
  - Take the PRA numbers used for the SSCs in those paths as performance targets

Different Approaches to Implementation

- Prescriptively gold-plating safety-class systems:
  - Identify everything impinging on that system
  - QA procurement, installation, operating procedures, ...
  - Mandate IST, ISI, …
  - Require Tech Specs
  - Inspect compliance with requirements
- Performance-Based Approach:
  - Determine needed level of performance (capacity / amount, reliability, availability)
  - Measure performance to confirm needed level of performance is being maintained
- Process-Oriented:
  - Mandate licensee processes intended to promote performance
  - Inspect the processes

“Performance-Based”…

…Is a shorthand term for an approach to implementation that is less prescriptive, more goal-oriented, and a more efficient way of assuring that the allocation is coming true.

“Margin” in Allocation and Implementation for a prototype plant:

- Allocate margin in the design
  - Physical margin and temporal margin
- Implementation: Instrument the prototype plant *very thoroughly* in order to provide a means of measuring margin all the time.

➢ These measurements are key to optimizing the design for mass production.

Summary:
Licensing Novel Designs on the Basis of Margin

- This talk does not address all of the questions that would have to be answered before going down the 50.43 path. It just illustrates a couple of key concepts.
- The general idea is
  - Propose a prototype facility that is overdesigned in ways that are deemed necessary to compensate for current lack of testing, so that approval of the prototype can be justified. Get the approval.
  - Build the overdesign and thoroughly test it.
  - Now you have a knowledge base that supports design optimization. Proceed with a version of the design that is optimal rather than overdesigned.
- Need to
  - Identify a set of success paths that
    - Collectively satisfy the top-level performance requirements (the top-level criteria for licensability)
    - Can be shown to have significant margin
  - Figure out how to assure, on an ongoing basis, that those paths actually have the margin that they need to have in order for the safety case to come true.