PSA R&D: Changing the Way We Do Business?*

N. Siu

ANS International Topical Meeting on Probabilistic Safety Assessment (PSA 2017)
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*The views expressed in this presentation are not necessarily those of the U.S. Nuclear Regulatory Commission

Introduction

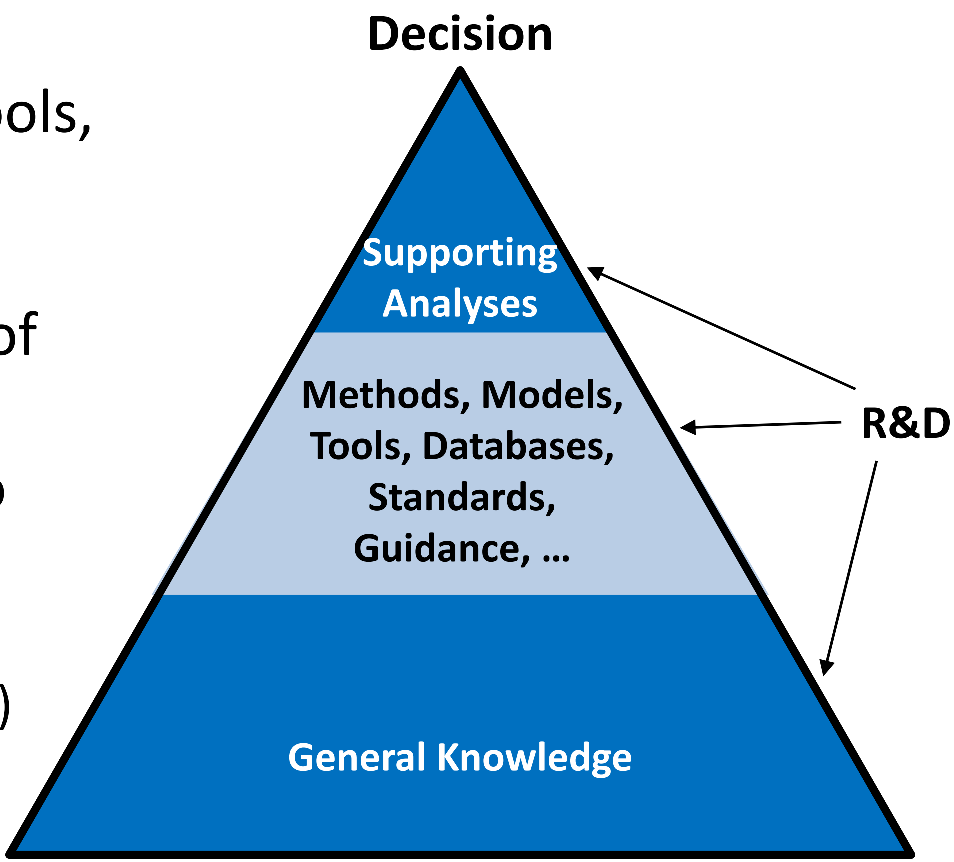
- This talk
  - Provides some personal, pragmatic views on R&D intended to support Risk-Informed Decisionmaking (RIDM) in the nuclear industry
  - Addresses formulation, practice, and support of R&D;* not a catalog of topic areas
  - Presented in two parts
    - General R&D context
    - Remarks for different PRA communities (developers, analysts, users)
- And about that title…

*In the remaining slides, the focus on RIDM support is understood

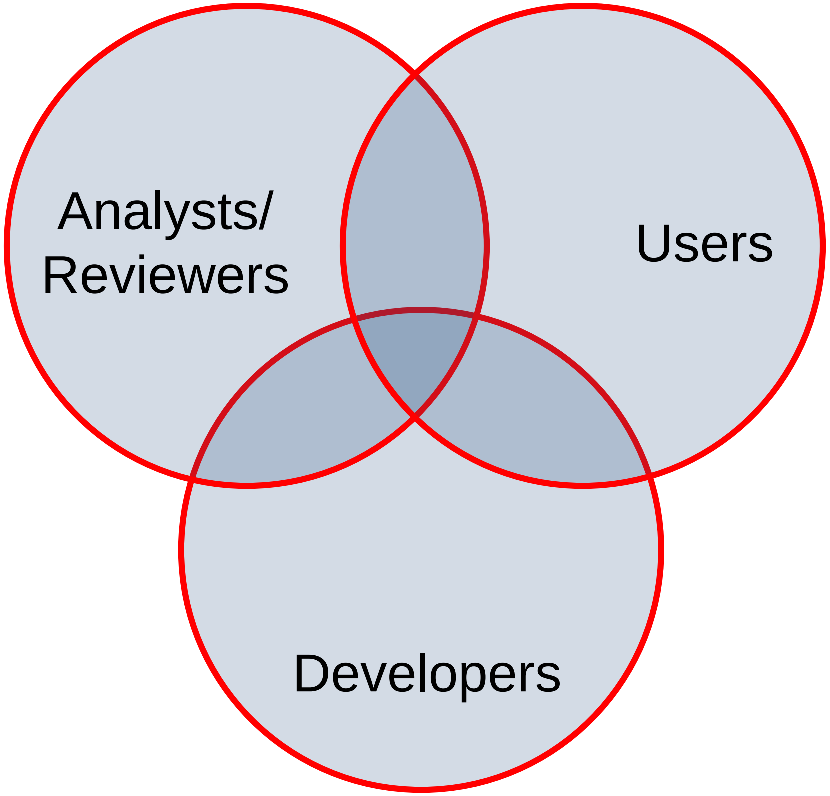
R&D CONTEXT AND PERSPECTIVES

R&D: A Broad Enterprise…

- Provides technical advice, tools, and information to meet organizational needs
- Broader than development of theory and methods
- At NRC, includes activities to support
  - Decisions on specific issues
  - Infrastructure (standards, etc.)
  - Understanding (context for decisions)
  - Communication with stakeholders



…with Multiple Stakeholders



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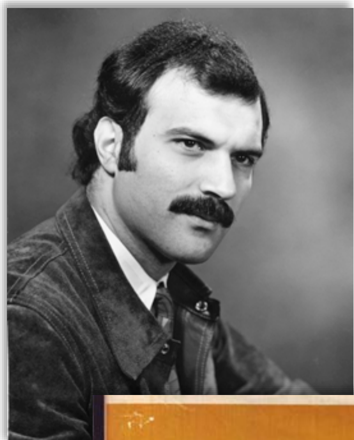
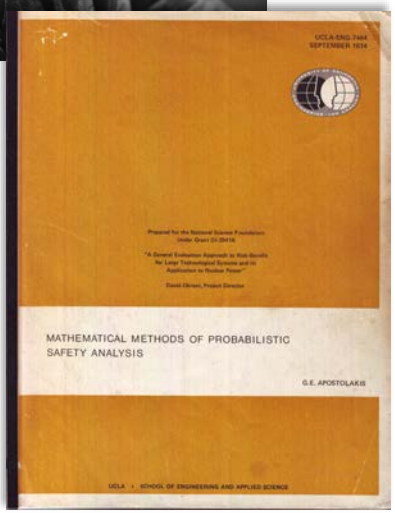
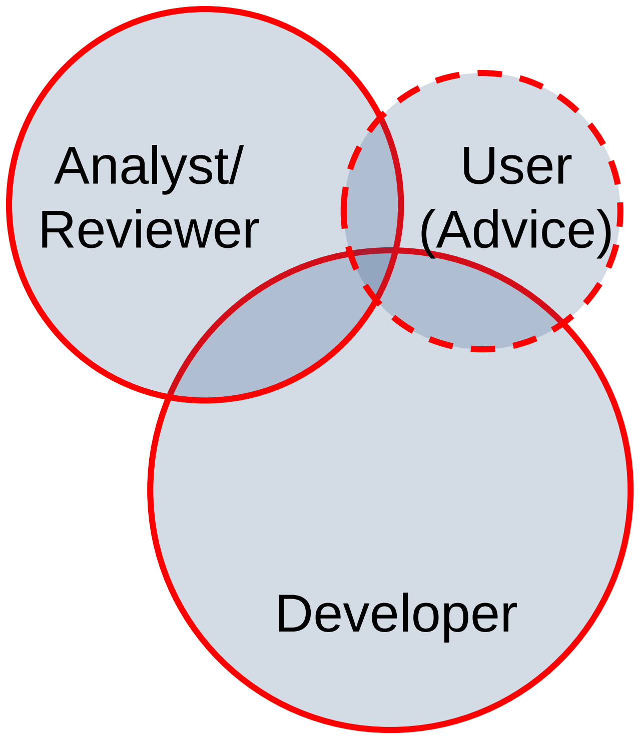
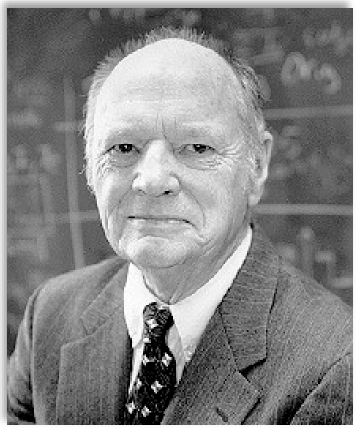
Personal Background => Perspectives









Dynamic R&D Environment

- Needs
  - "New" events/findings
  - "New" technologies/designs
  - Increasing demands on PRA technology
  - ***Risk-informed applications (current plants)***
- Resources
  - Computational infrastructure
  - ***Demographics***
  - ***Budget***

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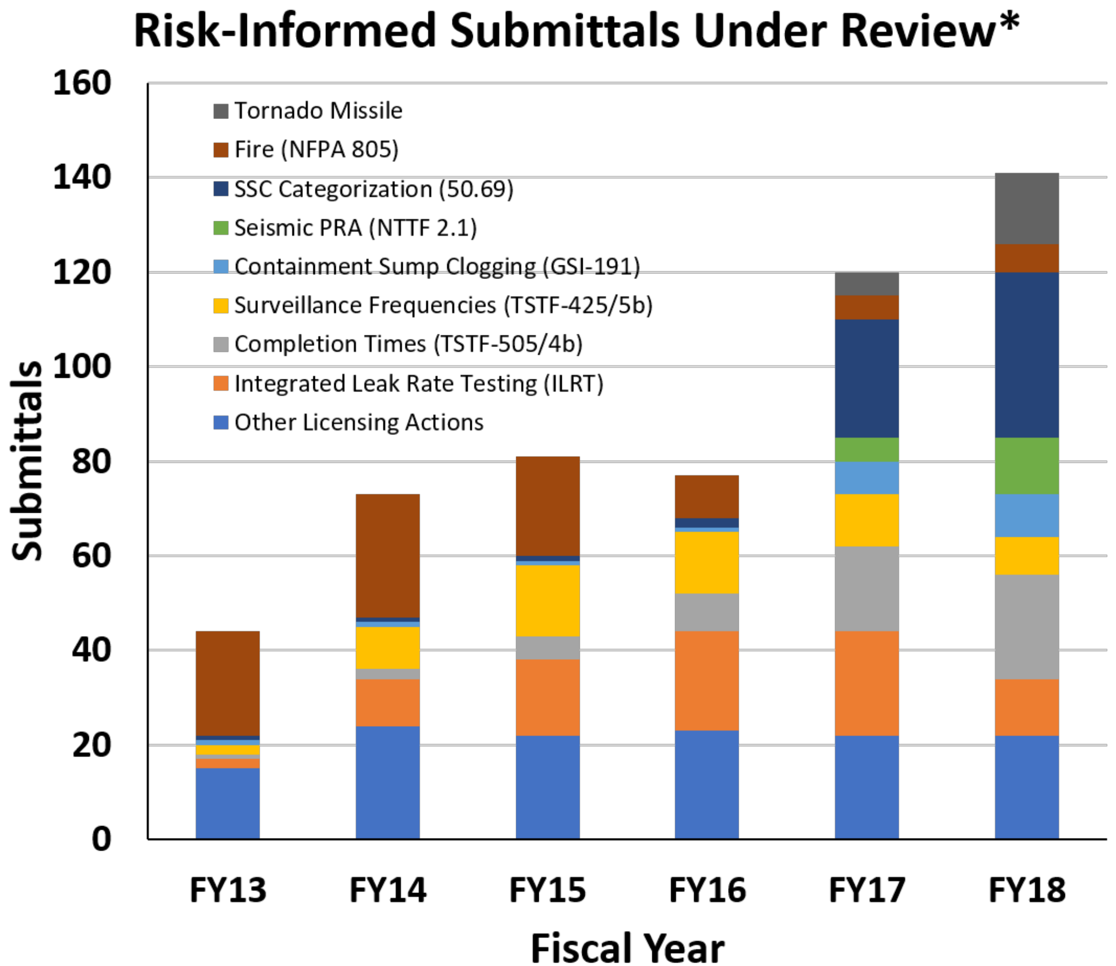
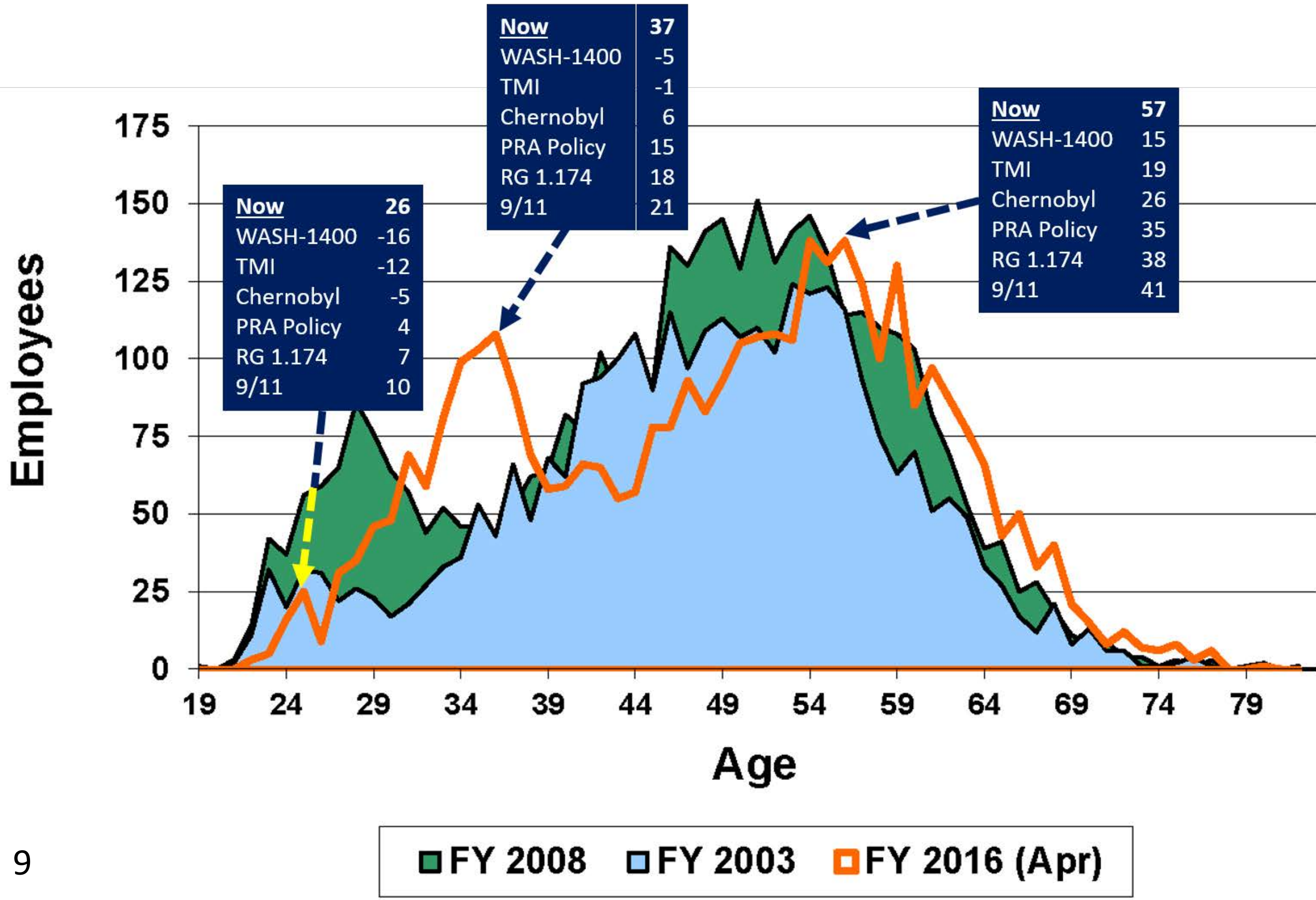
Dynamic R&D Environment - Applications

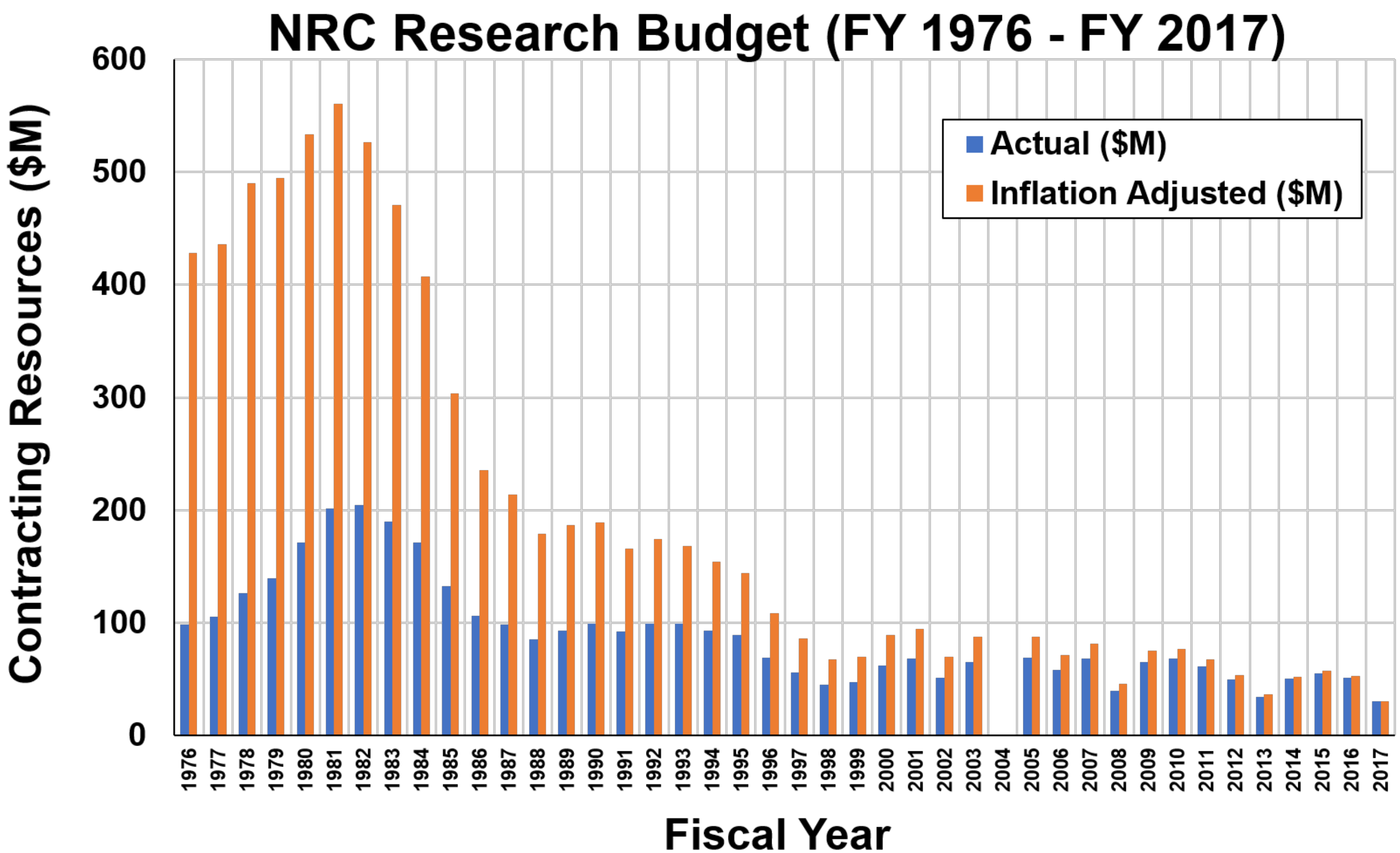


*As of April, 2017; estimates subject to change.

Dynamic R&D Environment – Demographics



Dynamic R&D Environment – RES Budget



Data from NUREG-1350 (NRC Information Digest)

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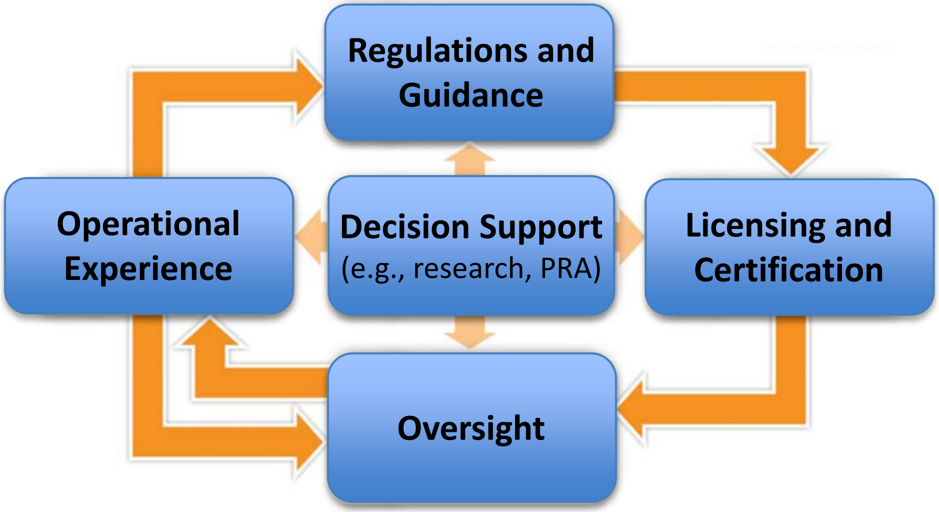
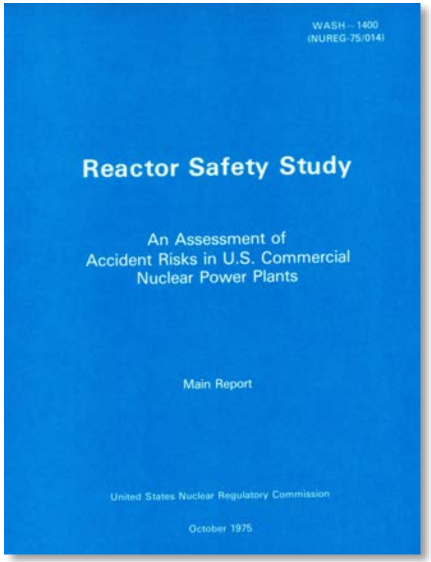
Assumptions

"We hold these truths to be self-evident…"

- Risk-related Regulatory R&D (R4&D) has been and continues to be a necessary component of a healthy nuclear enterprise
- R4&D products need to be implemented to affect safety
- There will continue to be challenges in R4&D
- No one community has all of the answers



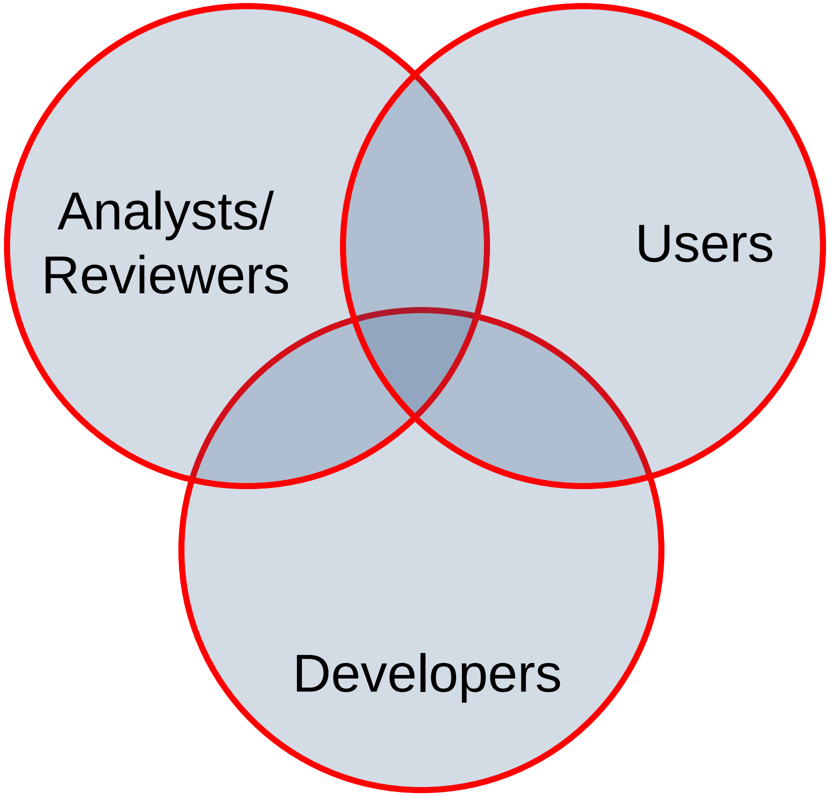


R4&D STAKEHOLDERS

Discussion Framework

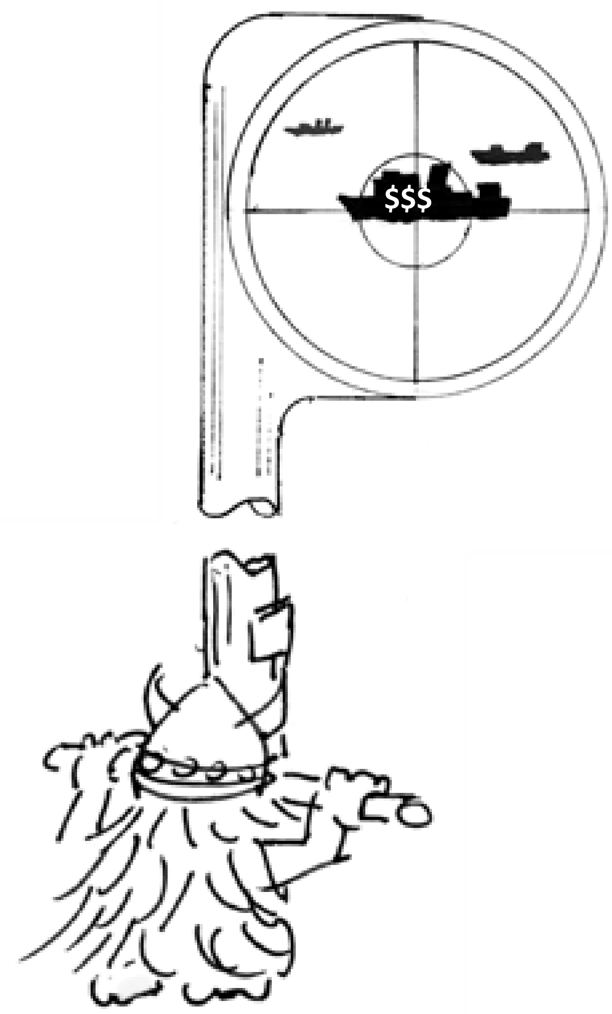
Sub-communities that are the focus of remarks

- Developers: academic community
- Analysts/Reviewers: PRA model builders
- Users: decision makers



Developers

- Typical challenges
  - Academic contribution
  - Nexus between personal and external interests
  - Support (esp. with declining budgets!)
- R4&D solutions include
  - Frameworks, methodologies, conceptual demonstrations
  - ***N+1 projects***



Technology-Driven vs. Issue-Driven R4&D
Is it "Hammer Time"?

- A common (and valid) research strategy

  {*New Tech**} + {"*Interesting*" *Problem*} => {*Research Topic*}

- (Of course) beware
  - Force-fitting the problem to match the new tech
  - Problems not truly requiring the new tech's special capabilities
  - Problems of tangential importance to major risk drivers

*Technology = {methods, models, tools}

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Big Data: Prognostics and Reliability

An N+1 Example

- Concept: use field data and physics of failure models to anticipate failures and develop prevention strategies
- "Formula 1" races
  - Heavily instrumented cars
  - Engineering models
    - Real-time support during race
    - Empirically calibrated through testing
    - ~100 supporting staff at home office
  - Miniscule performance Δ => major effects

A. Gilbertson, 2016

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Big Data: Prognostics and Reliability

23 sec video: 2016 US Grand Prix

Race footage courtesy of A. Gilbertson

<u>COTA Turn 15</u>
Entry speed ~210 km/h
Speed at apex ~84 km/h
Braking distance ~30m
Braking power ~800 kW
Load ~3g

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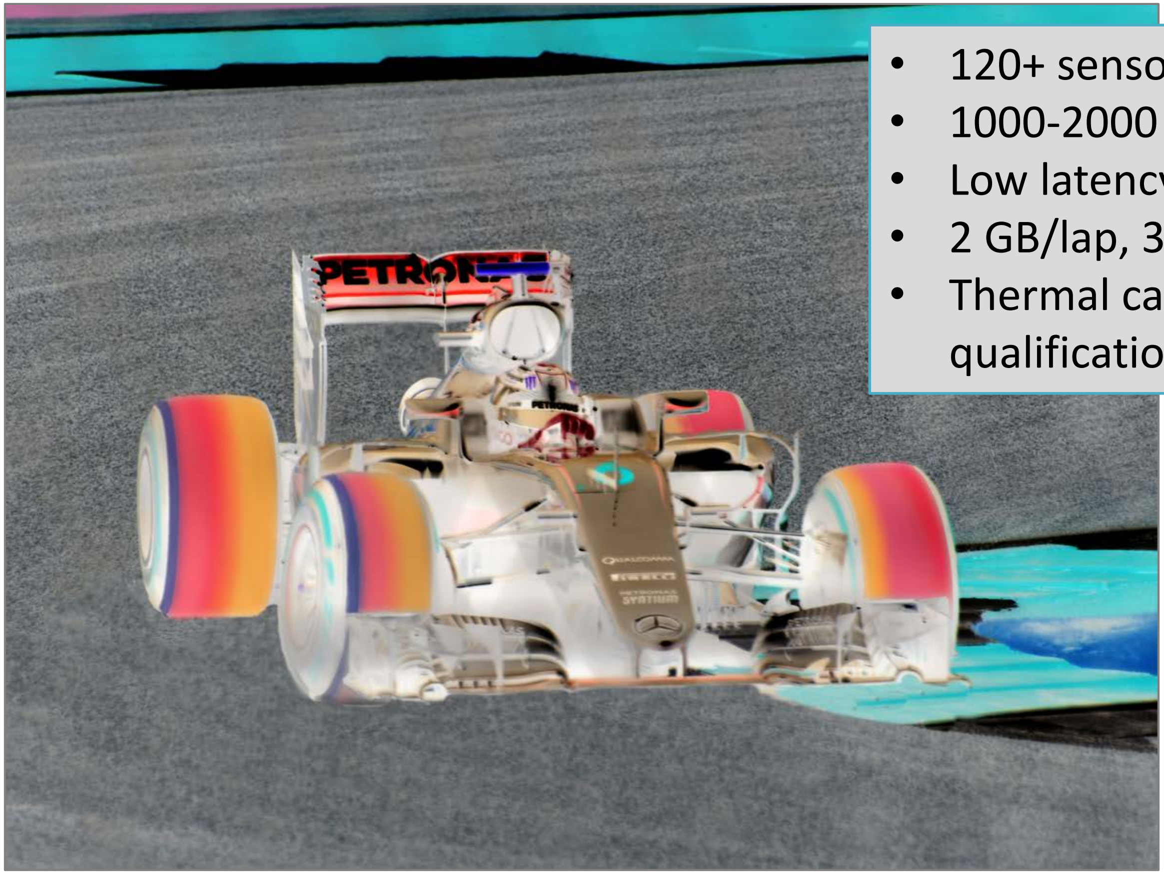
Big Data: Prognostics and Reliability



- 120+ sensors (car and driver)
- 1000-2000 wireless channels
- Low latency – o(ms)
- 2 GB/lap, 3 TB/race
- Thermal cameras during qualification

Big Data: Prognostics and Reliability
Will it work for R4&D?

- Engineering models
  - Empirically calibrated through testing
  - Predict performance and wear over time
  - Used to develop/modify race strategies
  - Models don't cover all factors
    - Road debris
    - Other drivers
- In a NPP application, what risk-significant failures would be caught by an analogous system?

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Big Data: Prognostics and Reliability

Some Old But Interesting Events

Year	Plant	Feature
1975	Browns Ferry	Cable fire affects multiple units
1985	Hatch	HVAC water falls into MCR panel; SRV cycles, sticks open
1993	Cooper	External flood, one evacuation route blocked
1997	Fort Calhoun	Steam line rupture, intermittent electrical grounds
1999	Blayais	High wind and external flood affect multiple units, site access
2001	Maanshan	High energy arc fault, station blackout

Big Data: Prognostics and Reliability

Multi-Unit Precursor Events

Date	Plant	Description
6/22/82	Quad Cities	LOOP, Maintenance
8/11/83	Salem	LOOP, Clogged screens
7/26/84	Susquehanna	SBO, Bkr mis-aligned
5/17/85	Turkey Point	LOOP, Brush fires
7/23/87	Calvert Cliffs	LOOP, Offsite tree
3/20/90	Vogtle	LOOP, Truck hit support
8/24/92	Turkey Point	LOOP, Hurricane
12/31/92	Sequoyah	LOOP, Switchyard fault
10/12/93	Beaver Valley	LOOP, Offsite fault
6/28/96	LaSalle	Trip, Foreign material in SW Tunnel
6/29/96	Prairie Island	LOOP, High winds

Date	Plant	Description
8/14/03	6 Sites	LOOP, NE Blackout
6/14/04	Palo Verde	LOOP, Offsite fault
9/25/04	St. Lucie	LOOP, Hurricane
5/20/06	Catawba	LOOP, Switchyard fault
3/26/09	Sequoyah	LOOP, Bus fault
4/16/11	Surry	LOOP, Tornado
4/27/11	Browns Ferry	LOOP, Winds/tornadoes
8/23/11	North Anna	LOOP, Earthquake
3/31/13	ANO	LOOP/Trip, Load drop
4/17/13	LaSalle	LOOP, Lightning
5/25/14	Millstone	LOOP, Offsite fault

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Big Data: Prognostics and Reliability

How Do Things Fail? (Service Water)

"the station declared all Core Standby Cooling Systems (CSCS), Emergency Core Cooling Systems (ECCS), and Diesel Generators (DG) inoperable due to foreign material identified on the floor of the service water tunnel…Although the systems were declared inoperable, they were available. The foreign material was an injectable sealant foam substance which had been used … in the Lake Screen House (LSH) to seal water seepage cracks." (LER 373/96-008)

"…manual reactor shutdown … conservatively initiated ... due to concern for the safety and well being of a diver working in the … Unit 2 circulating water pump house discharge piping … communications with one diver was [sic] lost and the retrieval efforts by a second and third diver were initially unsuccessful in reestablishing contact.. The plant equipment and systems … worked as designed. The divers were unharmed." (LER 266/00-001)

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Big Data: Prognostics and Reliability
An Alternate/Complementary Line of R4&D?

Investigation Committee on the Accident at Fukushima (7/23/2012): "*TEPCO lacked a sense of urgency and imagination toward major tsunami, which could threaten to deal a fatal blow to its nuclear power plants.*"

- Searching is fundamental to PRA:
  - First question of risk triplet: "What can go wrong?"
  - PRA Procedures Guide and ASME/ANS PRA Standard
- Sparse data, beyond design-basis concerns => imagination needed
- Operational experience can fuel, temper, and support imagination
  - Massive, unstructured databases
  - How to better use?

E. De Fraguier, "Lessons learned from 1999 Blayais flood: overview of EDF flood risk management plan," U.S. NRC Regulatory Information Conference, March 11, 2010.

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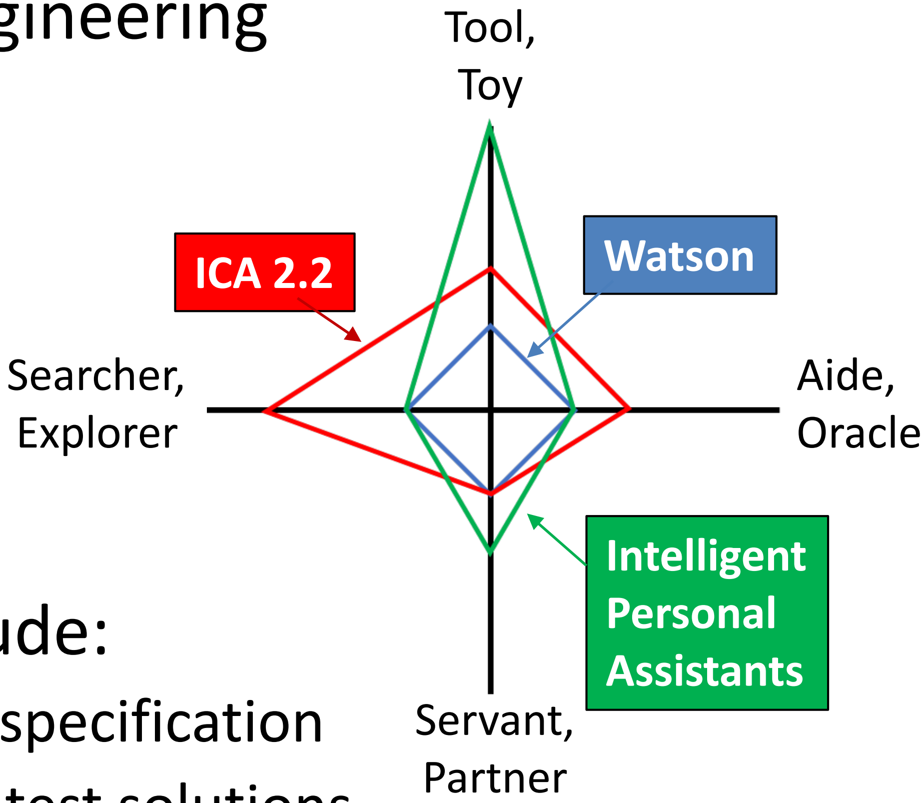
Big Data: Prognostics and Reliability
"Mr. Watson come here, I want you."

- Advanced knowledge engineering technologies can help
- IT challenges include:
  - Faulty data
  - Embedded structure
  - Machine learning
  - Speed
- PRA user challenges include:
  - "Use case" identification, specification
  - Working with IT: develop, test solutions



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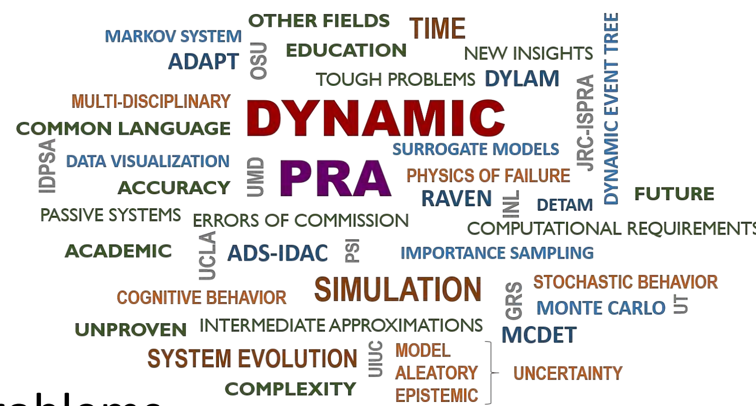
Analysts/Reviewers

- Typical challenges
  - Need near-term solutions: heavy time/budget pressure
  - Huge problem size and complexity
  - Multiple technical communities/cultures
  - State of technology: Too much/little diversity, “Holes”
- PRA solutions include
  - “Tried and true”; ***reluctance to try new approaches***
  - Engineering judgment
  - Completeness uncertainty

Reverse ageism in the PRA community

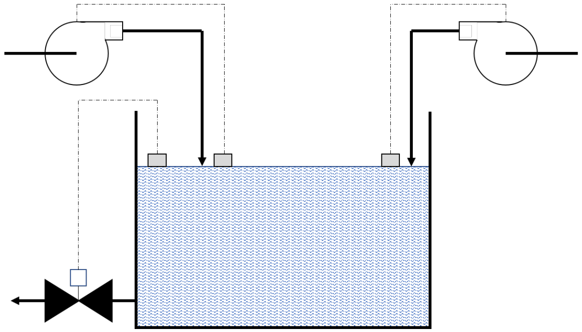
Dynamic PRA: What and Why

- Literal view: explicit treatment of time
- More broadly: explicit treatment of dynamic phenomena (simulation-based)
- Potential advantages include
  - Direct ties to other science/engineering models (with usual V&V)
  - Elimination of intermediate modeling approximations
  - Natural language for interdisciplinary enterprise
  - Consistent with external tech world
  - Most direct approach to some tough problems
  - Academically rewarding



Dynamic PRA: Why Not

- Dynamics not key issue for many problems
- Models can be complex:
  - Resource-intensive (construction, validation, computation, analysis/sensemaking)
  - Inscrutable (at least to practitioners)
  - Vulnerable to sub-model applicability limits
  - Massive output, but information?
- Long gestation, in early phase of maturity
  - Starting to expand from academic centers
  - Few real applications of full-power tools
  - Reward system has likely inhibited search for simple but practical applications



The Aldemir Tank

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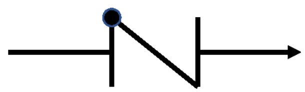
Dynamic PRA: An Opportunity Missed?

- Object-oriented simulation: long history, fully developed general technology
  - Operations Research and “System dynamics”
  - Military simulations and supporting tools
  - Considered but rejected for general PRA quantification (aleatory uncertainty)
  - Highly limited, demonstration-oriented NPP PRA applications (power recovery)
- Basis for advanced Vulnerability Assessment tools
- Well-suited for FLEX?



Case	Process Input	Initial State	Final State	Process Output
1	-	Failed closed	Failed closed	No
2	No	Closed	Closed	No
3	Yes	Closed	Failed closed Open	No Yes
4	No	Failed open	Failed open	No
5	Yes	Failed open	Failed open	Yes
6	No	Open	Failed open Closed	No No
7	Yes	Open	Open	Yes

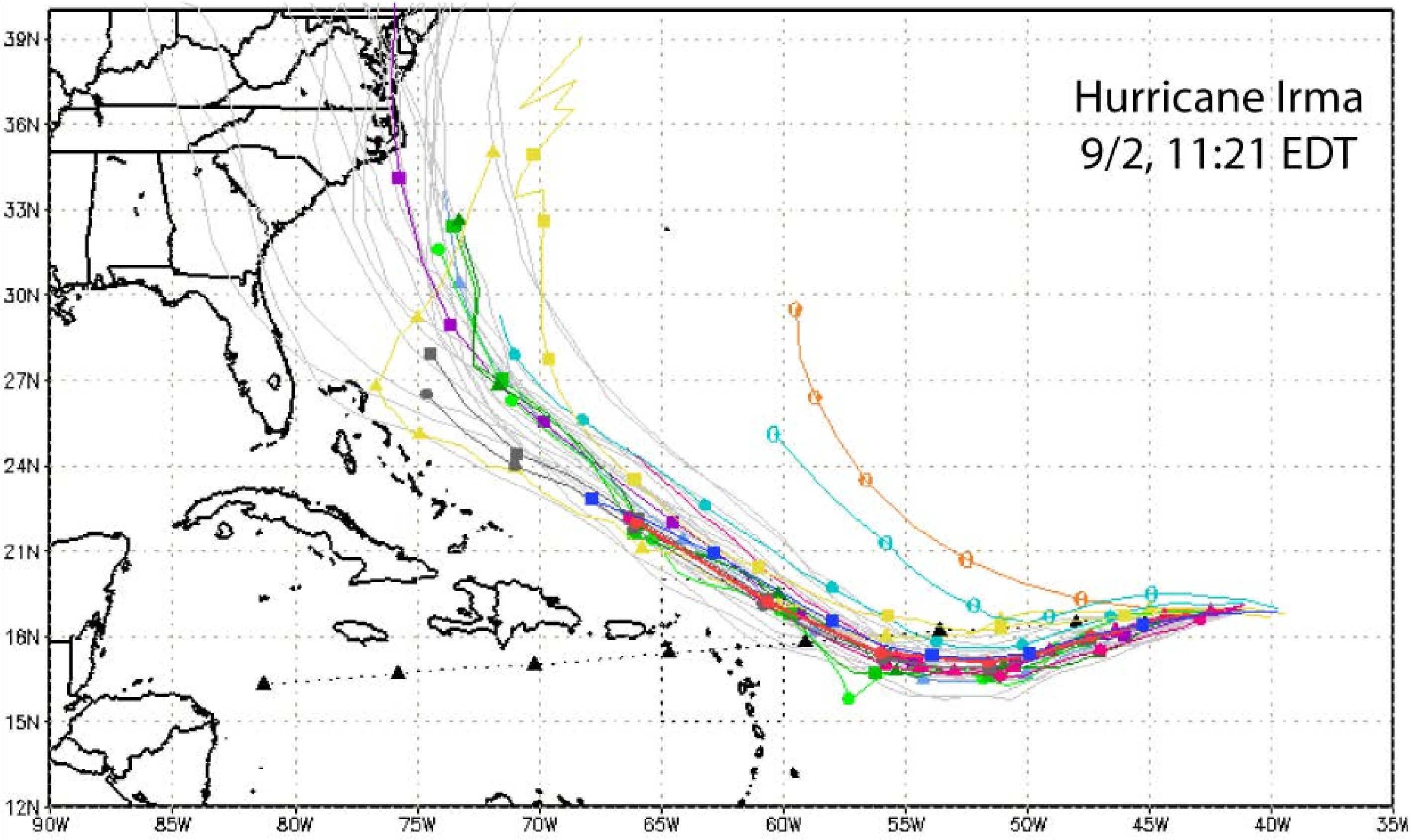
Fire PRA: From Research to Application

- Following 1975 Browns Ferry fire
  - NRC supported fire PRA R&D at UCLA and RPI
  - Methodology and tools used in industry-sponsored PRAs
  - Approach used in NUREG-1150
  - Formed basis for guidance
  - Currently continuing improvements on piece parts
- Success factors
  - Real problem
  - NRC and industry involvement
  - Researchers directly involved in application

Users

- Decision maker challenges include
  - Managing/leveraging resources
  - Prioritizing needs and activities
    - Short- vs. long-term
    - Organizational
    - Multiple stakeholders
  - Difficult decisions
    - Technical complexity
    - High uncertainty, diverse views
    - Multi-variate
- A key adviser challenge: communication

Communication Challenges: Model Uncertainty



Communication Challenges: Model Uncertainty

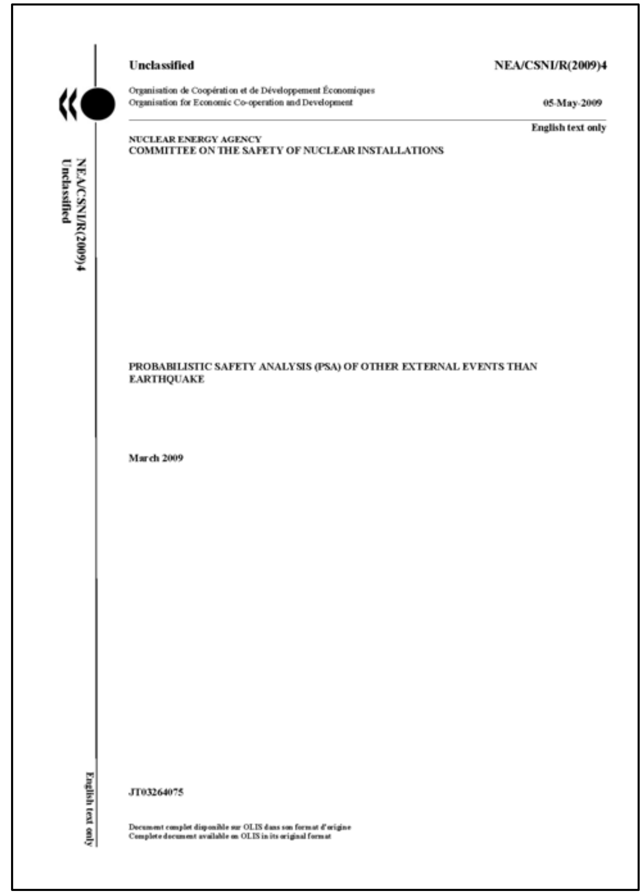
- Model uncertainty is important and real
- Some R4&D questions
  - Ensemble "better" than best estimate + sensitivities? Under what conditions?
  - How important is it to understand the technical reasons for model-to-model variability?
  - Ensemble doesn't necessarily capture (revealed) reality: what to do when all options have significant costs and potential consequences?

"If anything on these products causes confusion, ignore the entire product."

http://my.sfwmd.gov/sfwmd/common/images/weather/plots.html

Communication Challenges: Gatekeeping

- Pre-Fukushima WGRISK report on external hazards PSA
  - Varied country responses
    - Some treatment for internal events (CCF, LOOP, LOHS)
    - Research on some hazards (seismic, typhoon)
    - Some with no special considerations
  - Topic, findings, or recommendations not provided in Conclusions
- Omission: lack of actionable message
- R4&D question: When (under what circumstances) should we boost the signal? How? [see Blayais]


Unclassified NEA/CSNI/R(2009)4

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development 05-May-2009

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2009)4
Unclassified

PROBABILISTIC SAFETY ANALYSIS (PSA) OF OTHER EXTERNAL EVENTS THAN EARTHQUAKE

March 2009

JT03264075

English text only

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

Communication Challenges: Unintended Messages

How not to start an R4&D program…

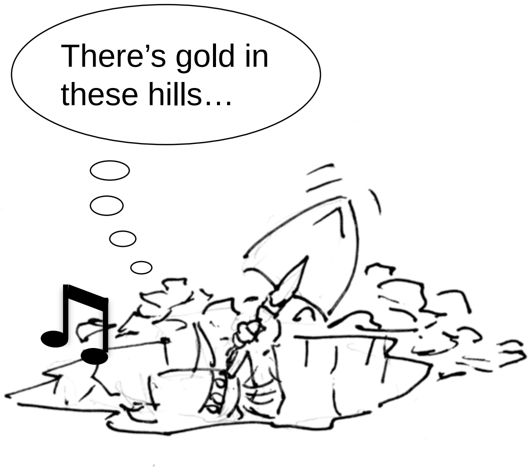
ID	Fire PRA "Issue"	ID	Fire PRA "Issue"
I1	Adequacy of fire events database	P1	Circuit interactions
I2	Scenario frequencies	P2	Availability of safe shutdown equipment
I3	Effect of plant operations, including comp measures	P3	Fire scenario cognitive impact
I4	Likelihood of severe fires	P4	Impact of fire induced environment on operators
E1	Source fire modeling	P5	Role of fire brigade in plant response
E2	Compartment fire modeling	R1	Main control room fires
E3	Multi-compartment fire modeling	R2	Turbine building fires
E4	Smoke generation and transport modeling	R3	Containment fires
H1	Circuit failure mode and likelihood	R4	Seismic/fire interactions
H2	Thermal fragilities	R5	Multiple unit interactions
H3	Smoke fragilities	R6	Non-power and degraded conditions
H4	Suppressant-related fragilities	R7	Decommissioning and decontamination
B1	Adequacy of data for active and passive barriers	R8	Fire-induced non-reactor radiological releases
B2	Barrier performance analysis tools	R9	Flammable gas lines
B3	Barrier qualification	R10	Scenario dynamics
B4	Penetration seals	R11	Precursor analysis methods
S1	Adequacy of detection time data	R12	Uncertainty analysis
S2	Fire protection system reliability/availability	O1	Learning from experience
S3	Suppression effectiveness (automatic, manual)	O2	Learning from others
S4	Effect of compensatory measures on suppression	O3	Comparison of methodologies
S5	Scenario-specific detection and suppression analysis	O4	Standardization of methods

42 = 1 [year]

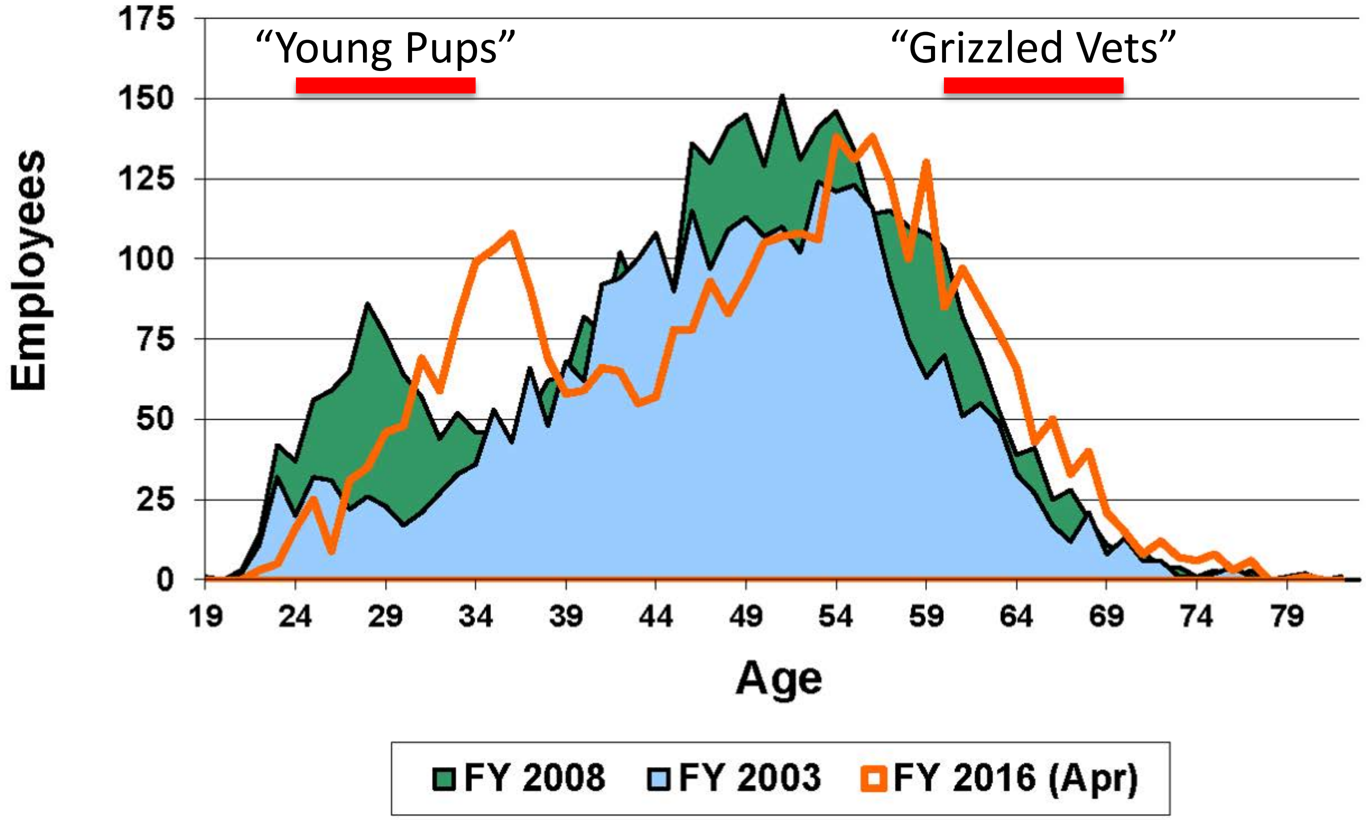
From: N. Siu, J.T. Chen, and E. Chelliah, "Research Needs in Fire Risk Assessment," NUREG/CP-0162, Vol. 2, 1997.

Closing Remarks

- R4&D has helped change the way we do business
- Continuous improvement + changing times => some suggestions
  - Developers: Dig a little deeper
  - Analysts/reviewers: Give ‘em a chance
  - Advisers: Be like Sherlock



Give ‘Em a Chance [2]



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ADDITIONAL SLIDES

Dynamic R&D Environment – Industry Needs*

- Finding Closure
- Risk-Informed SSC Categorization (50.69)
- Risk-Informed Completion Times (TSTF-505)
- Fire PRA Realism
- Methods Vetting
- Aggregation
- Realism in Reactor Oversight Process
- FLEX in Risk-Informed Decision Making

*From public meeting of NRC and Industry Risk-Informed Steering Committees, April 13, 2017 (ML17104A315)

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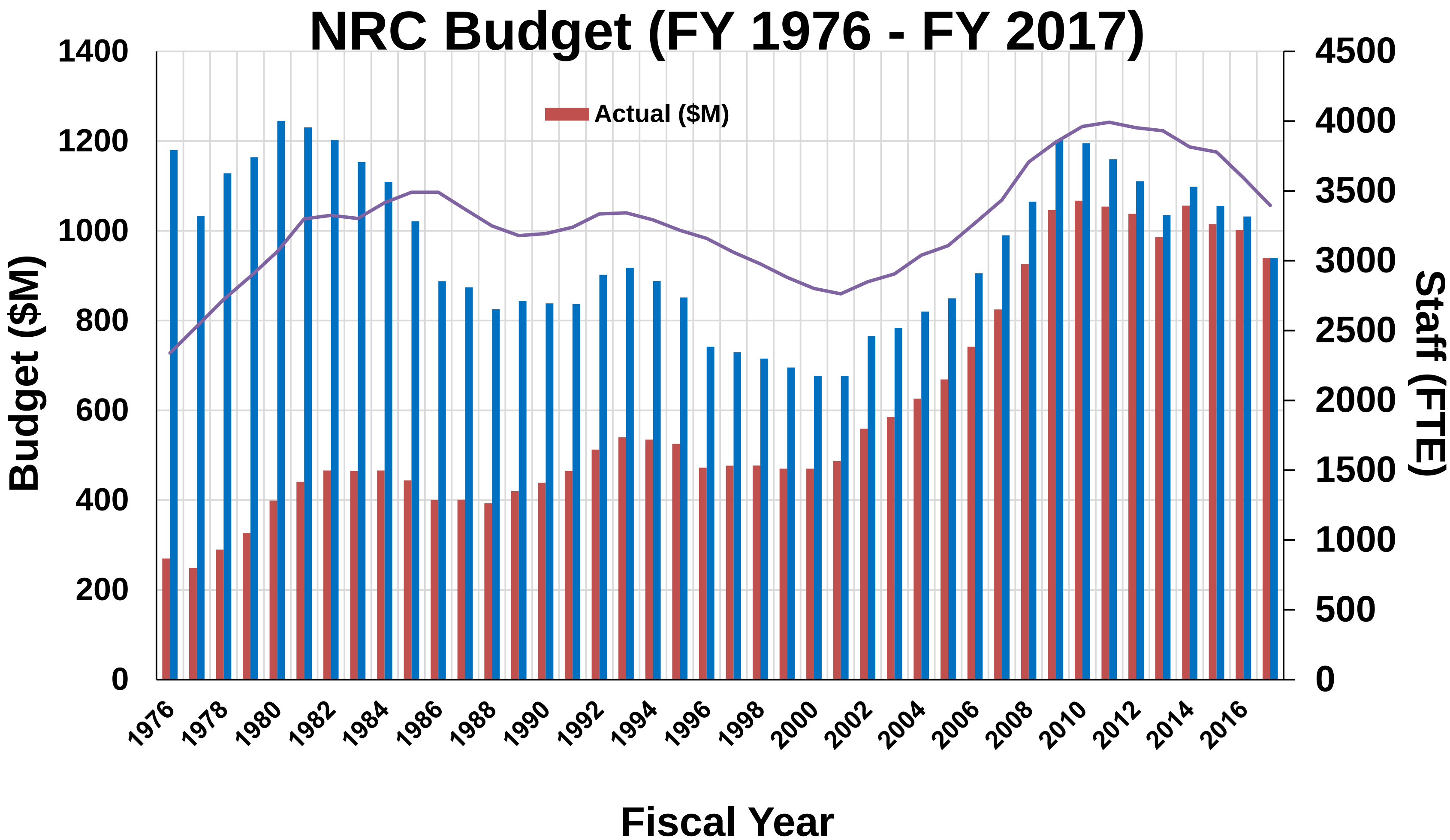

Data from NUREG-1350 (NRC Information Digest)

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Big Data: Prognostics and Reliability

How Do Things Fail? (Power)

"…both units tripped automatically from 100% power following a Loss of Offsite Power (LOOP) event. The event began when a fault occurred internal to a current transformer associated with one of the switchyard power circuit breakers. A second current transformer failure, along with the actuation of differential relaying associated with both switchyard busses, cleared both busses and separated the units from the grid... The root cause analysis … determined that … certain switchyard relay tap setting changes were not implemented." (LER 413/06-001)

"…Units 1 and 2 received an automatic reactor trip on reactor coolant pump (RCP) buses undervoltage. A loss of Common Station Service Transformer (CSST) C caused a loss of power to two unit boards on each unit that feed RCPs… The cause of the bus fault was determined to be degraded bus bar insulation and water intrusion into the CSST D secondary bus duct." (LER 327/09-003)

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Historical View on Searching
"PRA Procedures Guide," NUREG/CR-2300 (1983)

- The search for dependent failures should be performed as described in Section 3.7 and incorporated as appropriate into the plant and system models.
- A preliminary systems analysis can thus be a vital step in the search for initiators, helping to ensure completeness in the definition of accident sequences.
- Another approach is to more formally organize the search for initiating events by constructing a top level logic model and then deducing the appropriate set of initiating events.
- A systematic search of the reactor-coolant pressure boundary should be performed to identify any active elements that could fail or be operated in such a manner as to result in an uncontrolled loss of coolant.
- a more formal search and documentation of all elements that depend on input from another source beyond the identified system boundary may be appropriate.

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External Flooding: A Really Big Picture

- Sparse data and concerns with extrapolation => mechanistic analysis
- Daunting scale
  - Regional analysis
  - Human actions
  - Besides flooding level: duration, debris, dynamic forces, warning time
  - Multi-site impacts
- How can R4&D help?
  - Multiple, heterogeneous evidence sets => uncertainty
  - Demonstration of validity of more restricted representation

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