PHM in the Nuclear Power Industry

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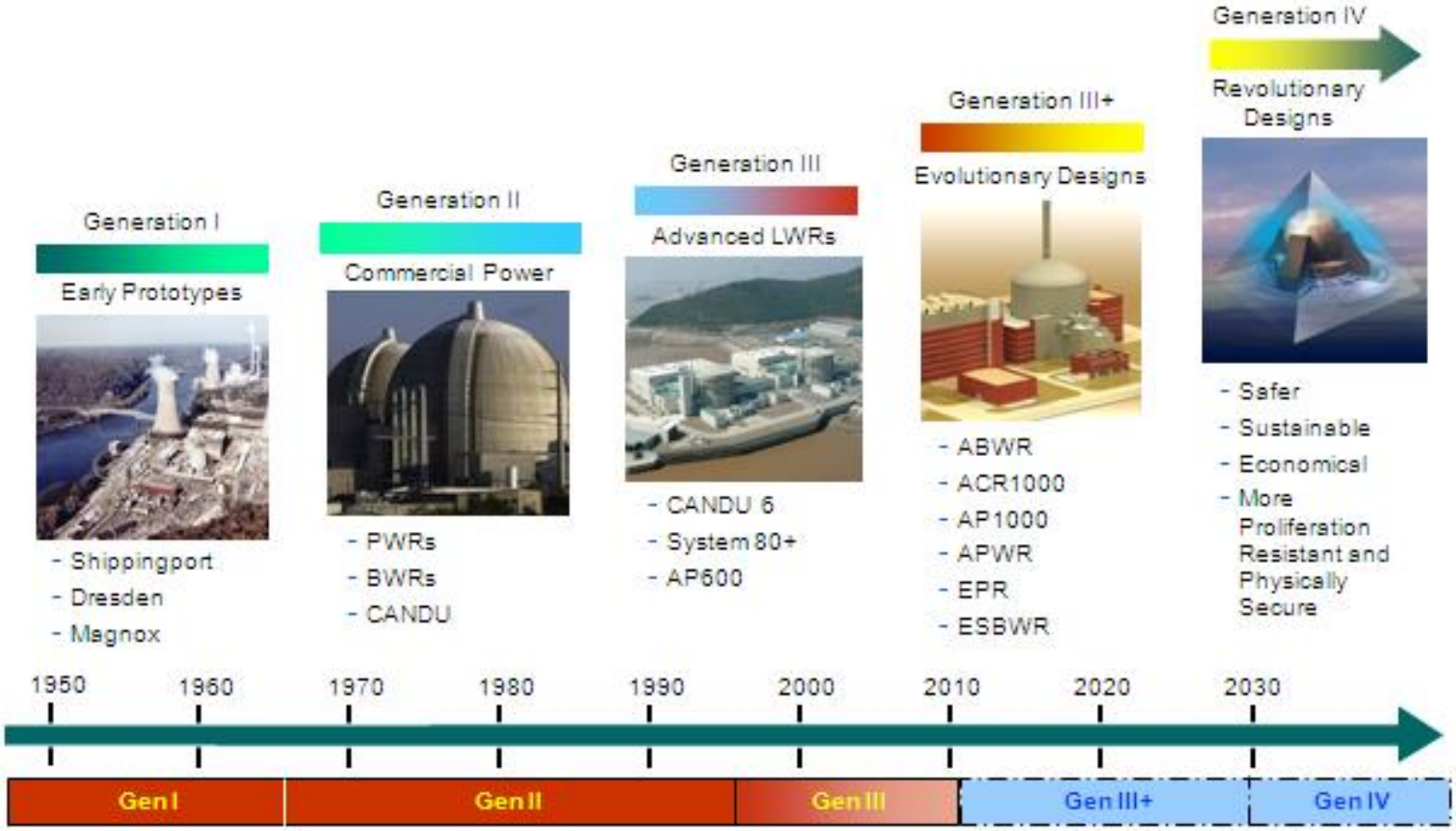
Jamie Coble
Assistant Professor, Nuclear Engineering
University of Tennessee

Why should we focus on Nuclear Power Plants?

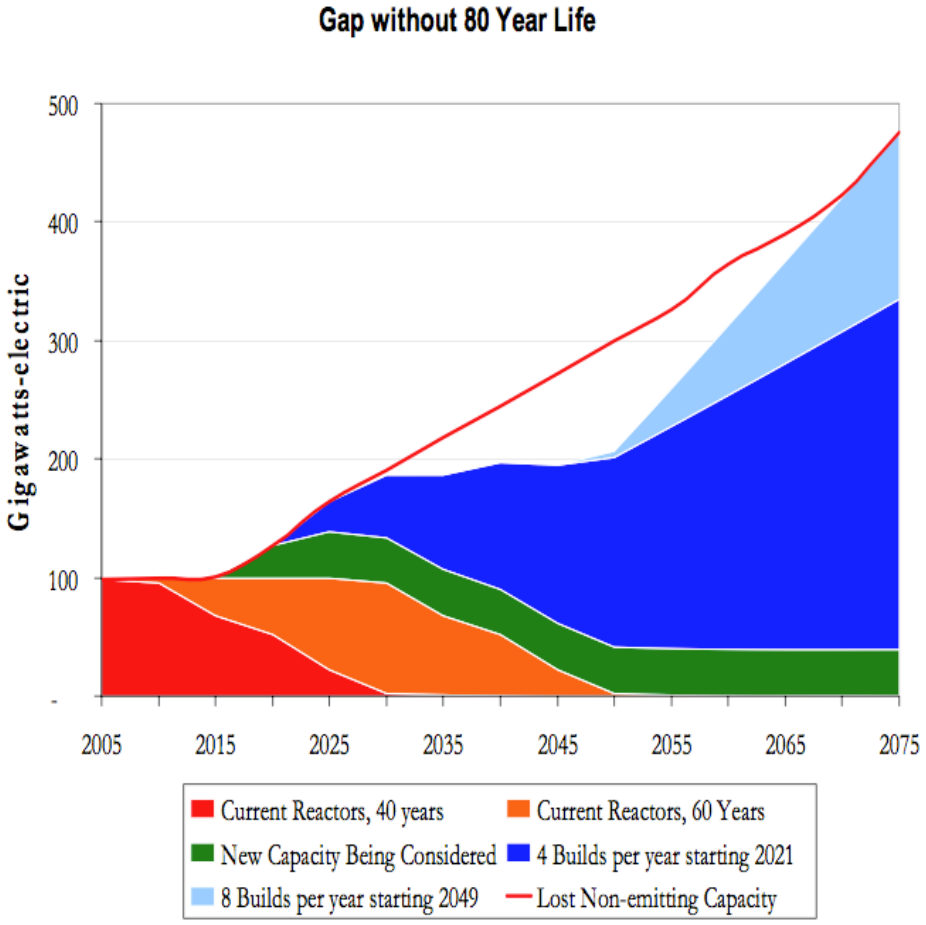
- Currently we have 449 operational NPPs worldwide
  - Produce ~13% of the world's electricity
  - Many are already operating beyond their original design life
  - Sixty additional plants are currently under construction
- Some future plant designs feature longer operating cycles
  - Fewer opportunities for inspection and maintenance
- Advanced reactor designs produce harsher operating conditions
  - Higher temperature and radiation levels, corrosive coolants, etc.

Nuclear power industry is not homogenous, but many underlying needs are common



For the next ten to fifteen years, PHM work will focus on light water reactor sustainability

- PHM information can be used to maintain safe, economic operation to 60 years and beyond
  - Make a case for life extension beyond 60 years
  - Identify key components for replacement and maintenance
  - Facilitate decisions about equipment replacement priority



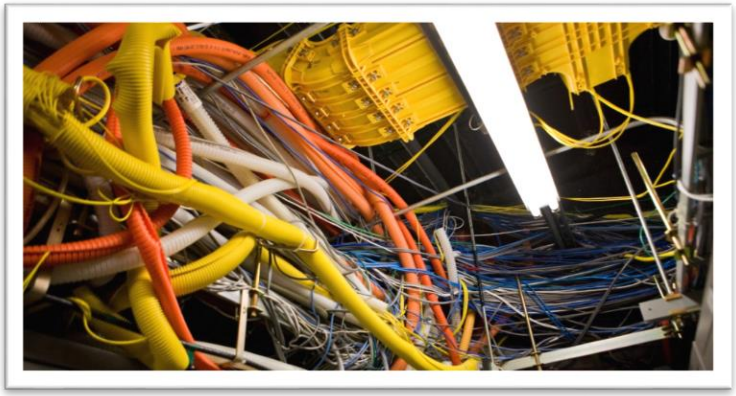
Key issues in life extension

Piping

Concrete Structures

Reactor Vessels

Large Components



Cables

The current approach to maintaining component health in NPPs

Active Components:

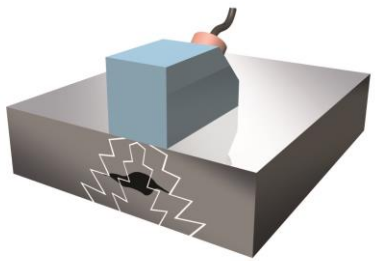
The Maintenance Rule

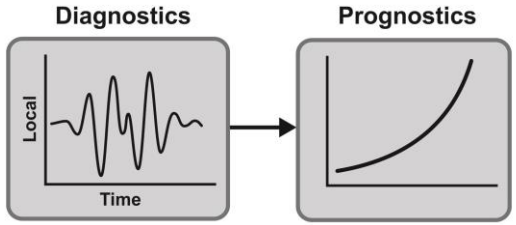
- Performance-based approach to equipment monitoring and maintenance
- Condition assessment methods (online and offline tests) are well developed for many key active components
- Currently a push to risk-informed regulation
  - May extend to O&M

Passive Components:

Aging Management Plans

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





Why do we need a new maintenance paradigm?

- O&M costs are 60-70% of generation cost in NPPs
  - 80% of O&M costs is labor
- Current approach does not encourage efficient (or discourage inefficient) maintenance practices
  - Unnecessary maintenance and inspection actions
  - Inspection period may increase to accommodate new degradation modes
- The same (or higher) safety margins can be maintained with fewer targeted maintenance actions

Current condition assessment does not satisfy the real needs of PHM 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 and advanced control algorithms

Research Opportunities

- General PHM research needs
  - Uncertainty quantification
  - Online performance metrics
  - Verification and validation methodologies
  - Prognostic algorithms for transient operation
- Research needs specific to NPPs
  - Sensors and measurements to assess condition
    - Measurement modes to detect degradation precursors
    - Long-lived, harsh environment sensors
    - Online, autonomous data collection
  - Optimal sensor placement and identification of high risk regions
  - High-fidelity physics of failure models
- Integration of PHM results into plant operations and maintenance planning, accurate risk assessment, and optimal control