INL/CON-25-84818-Revision-0

ACCELERATED DEPLOYMENT OF NOVEL MATERIALS BASED ON RELIABILITY INTEGRITY MANAGEMENT USING CUMULATIVE DAMAGE MODELING

Changing the World's Energy Future

Robert Walker Youngblood III, Todd Michael Anselmi, Scott E Ferrara

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Robert Walker Youngblood III, Todd Michael Anselmi, Scott E Ferrara

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Presenter: Bob Youngblood

Accelerated Deployment of Novel Materials Based on Reliability Integrity Management (RIM)* Using Cumulative Damage Modeling

Robert Youngblood, Todd Anselmi, Scott Ferrara
Idaho National Laboratory

* 2023 ASME Boiler and Pressure Vessel Code, Section XI (Rules for Inservice Inspection of Nuclear Power Plant Components), Division 2 (Requirements for Reliability and Integrity Management (RIM) Programs for Nuclear Reactor Facilities), ASME International, 2023.

Acknowledgment

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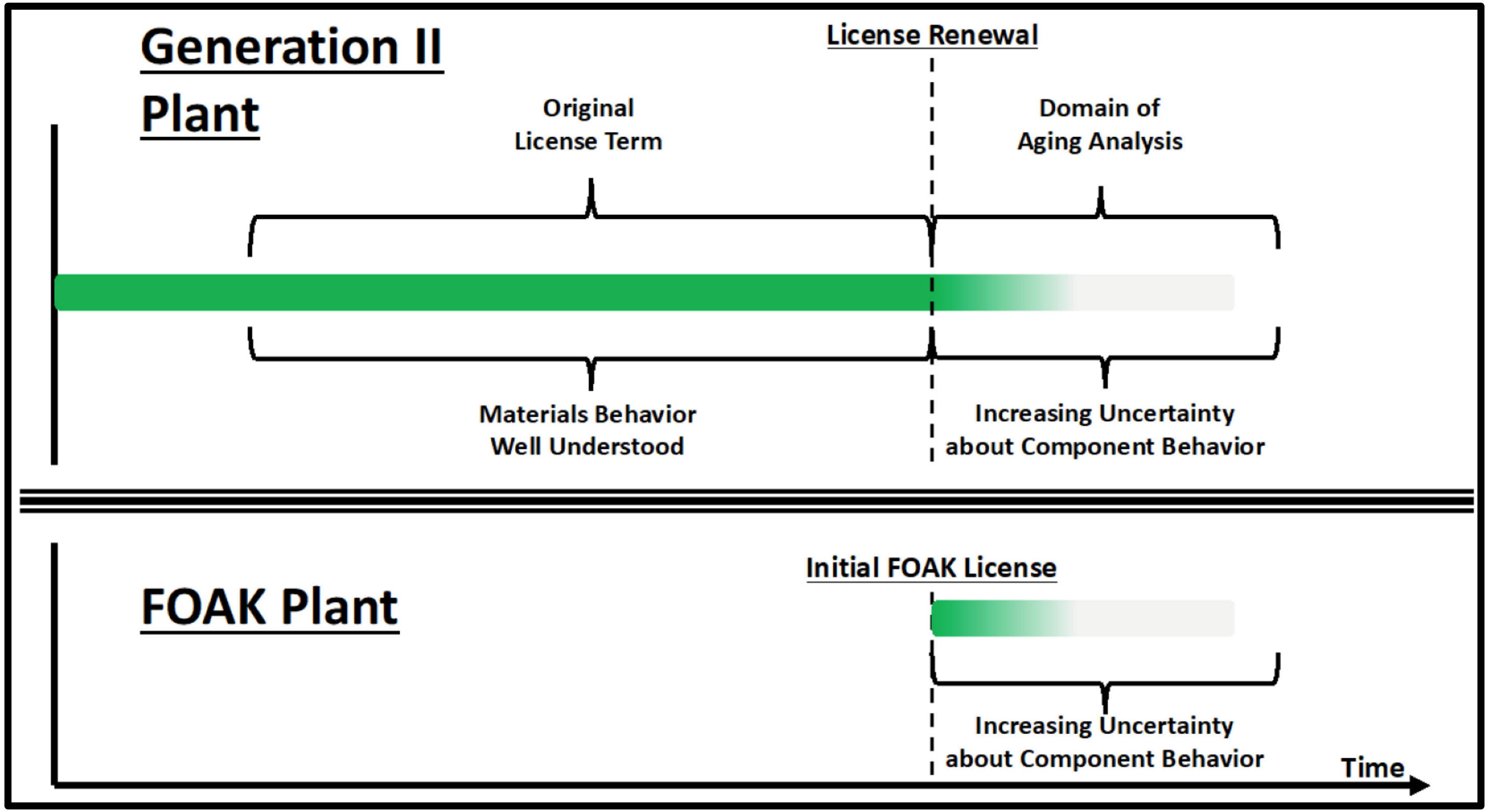
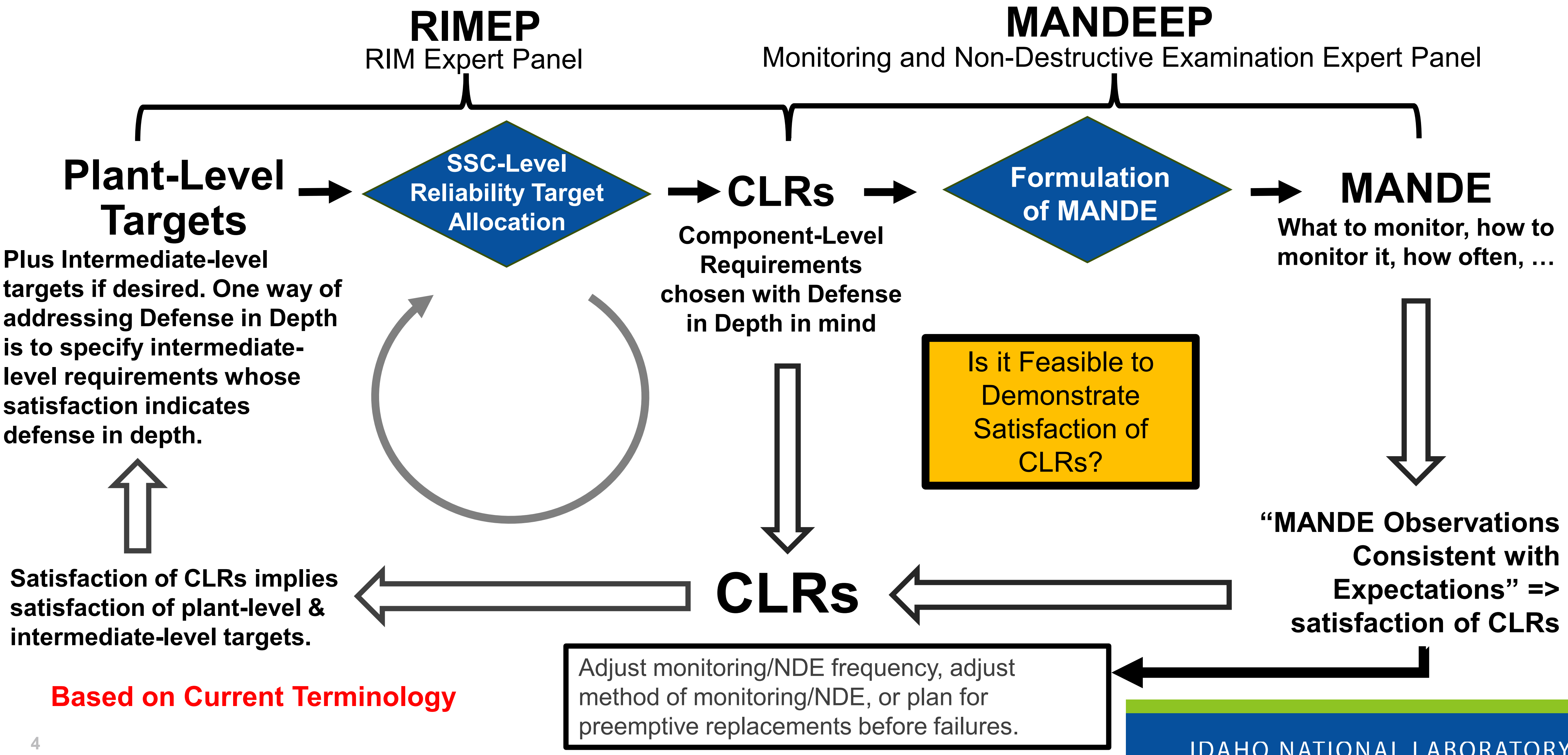
Disclaimer

Suggesting an analogy between uncertainty management after license renewal and uncertainty management in a first-of-a-kind (FOAK) plant



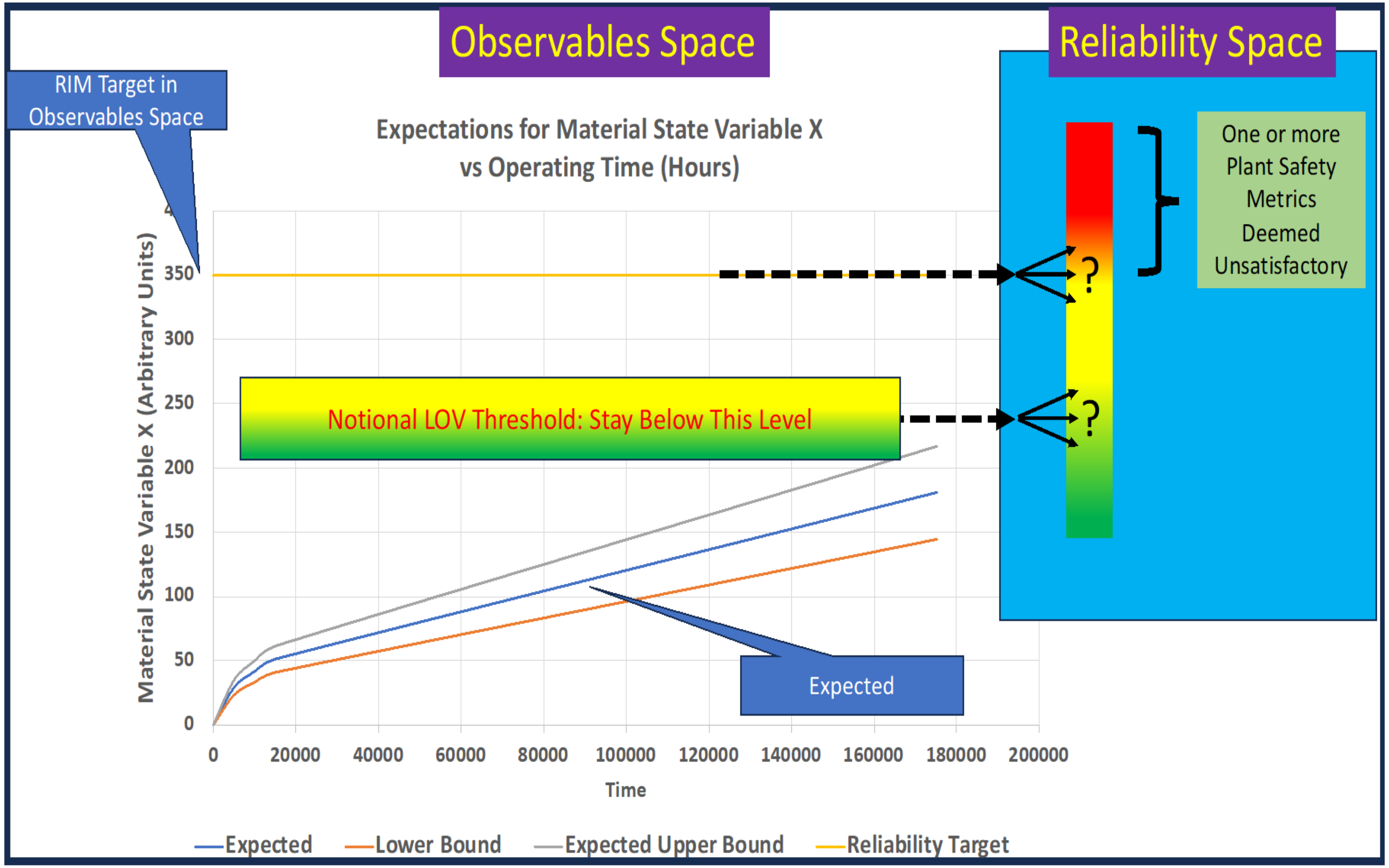
Simplified Diagram of RIM



Observables space versus reliability space

LOV (Limit of Validity) is a Federal Aviation Agency (FAA) idea for avoiding widespread fatigue damage in aircraft wings. Operators are required (CFR 2007; FAA 2011) to:

Establish a limit of validity of the engineering data that supports the structural maintenance program (hereafter referred to as LOV) that corresponds to the period of time, stated as a number of total accumulated flight cycles or flight hours or both, during which it is demonstrated that widespread fatigue damage will not occur in the airplane.



State transition model inspired by Fleming's Markov model

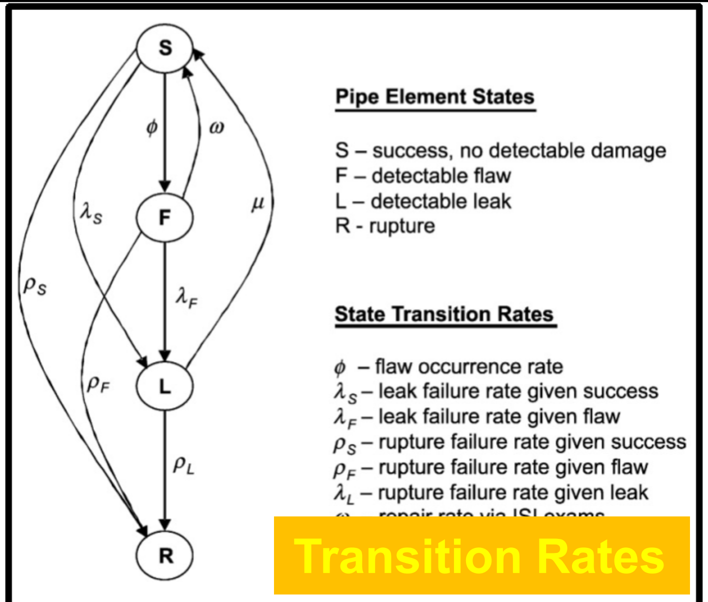
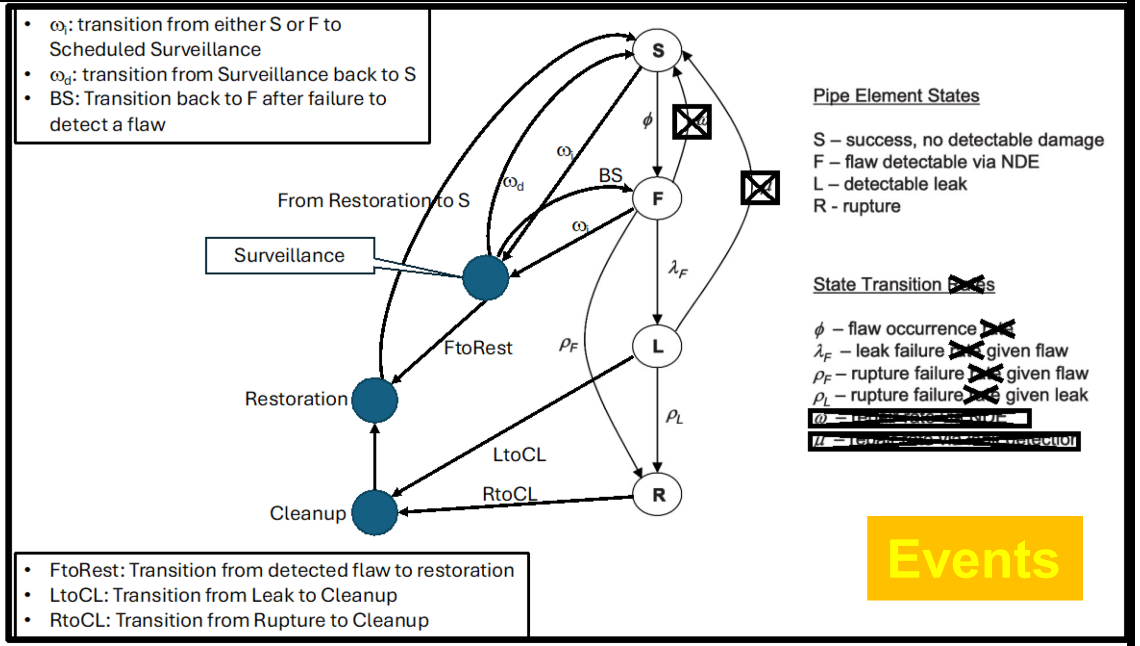


Fig. 1. Four state Markov model for all failure mechanisms.

This work



Karl N. Fleming, Markov models for evaluating risk-informed in-service inspection strategies for nuclear power plant piping systems
Reliability Engineering and System Safety 83 (2004) 27–45

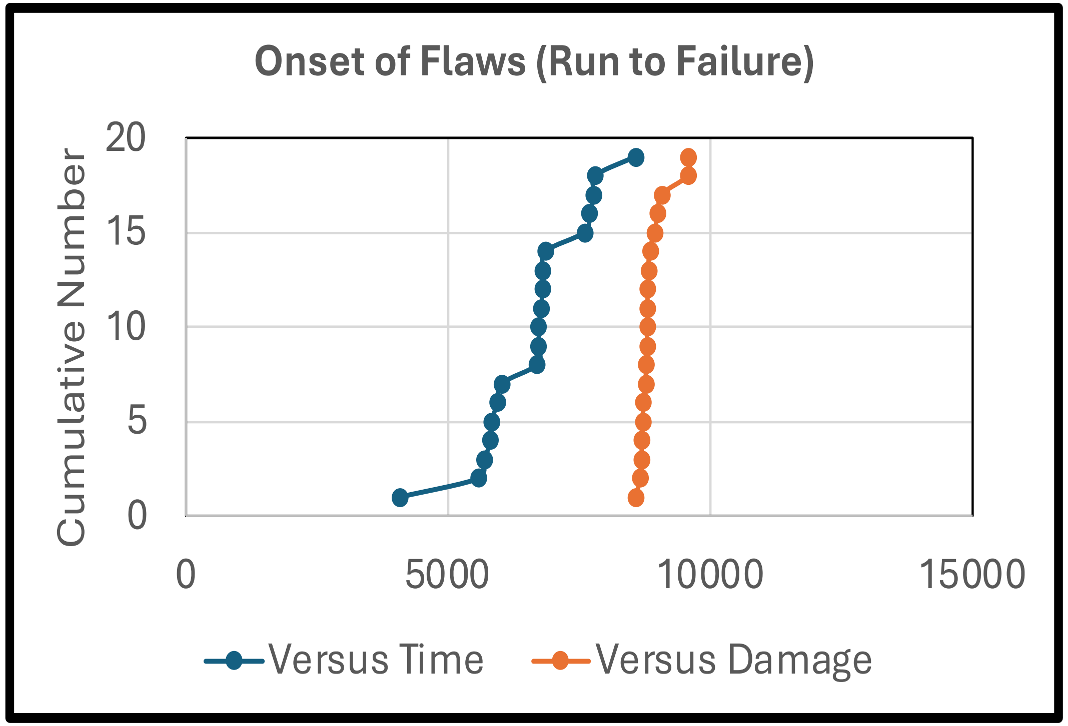
State Transitions are "Events" driven by Stressor "Events"

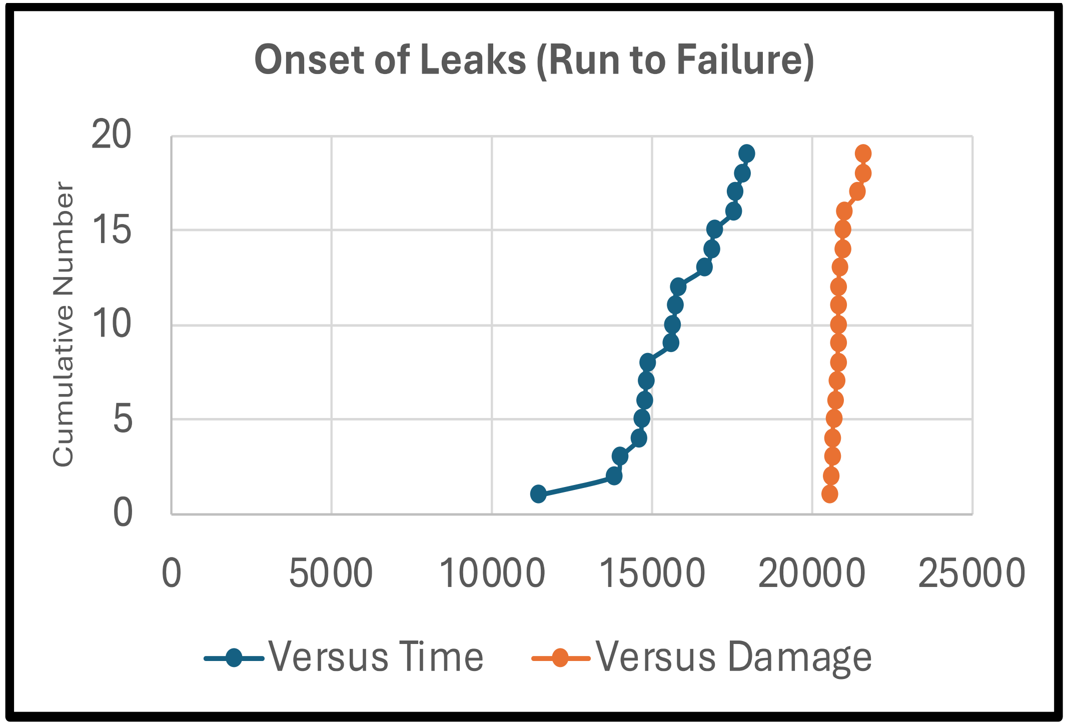
Damage accumulating in time interval $[t_0, t_1]$ = Factor1*(t_1-t_0) + Factor2 * # of ES occurring in $[t_0, t_1]$.

Parameters	Values
Factor1 (Damage Model)	1
Factor2 (Damage Model)	1000
Parameters (μ, σ) of Gaussian Distributions for Flaw, Leak, Rupture Thresholds:	
Flaw (μ, σ)	(8760,100)
Leak (μ, σ) (additional damage given flaw)	(12000,100)
Rupture (μ, σ) (additional damage given flaw)	(14000,100)
Average rate of ES (their times are Poisson-distributed)	3.42E-4 / hr (about 3 per year)

ES: Episodic Stressor

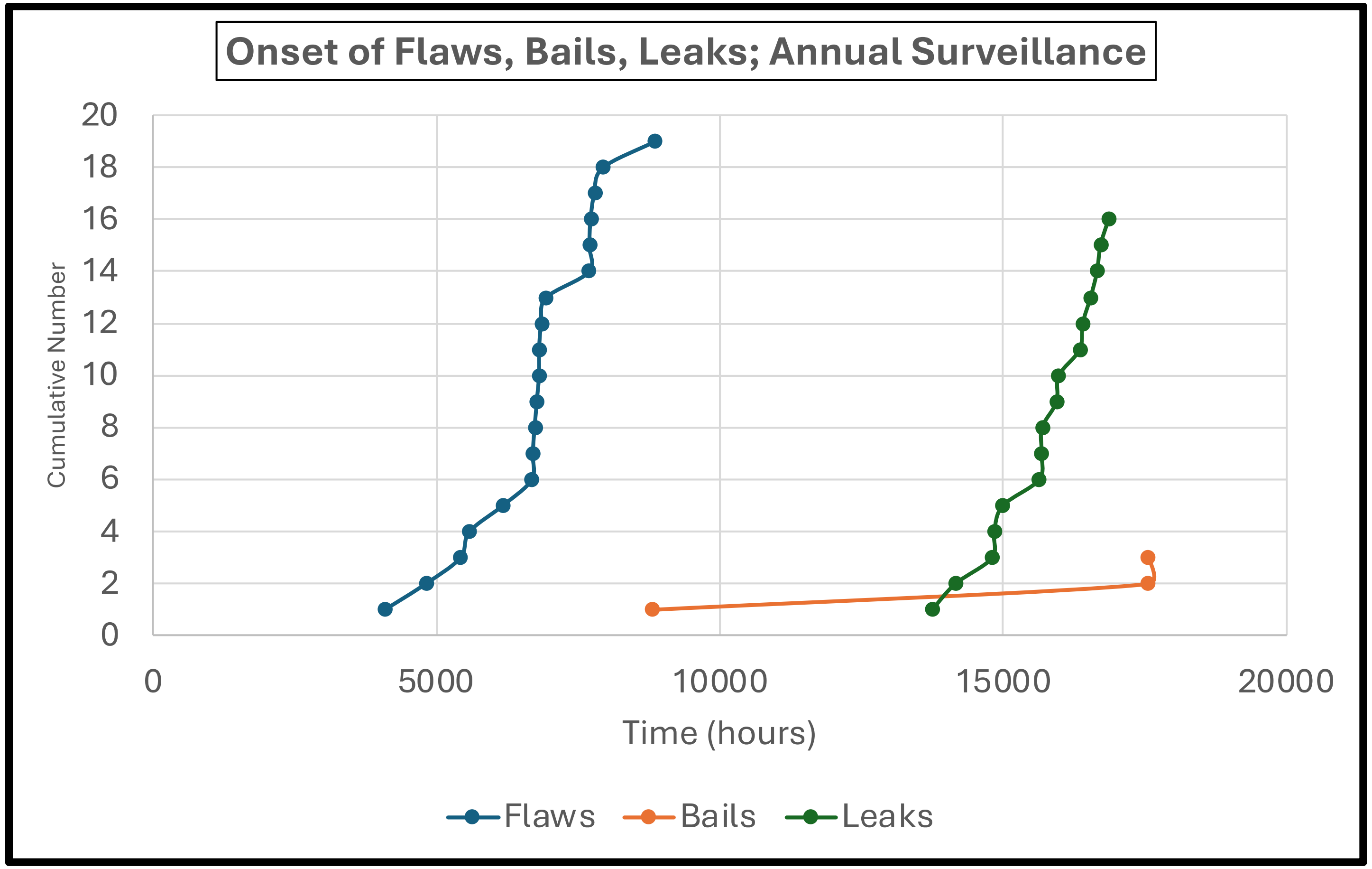
Base case: Results for a series of component lifetimes culminating in failure (in this case, onset of leak)





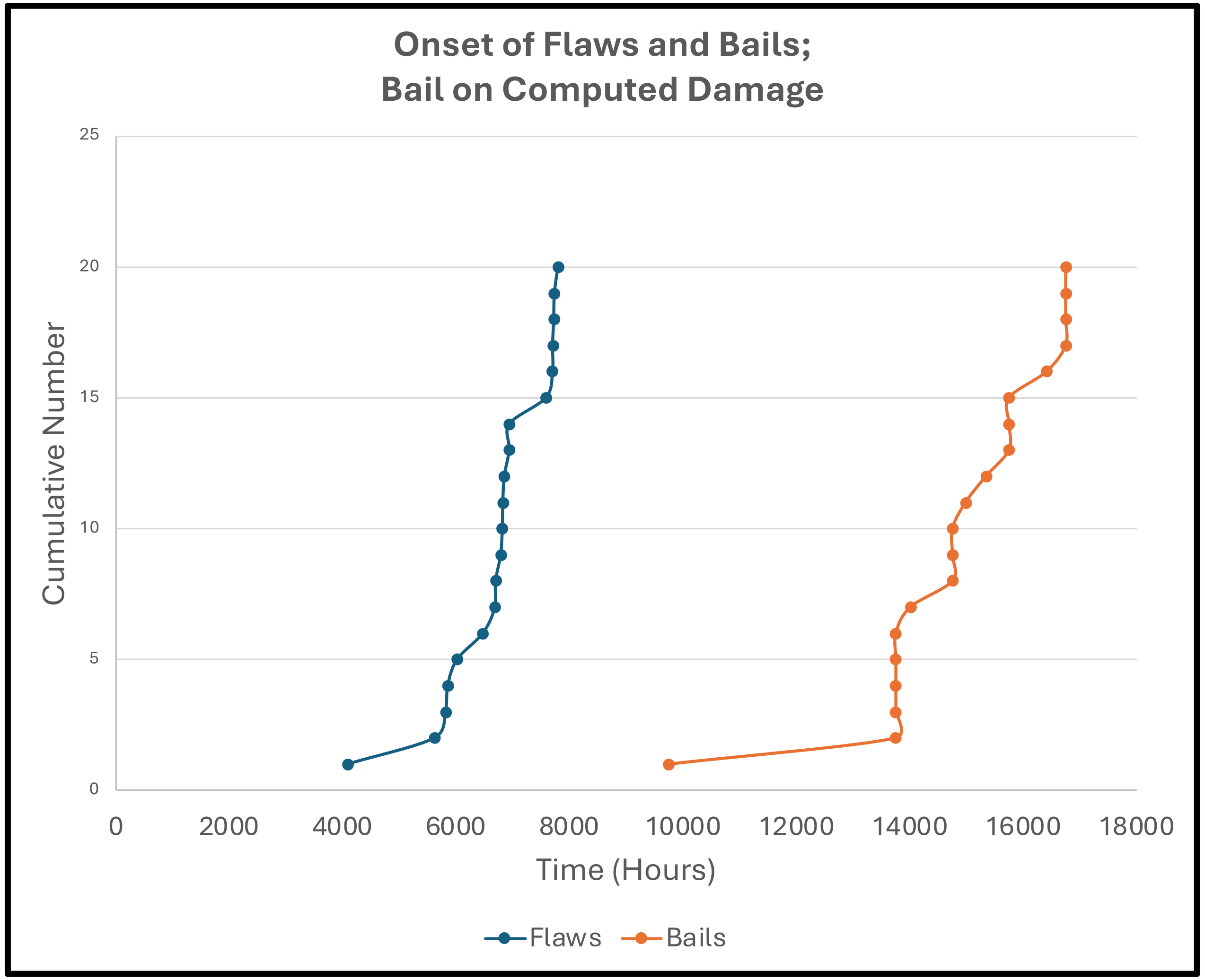
Crediting Annual Surveillance in Preventing Failure

In this run, surveillance occurs annually, and if the observed damage exceeds a specified level of damage, the component is renewed (“bail”).



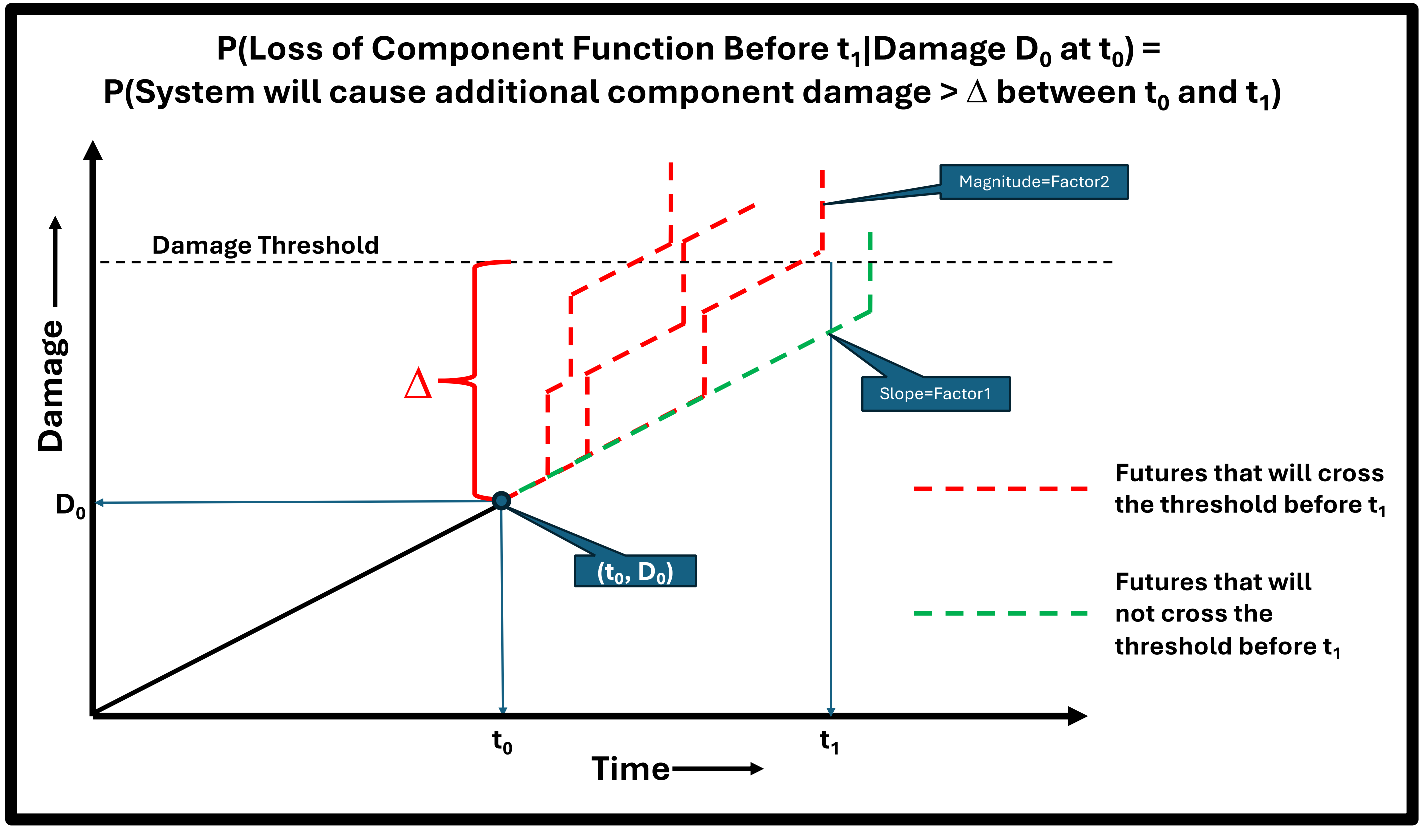
Flaws and bails versus time, given perfect knowledge

- In this run, no surveillance occurs at all; rather, it is assumed that the damage formula (Equation 1) accurately reflects the damage to the component.
- When the operating history implies that the time for component renewal has arrived, the component is renewed.
- In this campaign, we assume perfect knowledge of component state (including the number of ES that have occurred), so “bail” always occurs before “leak.”



Calculating Component Reliability Given Current Damage

- The lower left of the plot shows damage increasing linearly in time (Factor 1 > 0).
- Beyond t_0, we see occasional step changes in damage, corresponding to ES.
- Given the damage level at t_0, we know whether Factor1 will cause a loss of function at or before t_1.
- In the green time history, Factor1 will not by itself cause a threshold crossing, so a transition occurs only if some ES occur.
- Were Factor2 zero, the reliability in this situation would be 1; but it is not zero, and in the red time histories, enough ES occur to cause the transition.



The “unreliability” (probability of failure before t_1, given damage level at t_0) is the probability of enough damage accruing before t_1 to cause a transition to a failed state.

Summary

- RIM offers a potential way of being allowed to deploy novel materials without first ”qualifying” them.
- In such an RIM application, reliability targets are set for RIM SSCs, and ongoing application of MANDE shows whether those targets are being met.
  - In effect, RIM replaces the assurance provided, at significant expense, by prior qualification with the assurance provided by assiduous monitoring based on careful analysis, thus allowing for detection of performance issues, timely renewal of degraded components, and updating of the MANDE protocols when necessary.
- **This paper briefly discussed one way to map current physical observations into a reliability figure of merit, as required by RIM.**
- The simple model used in this work treats component loss of function (leak or rupture) as resulting from the component having crossed a specific damage threshold.
- The damage model used in this work will be too simple for real-world applications, but shows that the non-Markovian aspects of such models can be dealt with straightforwardly in discrete-event simulation.
- We believe that extension to multiple degradation mechanisms is straightforward.

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Responding to MANDE observations (Notional)