Delivering the Nuclear Promise through Improved Economics:

The Role of Data Analytics in Nuclear Power Operations and Maintenance

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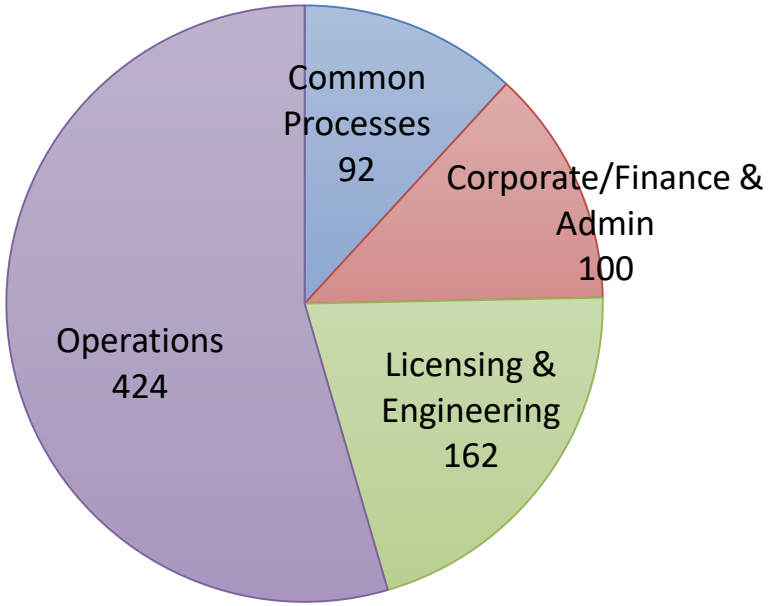
US Reactors are shutting down!

Plants	Fuel	Capital	Operating	Total
All U.S.	6.44	6.64	20.43	33.50
Single-Unit	6.42	8.92	27.32	42.67
Multi-Unit	6.44	5.99	18.46	30.89

- Table in 2017 $/MWh
- Minimal staffing across best performing plants: ~750 FTEs
- Operations and Maintenance are the largest addressable categories

FTEs at a 1 GWe Reactor



Slide from R. Slaybaugh, ARPA-E https://arpa-e.energy.gov/?q=workshop/optimal-operations-advanced-nuclear-reactors
Table: https://www.nei.org/CorporateSite/media/filefolder/resources/reports-and-briefs/nuclear-costs-context-201810.pdf
Pie chart: https://www-pub.iaea.org/MTCD/Publications/PDF/te_1052_prn.pdf

The current approach to maintaining component health in NPPs largely periodic inspection

Active Components:

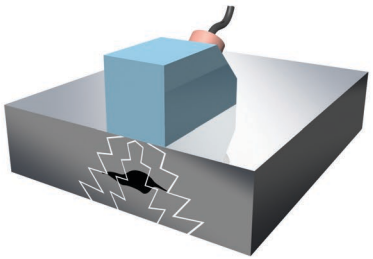
The Maintenance Rule

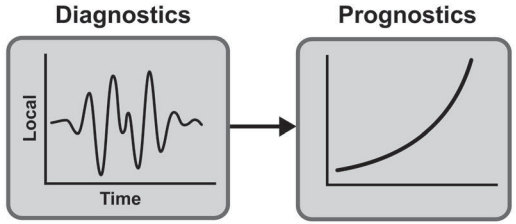
- Performance-based approach to equipment monitoring and maintenance
- Condition assessment methods (online and offline tests) are well developed for many key active components
- Currently a push to risk-based regulation
  - May extend to O&M

Passive Components:

Aging Management Plans

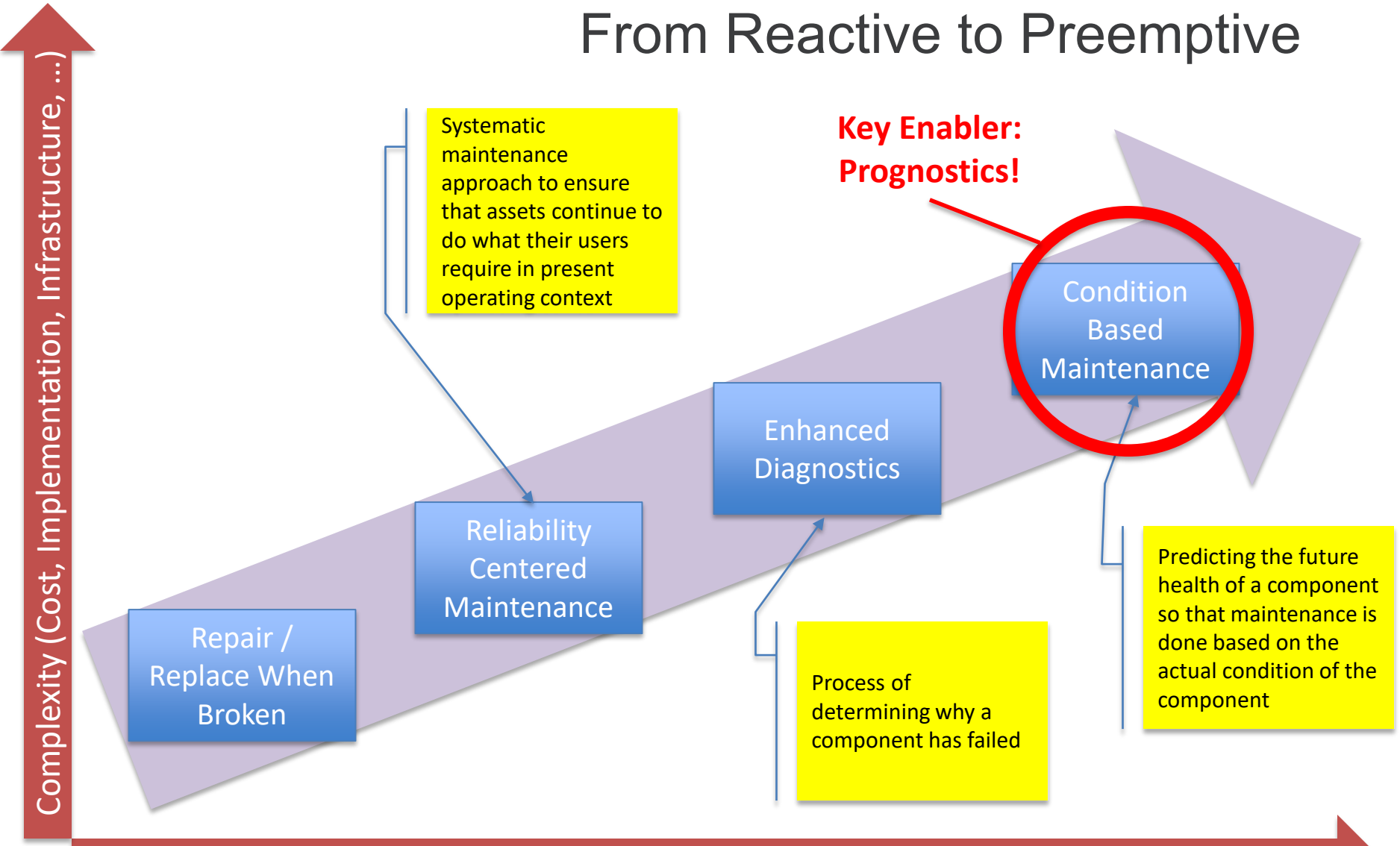
- In-service Inspection
  - Frequency prescribed by AMP
  - Nondestructive evaluation methods given by ASME BPV code, section XI





Evolution of Maintenance Practices

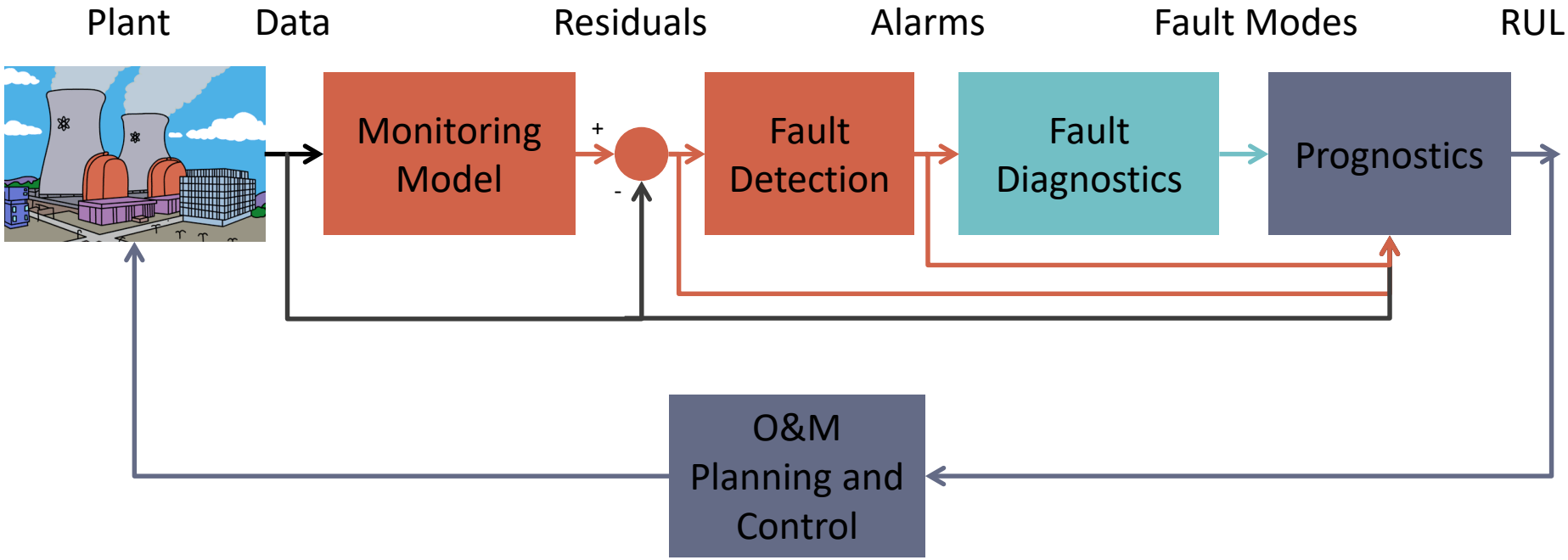
From Reactive to Preemptive



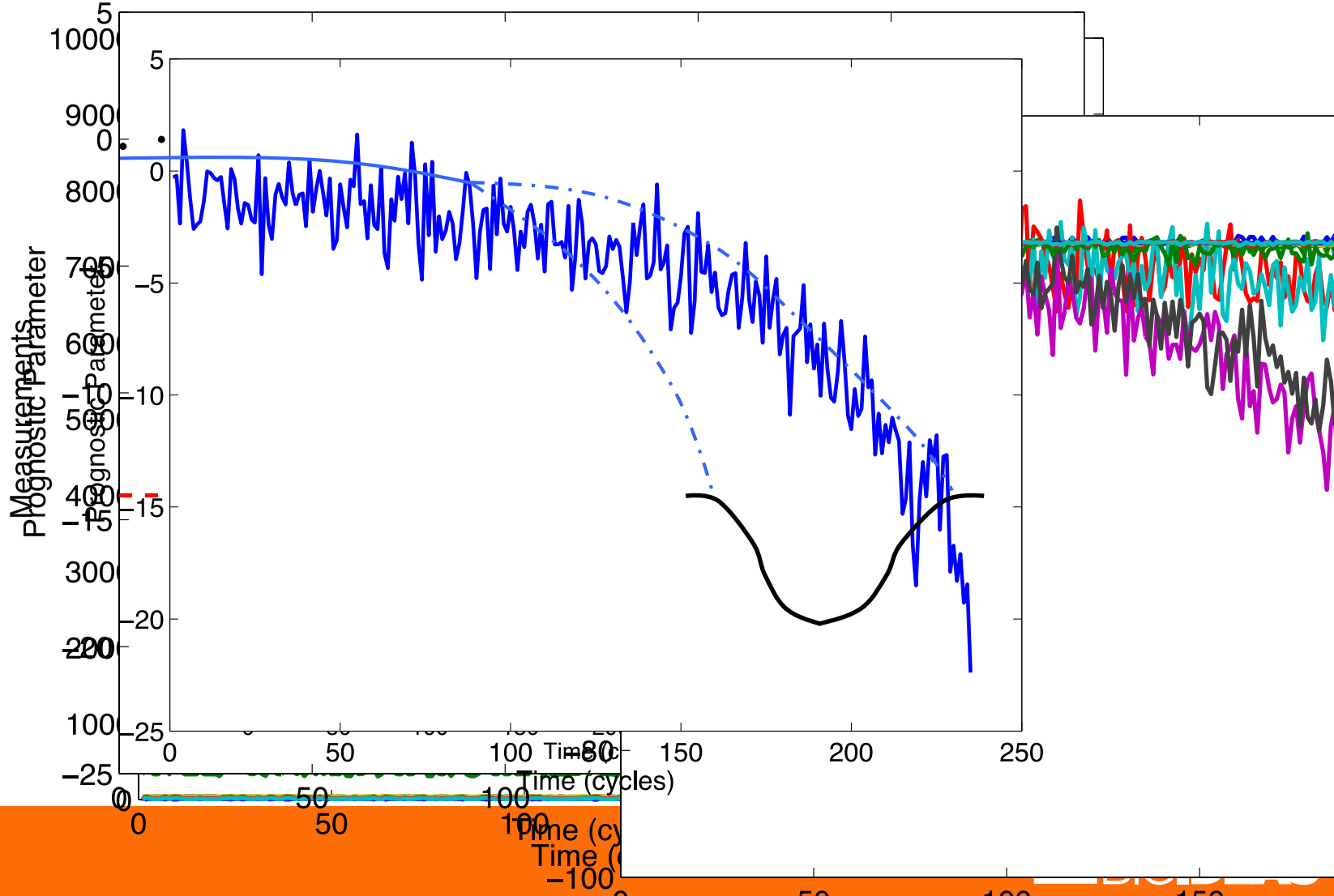
Current condition assessment does not satisfy the real needs to optimize maintenance in NPPs

- Nondestructive **measurement** methods and analyses to detect degradation and anomalies
- **Algorithms** to characterize and monitor the degradation state of the component
- **Prognostics** that use the degradation state information to determine remaining useful life (RUL) and probability of failure (POF) of components
- Methods to **integrate prognostic estimates** into risk estimates, operations and maintenance planning, and advanced control algorithms

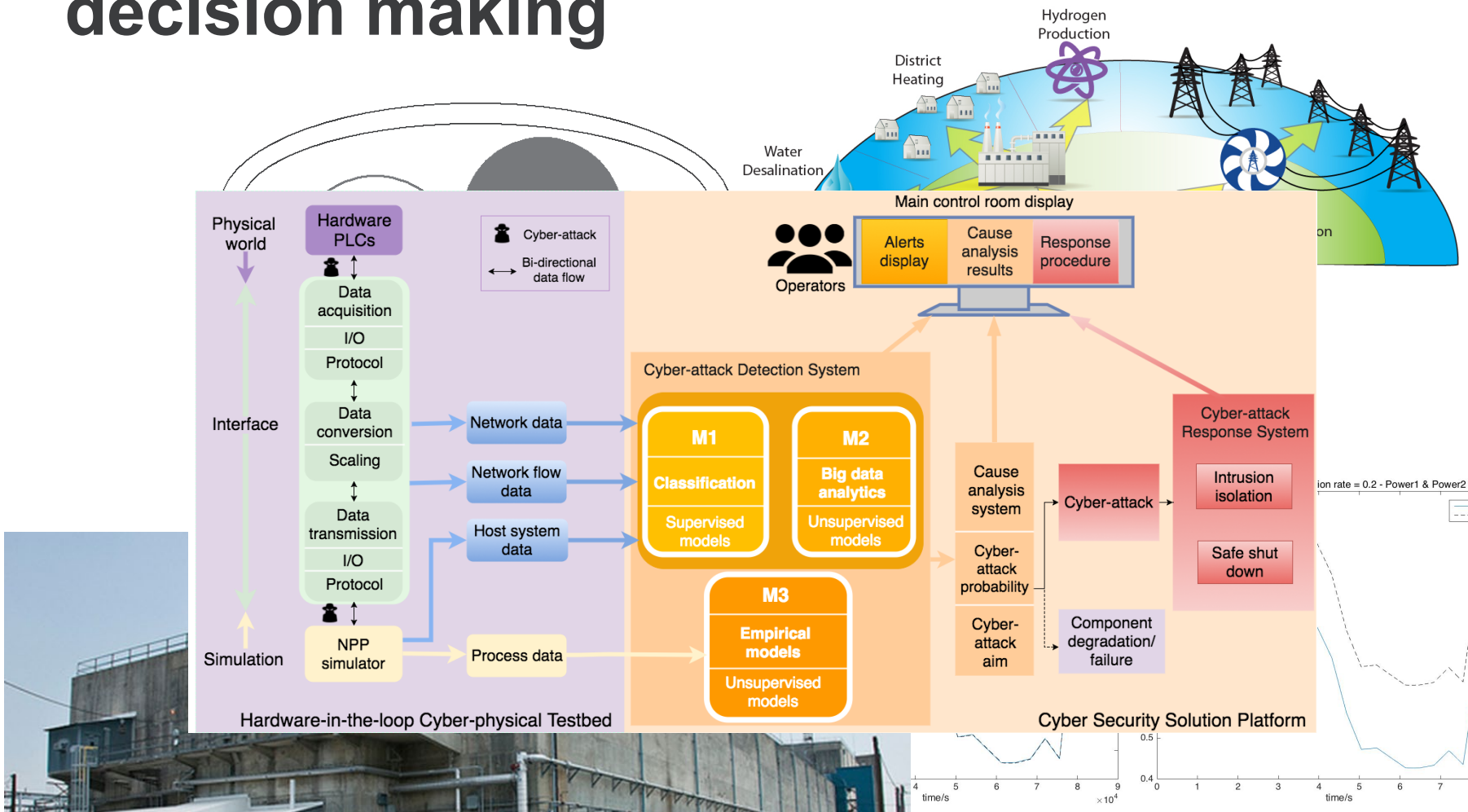
Information about the evolving condition of equipment is contained in plant data



Asset surveillance systems extract knowledge from data

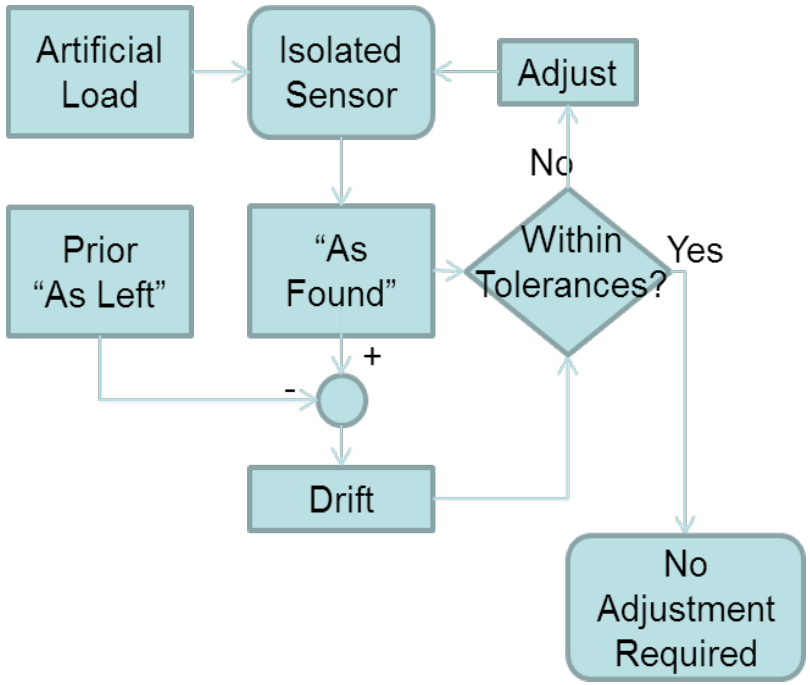


R&D focuses on data analytics for situational awareness and robust decision making



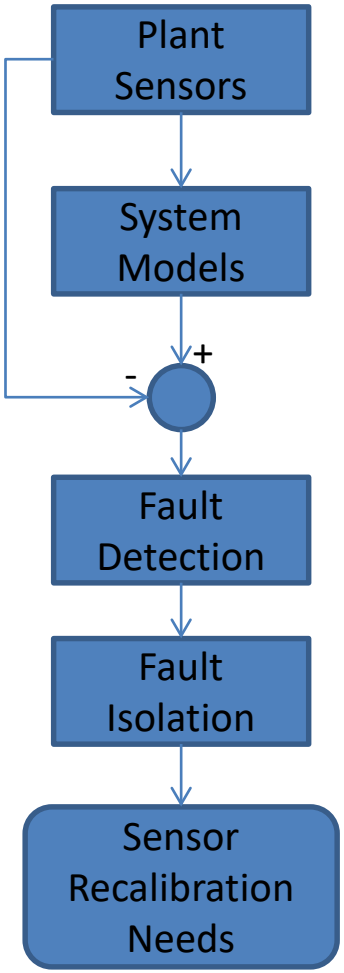
Current practice requires periodic recalibration of transmitters

- All safety sensors at least every 2 years
  - Typically performed at every refueling outage
- Industry studies find 5-10% of transmitters are out of calibration



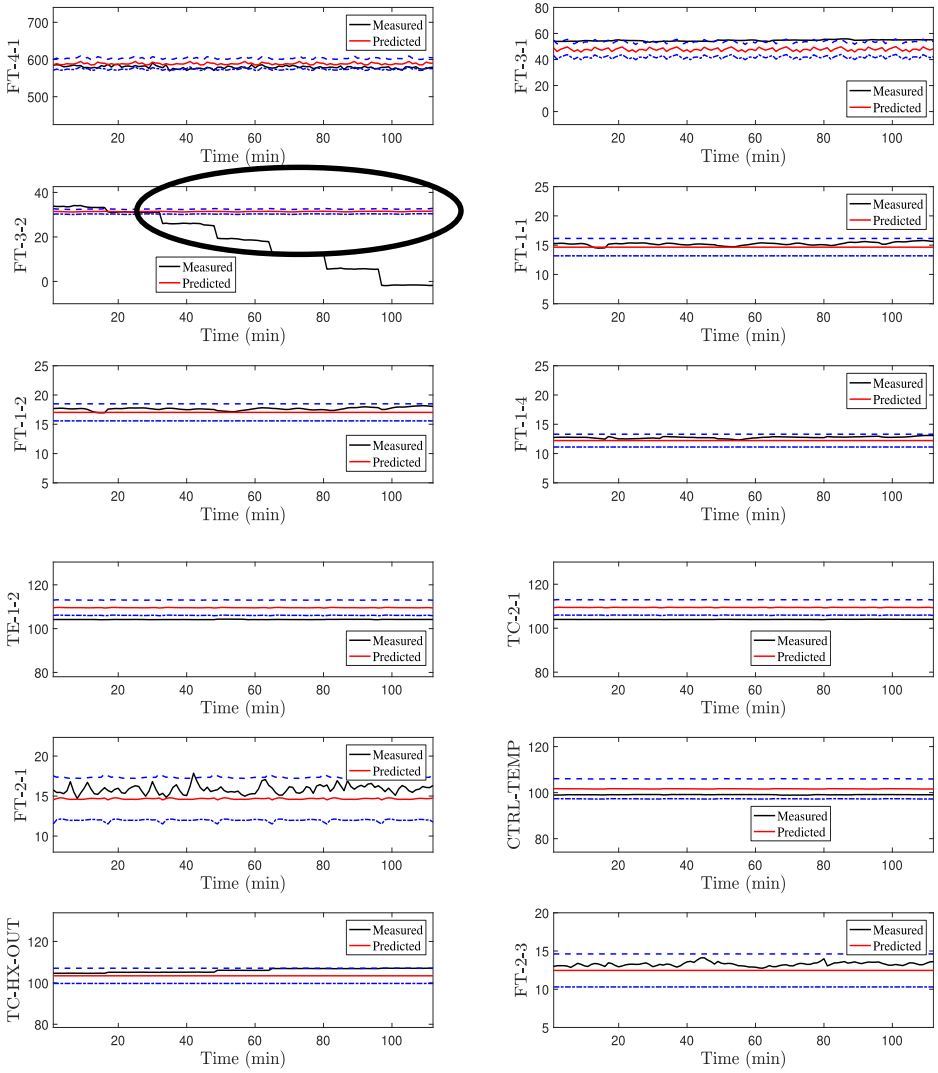
Sensor calibration status evaluated *in situ* with OLM

- OLM uses plant data collected **during operation** to assess condition
  - Models of nominal system behavior estimate the "true" sensor value
  - Measured values are compared to estimated values to detect and isolate sensor calibration faults
- On-line calibration assessment has been applied in NPPs overseas but not presently used in the US
  - Sizewell B (UK) plant has longer calibration intervals, up to 8 years depending on measurement redundancy
  - Électricité de France allows calibration intervals up to 12 years

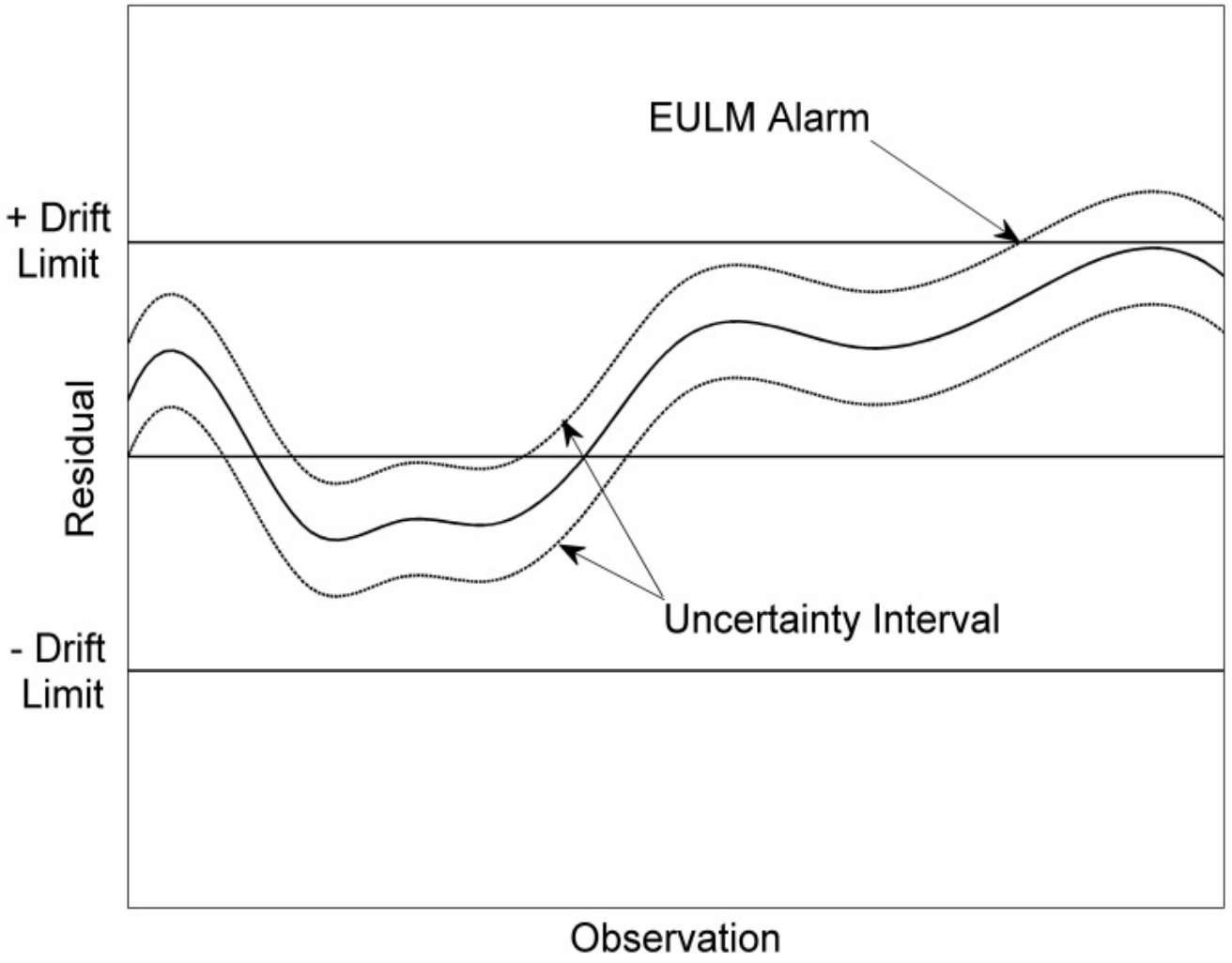


Online monitoring models provide *virtual sensors* in faulted conditions

- OLM models estimate “true” process value
- Predictions can be used as a *virtual sensor* during degraded sensor performance



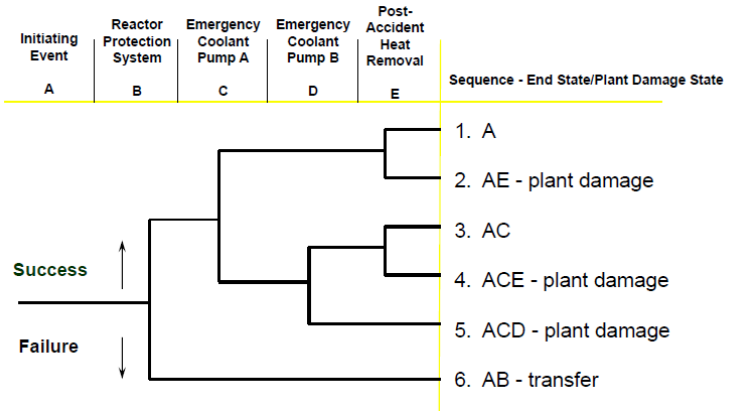
Monitoring system residuals create a “moving threshold” for anomaly detection

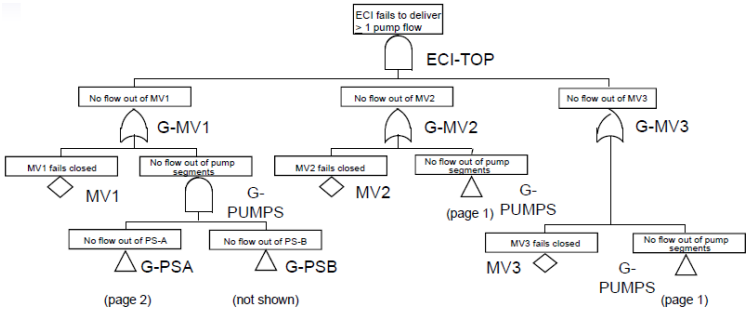


Prognostics allows us to answer key questions about our equipment

- When is it going to fail?
- Why is it going to fail?
- How can I stop it from failing?

Incorporating Equipment Condition in Operating Risk



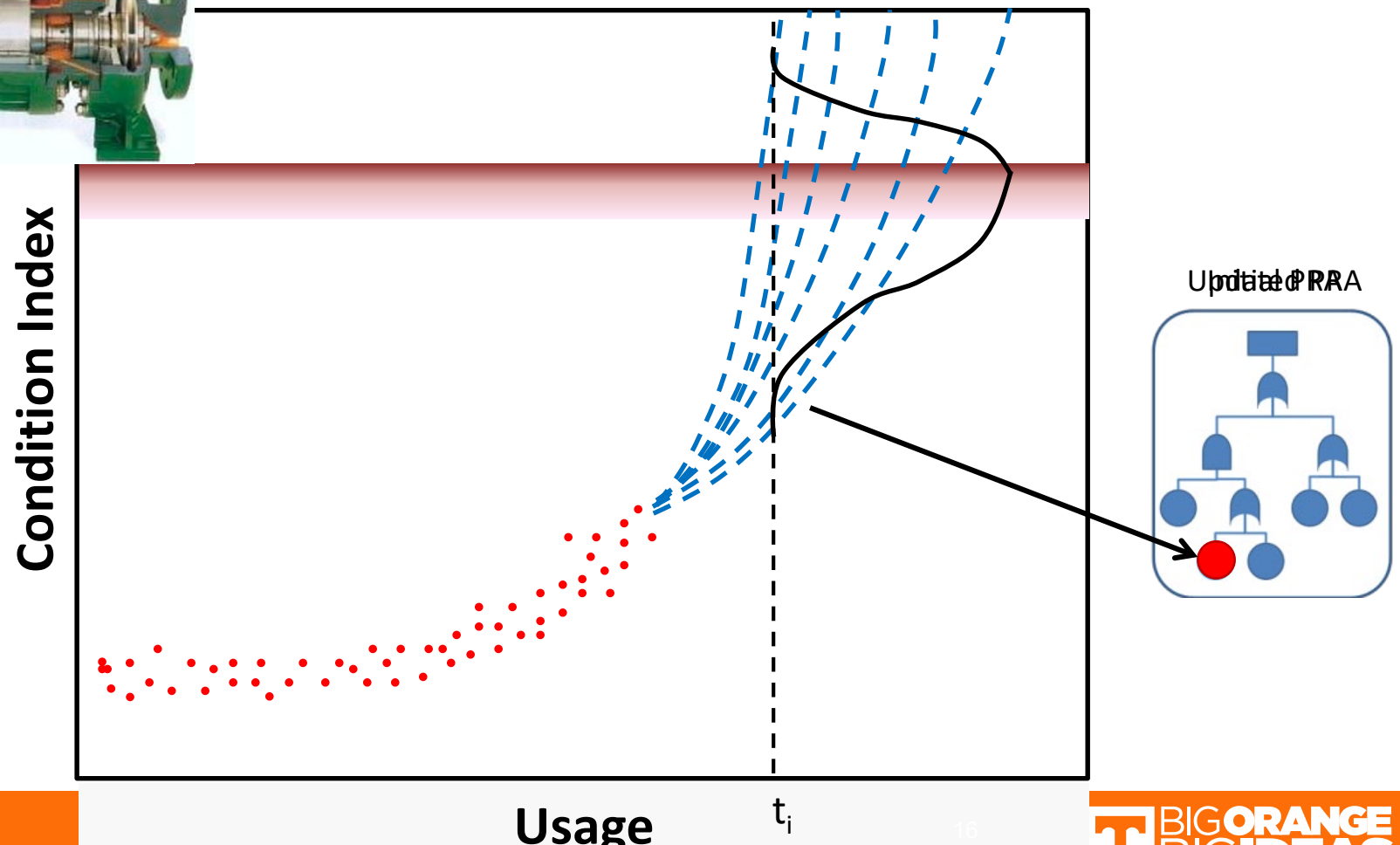


Graphics From 2011 Fire PRA Workshop presentation, A collaboration of the Nuclear Regulatory Commission (NRC) and Electric Power Research Institute (EPRI)

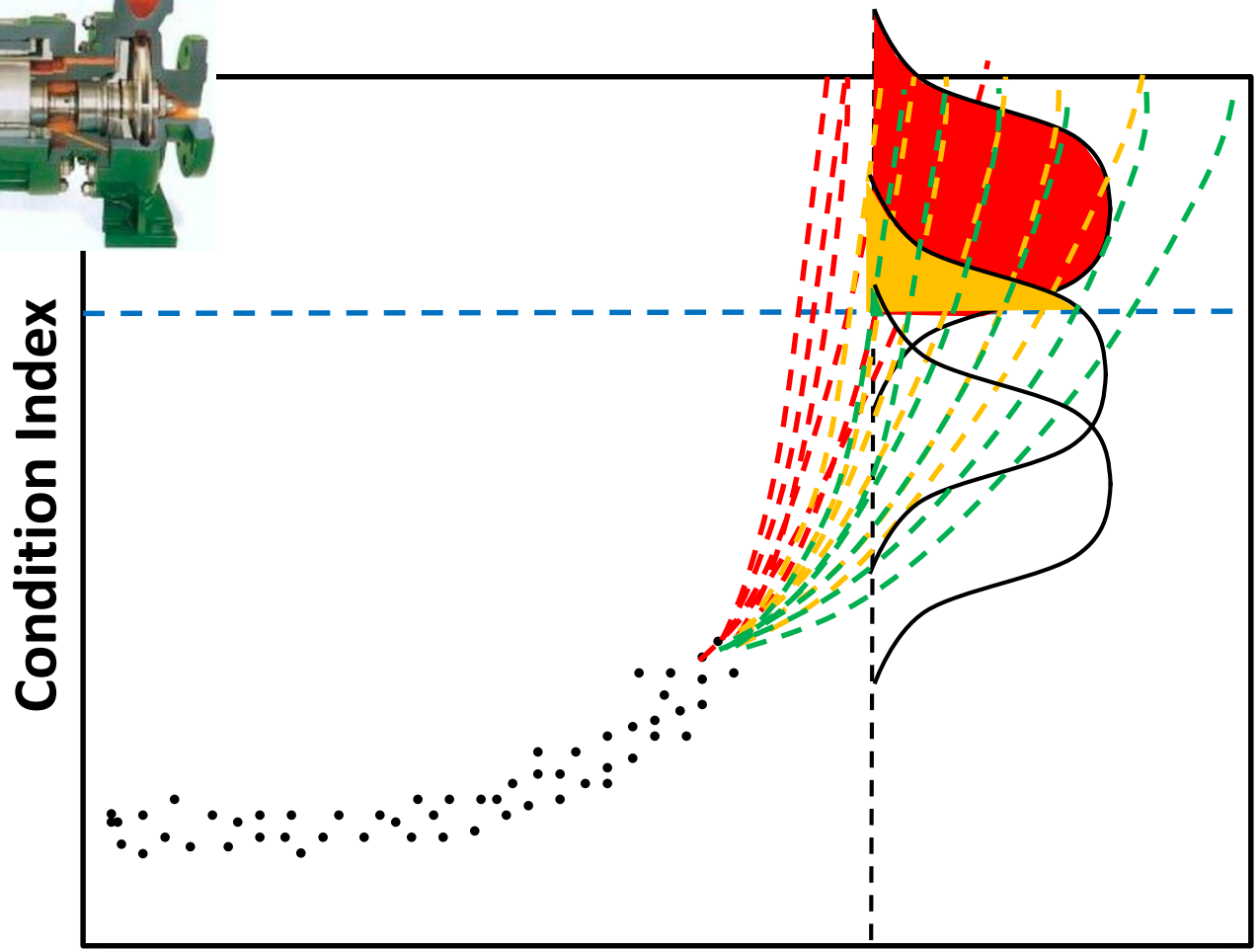
- Probabilistic Risk Assessment (PRA) is a systematic method to quantify the risks associated with operating a system
- Risk monitors extend PRA to reflect the dynamically changing plant configuration
  - Equipment availability, operating regime, environmental conditions
- Current risk monitors do not account for the actual condition of SSCs when evaluating risk
  - Population-based event and failure probabilities are used
  - Passive component failures are largely excluded from risk monitors (except as initiating events)

Enhanced Risk Monitors integrate information from a variety of sources …

… to incorporate the current and evolving condition of equipment into calculations of risk.



Operational stressors can be incorporated into POF estimates



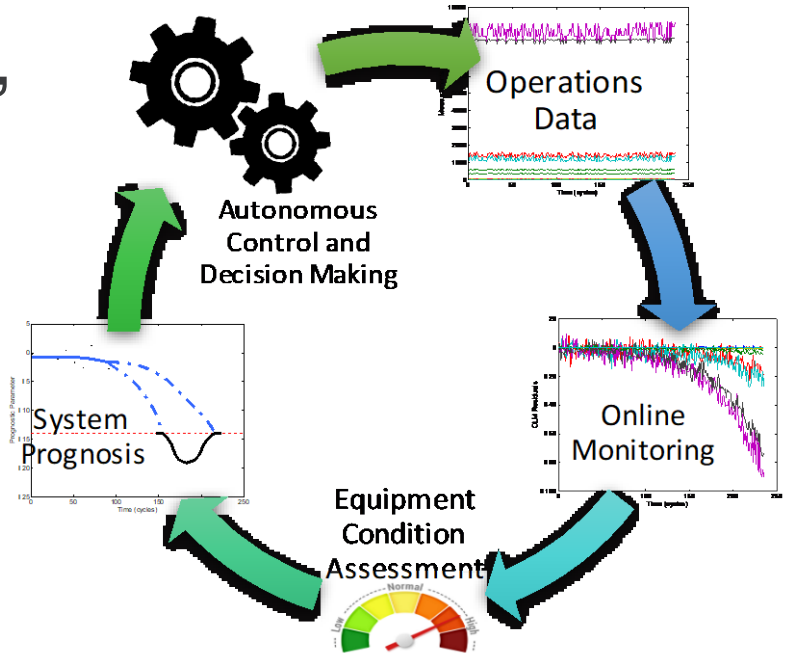
Prognostic results and accurate risk estimates can inform control algorithms or O&M planning

- PHM systems can provide a new maintenance paradigm for NPP
  - Leverage existing condition monitoring techniques
  - Inspection and maintenance activities can be planned based on condition, instead of conservative periodic schedules

- Lifetime of components or systems may be extended by changing the operating conditions
  - Extend life to a convenient maintenance opportunity
  - Trade-off between lifetime and productivity

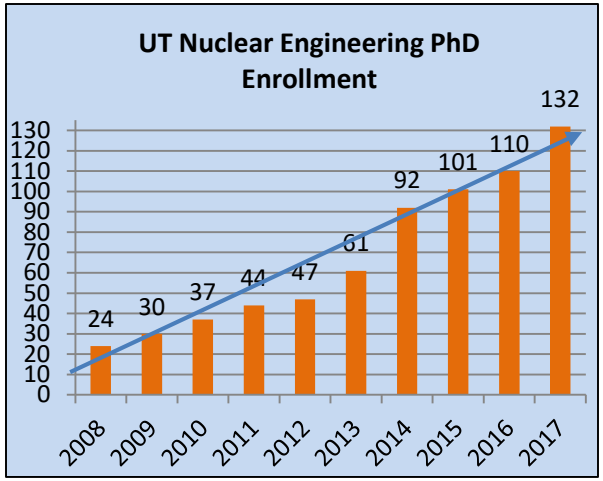
Future Research Directions

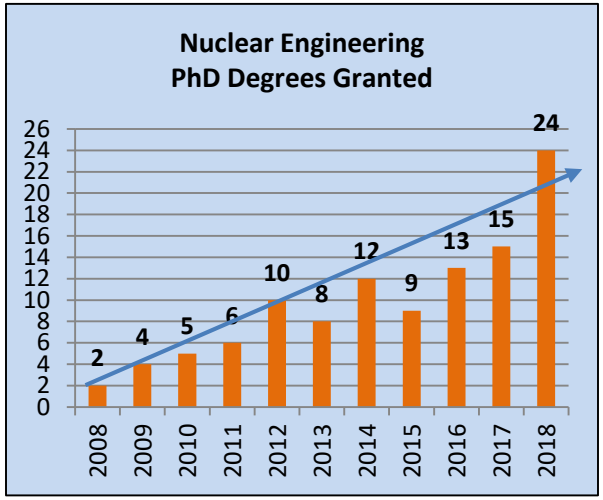
- Algorithms to mine information from **large data**
- Integration of PHM results into plant operations and maintenance planning, risk assessment, and risk-informed decision making
- Operations and control strategies for hybrid energy systems and co-generation



Growth in UTNE graduate education

- 2017: Largest Nuclear Engineering PhD enrollment in the history of the US for two years straight (110, 132)
  - Prior top: U.M. had 105 PhD students
- 2018: Largest Nuclear Engineering PhD graduating class in the history of the US (24)
  - MIT had 22 PhD graduates in 2014





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Questions?

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