Joint NRC and DOE Workshop on US NPP Life Extension R&D Issues

NDE to Prognostics: a review

Leonard J. Bond, Ph.D.,
Laboratory Fellow
Pacific Northwest National Laboratory

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Some past nuclear plant experience

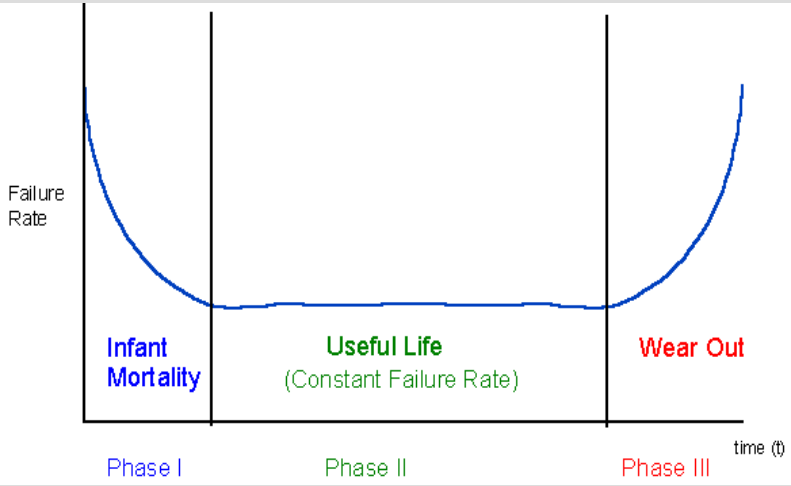
- Majority of component failures
  - Active components – e.g. valve not operating
  - Passive components – service degradation
- Active components managed through maintenance program
- Passive components managed through periodic inspection

Surprises – result from new degradation mechanisms

New programs and approaches being considered for "life-after-60"

Unit life cycle

- Start-up phase: faults related to installation and assembly
- Useful life phase: machine will be reliable as long as it is maintained and used within its design parameters.
- Wear-out phase: machinery reaches the end of its design life, and parts begin to fail more rapidly.



Some Definitions

- Degradation and ageing are terms used to describe both the deterioration of components -useful to distinguish between them.
- Degradation is immediate or gradual deterioration of characteristic of an SSC that could impair its ability to function within acceptance criteria.
- Ageing is general process in which characteristics of an SSC gradually change with time or use.
- When ageing processes are known, they can be allowed to monitor through an appropriate ageing management program (AMP) and plant life management (PLiM) program and potentially mitigated.

IAEA Proceedings Series (2005)

Mechanism classification

- Ageing degradation mechanisms are usually classified into two main categories:
  - Affect the internal microstructure or chemical composition of the material and thereby change its intrinsic properties (thermal ageing, creep, irradiation damage, etc.).
  - Impose physical damage on the component either by metal loss (corrosion, wear) or by cracking or deformation (stress-corrosion, deformation, cracking).
- Phenomenon of ageing degradation in NPPs are complex
  - requires sophisticated, state of science and technology procedures to effectively manage it and ensure safe, reliable operation.
  - not only technology is involved,
  - an effective management system is needed in order to correctly implement mitigative or monitoring actions.

IAEA Proceedings Series (2005)

Motivation for structural health monitoring

- Life extension & enhanced safety
- Local damage detection – NDT widely used
- NDE methods have difficulty when large areas need inspection and damage below surface
- More global damage, quantifiable and automated methods needed

Recent (2001) failure of offshore oil platform near Brazil

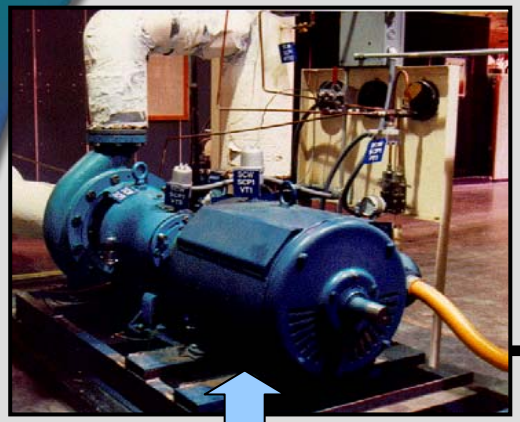
Aging & Life Extension to Prognostics

- **Nuclear power plant life extension (USA)**
  - 40-60 years developing since ~ 1972
- Chemical and process industries (MTI) looking towards on-line monitoring, wireless sensors etc.
- Long term stewardship of nuclear weapons
- Aging aircraft programs
- Energy efficiency and plant optimization
- Embedded diagnostics and prognostics
  - Military platforms
  - Aircraft VHM

Some Recent Developments and Meetings

- During Cold War military systems replaced due to obsolescence – NOT due to reaching end of service life.
- LIFE EXTENSION IS NOW REQUIRED for many military systems
- Pan American Advanced Study Institute on Damage Prognosis: October 2003
- DARPA Prognostics Program (2002) – Aero engines
- The Material Society Meeting – September '04
  - 3-day Damage Prognostics workshop
- MFPT Meeting (April 2005) – Theme:
  - Essential Technologies for Successful Prognostics
- 2nd Int Symp Nuclear Power Plant Life Management (IAEA)
  - Shanghai, China, October 2007
- 2nd Int Symp – Aging Management & Maintenance PPP's (ISaG2008)
  - Tokyo Japan – July or August 2008
- International Conf. on Prognostics and Health Management
  - October 6-9, 2008 IEEE Reliability Society

Condition Based Maintenance



Stressor Applied

Time =>

Degradation Zone

Preventive Maintenance Zone

Predictive Maintenance Zone

FAILURE

No Failure

Life Cycle

Proactive Operations and Maintenance Zone

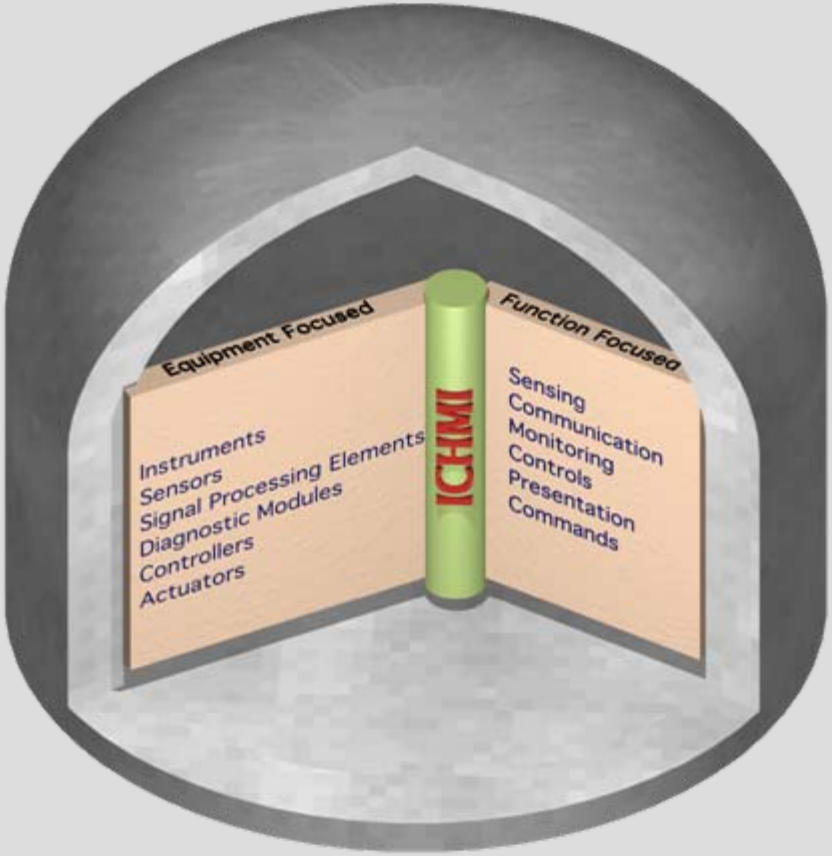
Prediction and Planning

Mitigation and Repair

Fix What Broke

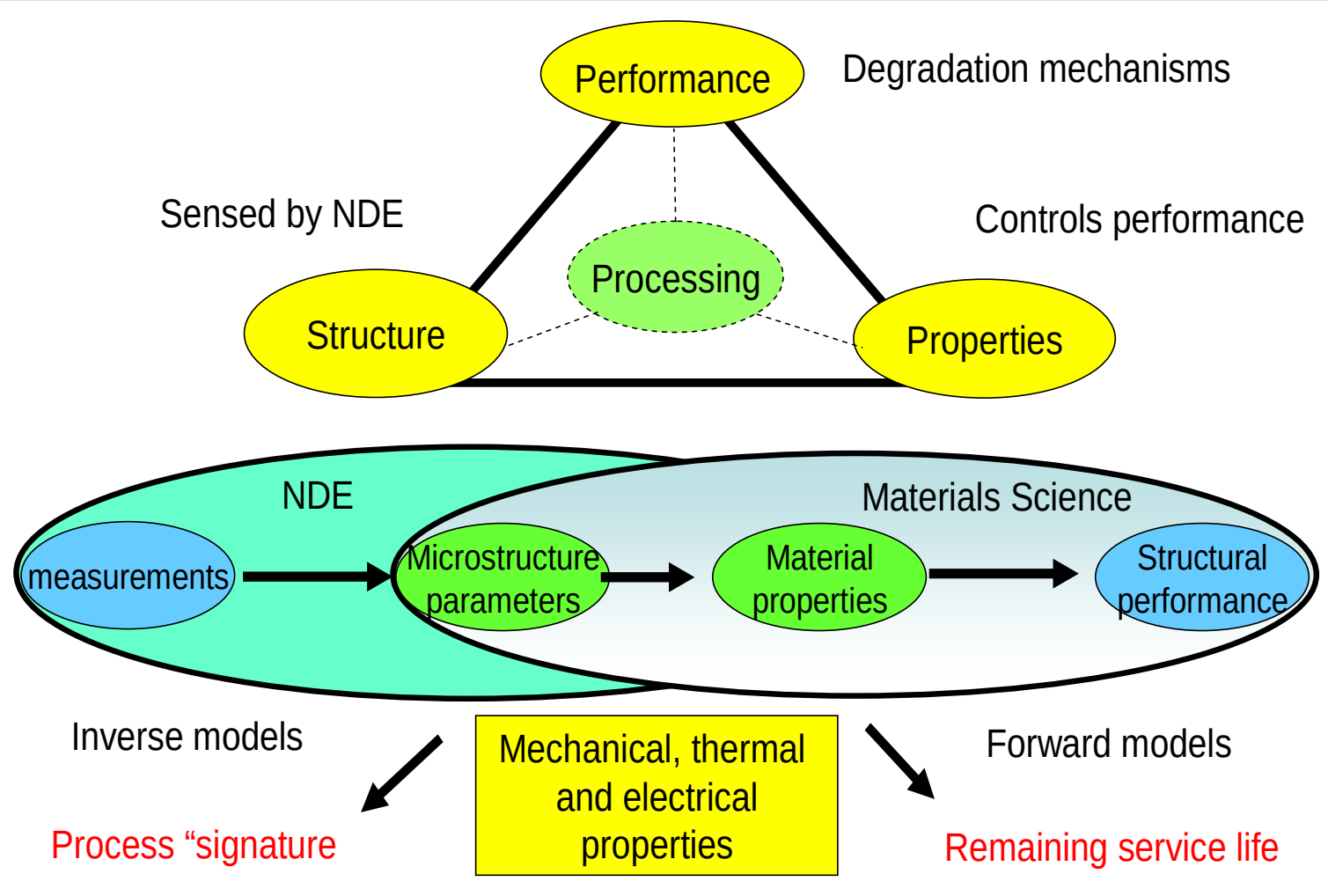
Motivation for structural health monitoring

- Periodic NDE methods challenged by aging systems – frequency of inspection and inspection technology need to be reviewed in light of known degradation mechanisms
- Condition-based maintenance philosophies, on-line monitoring and diagnostics can reduce O&M costs
- Digital systems give enhanced functionality

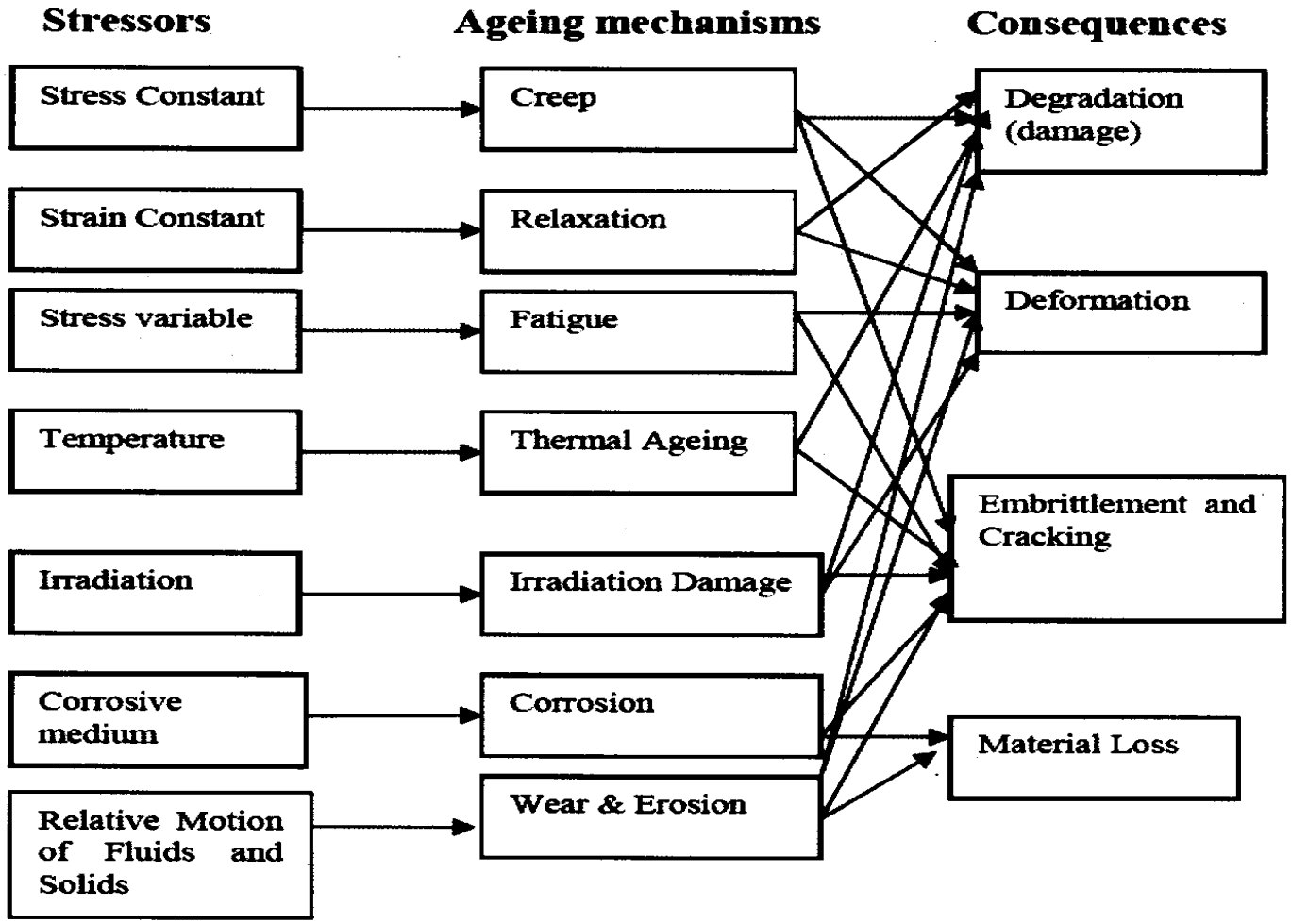


Nuclear Power Plant Systems:
ICHMI – Instrumentation Controls – Human Machine Interface

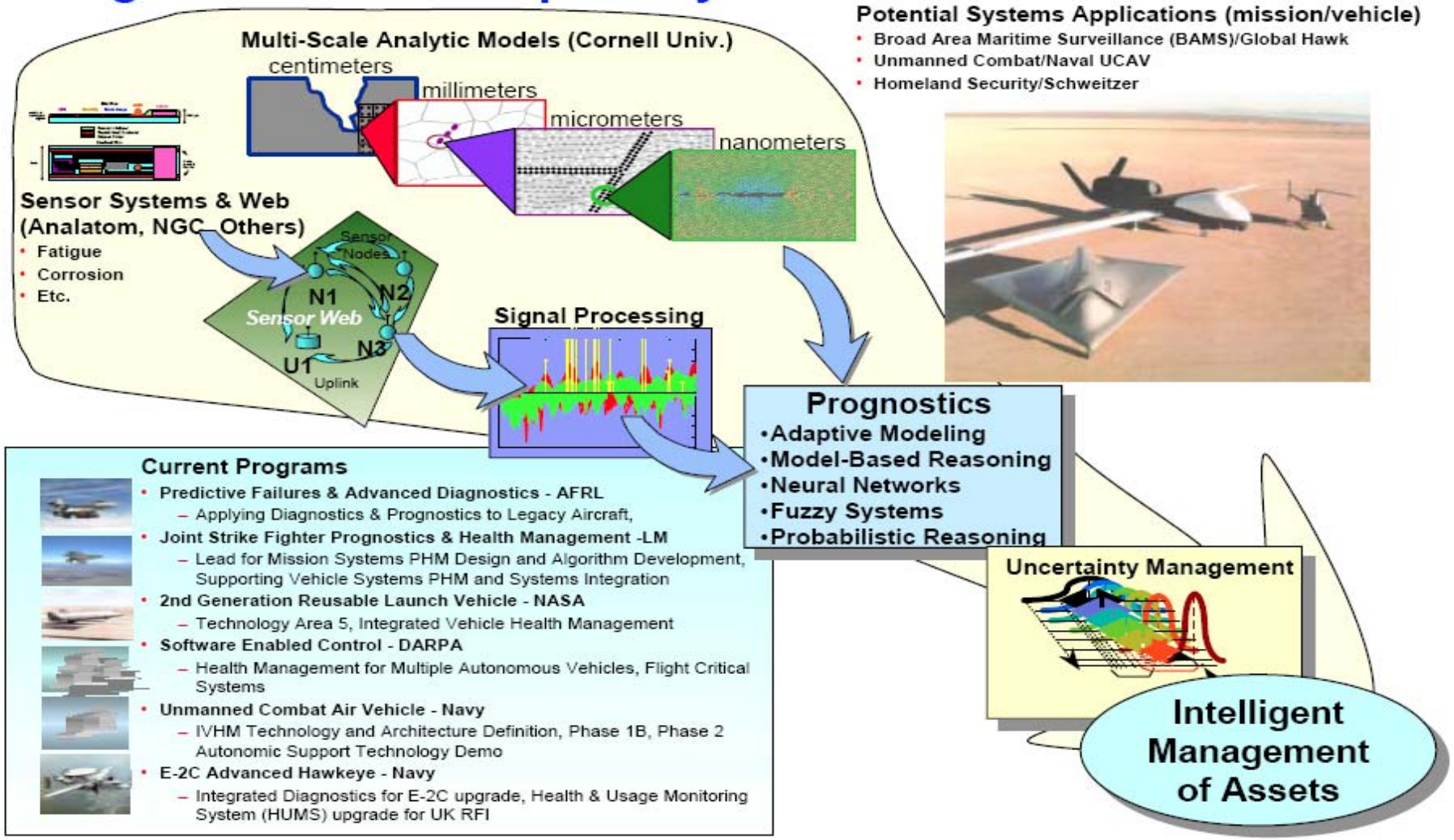
Advanced monitoring



Aging factors, mechanisms and possible consequences

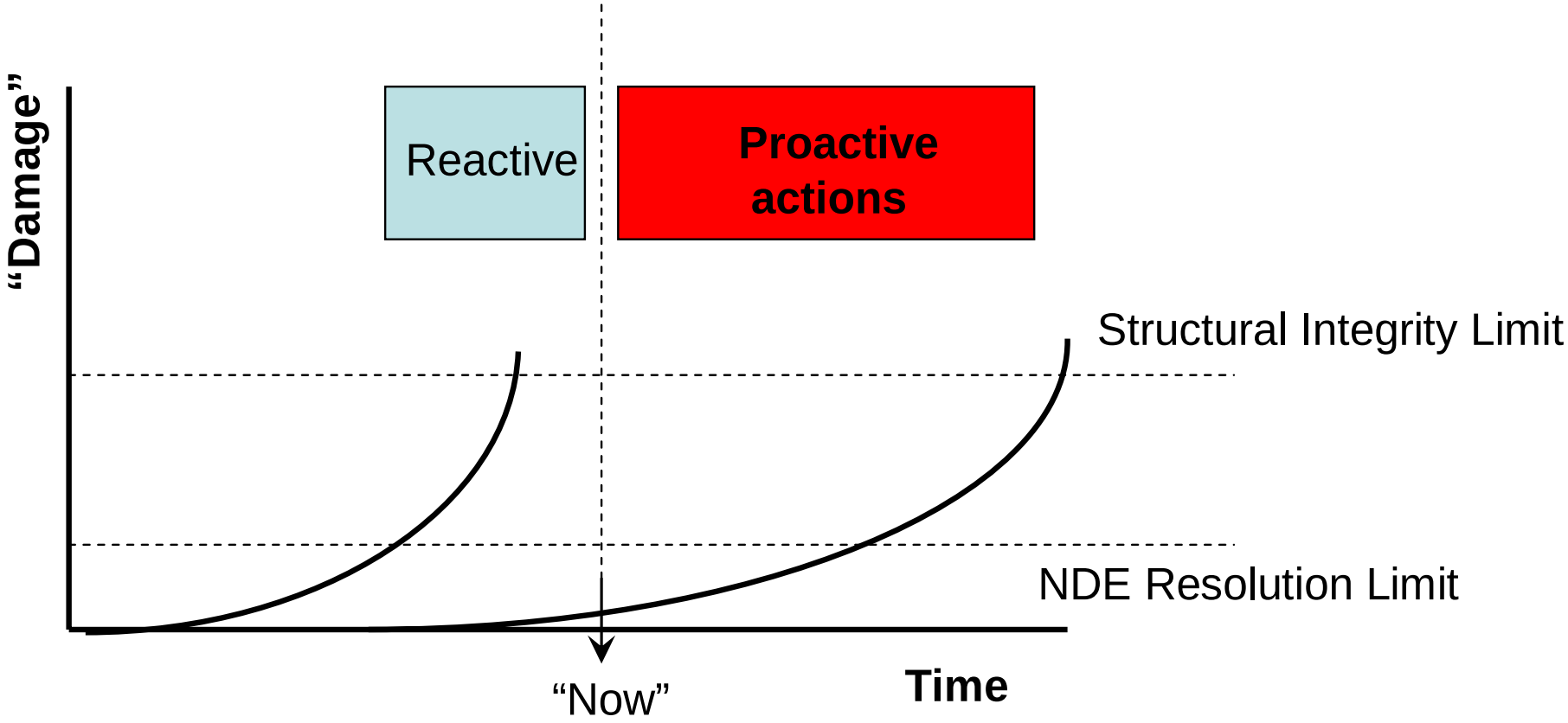


Northrop Grumman AEW/EW Bethpage
Prognostics for Aerospace Systems



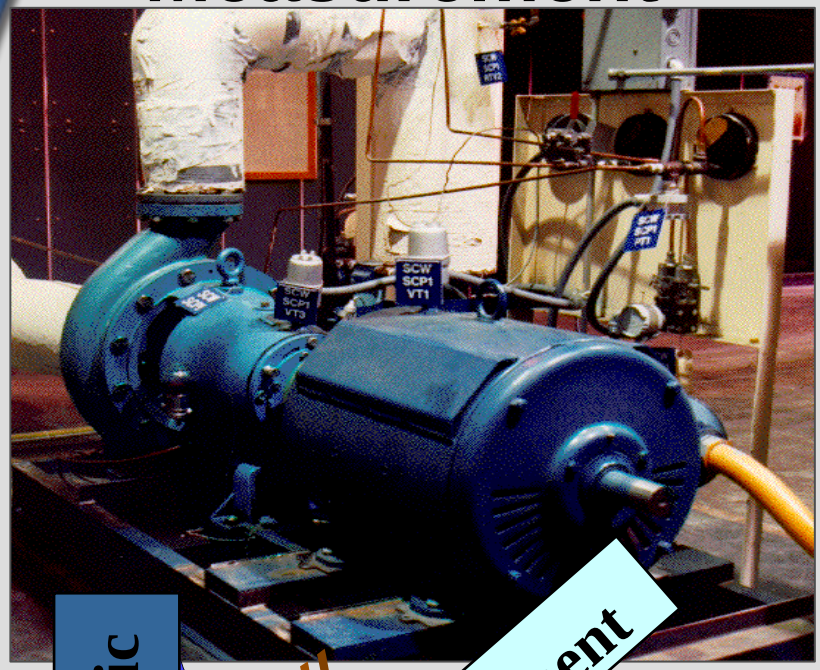
EXAMPLE FROM DARPA WEB SITE

Move from “reactive” to “pro-active”



Component Health Prognostics

Stressor Measurement



Acoustic

Alignment

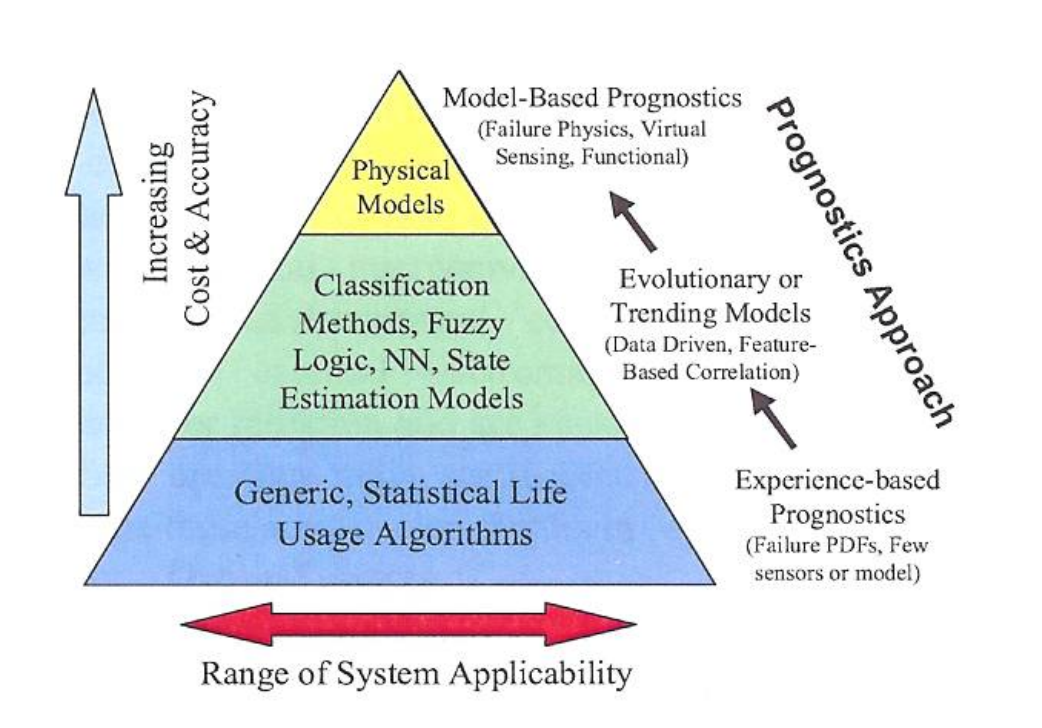
Sensor Fusion

NDE to Prognostics

- NDE performed at time of fabrication and as in-service inspections
- Condition based maintenance – active component monitoring
- Move from diagnosis to prediction of remaining life and structural health monitoring/management
- Prognostics (for machinery) is the prediction of a remaining safe or service life, based on an analysis of the system or material condition, stressors and degradation phenomena

Prognostics for Systems and Components

- Health monitoring
- Time to failure
  - Thermal cycling
  - Radiation damage
  - Fatigue
- Unit and component analysis



Diagnostics and Prognostics: technology base maturity matrix

Diagnostic/Prognostic Technology For:	AP	A	I	NO
Basic Machinery (motors, pumps, generators, etc.)	D		P	
Complex Machinery (Helicopter Gearboxes, etc.)		D	P	
Metal Structures	D		P	
Composite Structures			D&P	
Electronic Power Supplies (Low Power)		D	P	
Avionics and Controls Electronics	D		P	
Medium Power Electronics (Radar, etc.)		D		P
High Power Electronics (Electric Propulsion, etc)				D&P

D – Diagnostics: P - Prognostics

- AP – technology currently available and proven effective
- A - technology currently available, but V&V not completed
- I – technology in process, but not completely ready for V&V
- NO – No significant technology development in place

[Howard (2005)]

Advanced technical challenges…

- Sensing: what to measure and how to measure
- Data interrogation, communication and integration
- Predictive models (e.g. damage evolution)
- System integration and deployment on real-world hardware
- *Quantification of uncertainty* – (ill-posed problems)
- Integration of prognostics into plant operation and O&M approach

Prognostics - Technical Challenges

<u>Need:</u> Detect, monitor, and characterize degradation severity to drive a cost effective proactive O&M AND PREDICT REMAIN USEFUL/ECONOMIC PLAN LIFE/OPERATION.

- Smart components and structures
- Self-diagnostic systems
- Embedded Micro-Electromechanical Systems (MEMS) (and other) health monitoring sensors
- Wireless communication
- Distributed data processing and control networks
- Prognostics implementation
- Advanced NDE technologies
- Proactive operations and maintenance program

What everyone wants!

"Tricorder"

Prognostic technologies being used in other industries & ready to deploy

Conclusions

- Many researchers working on Structural Health Monitoring / condition-based maintenance and prognostics
- In most cases Structural Health Monitoring and Prognostics have not transitioned from research to engineering practice
- Few are bring ALL the requisite technologies together and then advancing these in a synergistic manner
- On-line monitoring and advanced diagnostics has the potential:
  - reduction in mandated surveillances,
  - more accurate cost-benefit analysis,
  - “just-in-time” maintenance,
  - pre-staging of maintenance tasks,
  - moving towards true “operation without failures”
- USA 104 legacy systems: deployment of on-line monitoring and diagnostics has potential for savings at over $1B per year when applied to all key equipment (to 60 years)
- Prognostics is a “Grand Challenge” for the engineering community to address in the 21st century – that is VITAL for optimization of operation of next generation energy and process plant systems