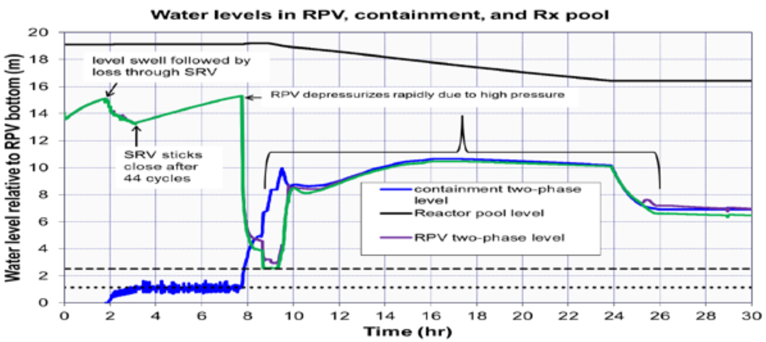
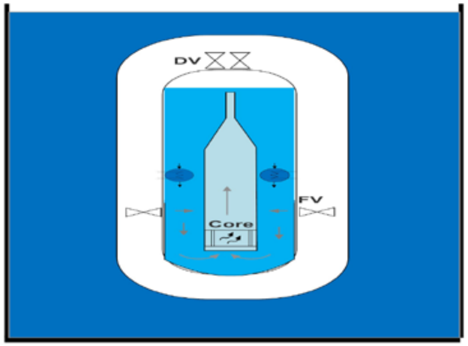
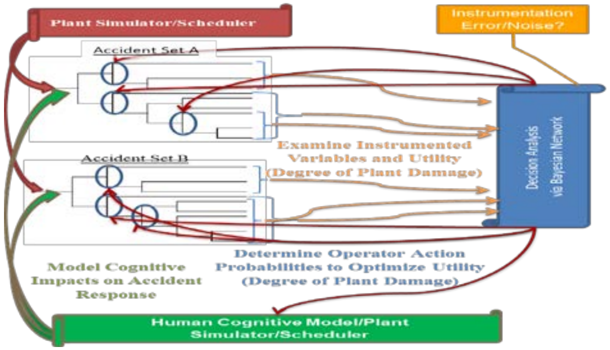
SAND2015-9032PE

Sandia National Laboratories







Nuclear Power Accident Analysis at Sandia National Labs

Matthew Denman
Risk and Reliability Analysis
Presentation to MIT, October 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

How Sandia Got Involved in the Safe Production of Nuclear Energy

- Atomic Energy Commission divided 1974
  - Department of Energy to develop commercial nuclear energy
  - US Nuclear Regulatory Commission to assure nuclear energy development provides adequate protection of public health and safety
- Sandia made a National, multi-mission laboratory
  - Expertise in nuclear science and engineering
  - No past involvement with commercial nuclear power

Timeline of Nuclear Safety Technology Evolution

simplified parametric → *detailed best estimate*

Tier 1: Integrated Codes: MELCOR, MAAP, ASTEC

Tier 2: Mechanistic Codes
SCDAP, CONTAIN, VICTORIA

US Research → *International Research*

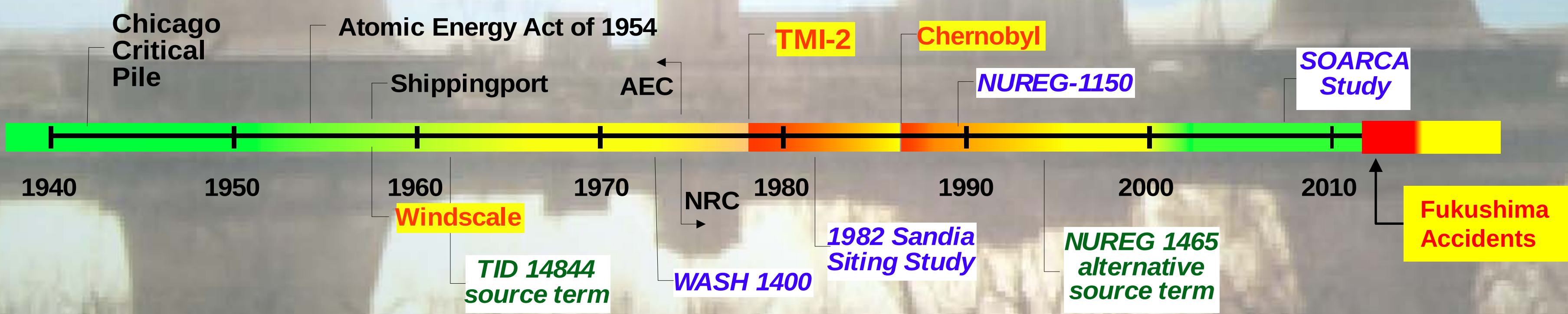
Phenomenological Experiments (PBF, ACRR, ACE, HI/VI, HEVA)

QUENCH, Phebus FP, VERCORS, MASCA

Deterministic Bounding Analysis

Risk Informed Regulation

Probabilistic Risk Informed Analysis



Nuclear Power Outlook

- Optimistic
- Guarded
- Pessimistic

Emerging Issues.....

Risk Informing Regulation
- *Modernization, NUREG-1465*

License Amendments and Extension
- *MOX, High Burnup*
- *Plant aging*

Emergency Response Planning

Advanced Reactors
- *AP1000, ESBWR, US-EPR*

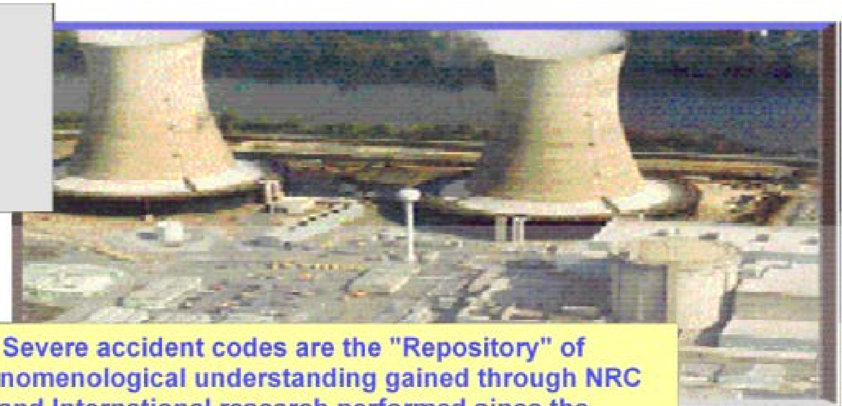
NGNP - HTGR, VHTGR, H2 Economy

GNEP - Fast Burner Reactor, Reprocessing

MELCOR Severe Accident Phenomena

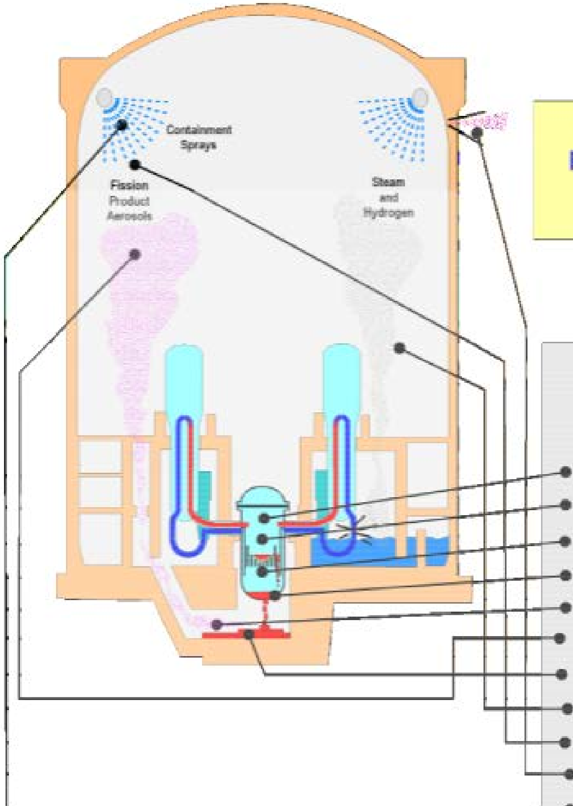
Sandia National Laboratories

Modeling and Analysis of Severe Accidents in Nuclear Power Plants



Severe accident codes are the "Repository" of phenomenological understanding gained through NRC and International research performed since the TMI-2 accident in 1979

Integrated models required for self consistent analysis



Important Severe Accident Phenomena

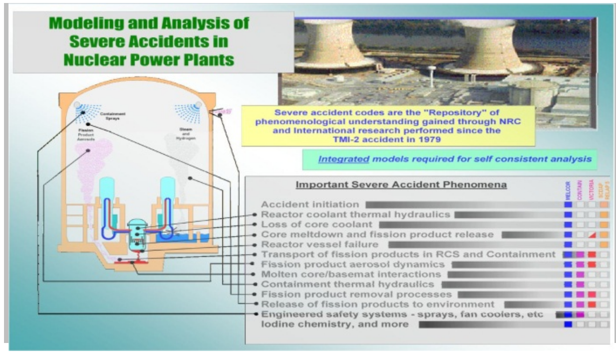
MELCOR | CONTAIN | VICTORIA | SCDAP RELAP5

- Accident initiation
- Reactor coolant thermal hydraulics
- Loss of core coolant
- Core meltdown and fission product release
- Reactor vessel failure
- Transport of fission products in RCS and Containment
- Fission product aerosol dynamics
- Molten core/basemat interactions
- Containment thermal hydraulics
- Fission product removal processes
- Release of fission products to environment
- Engineered safety systems - sprays, fan coolers, etc
- Iodine chemistry, and more

Exceptional service in the national interest

Sandia National Laboratories

Source: Tokyo Electric Power Company



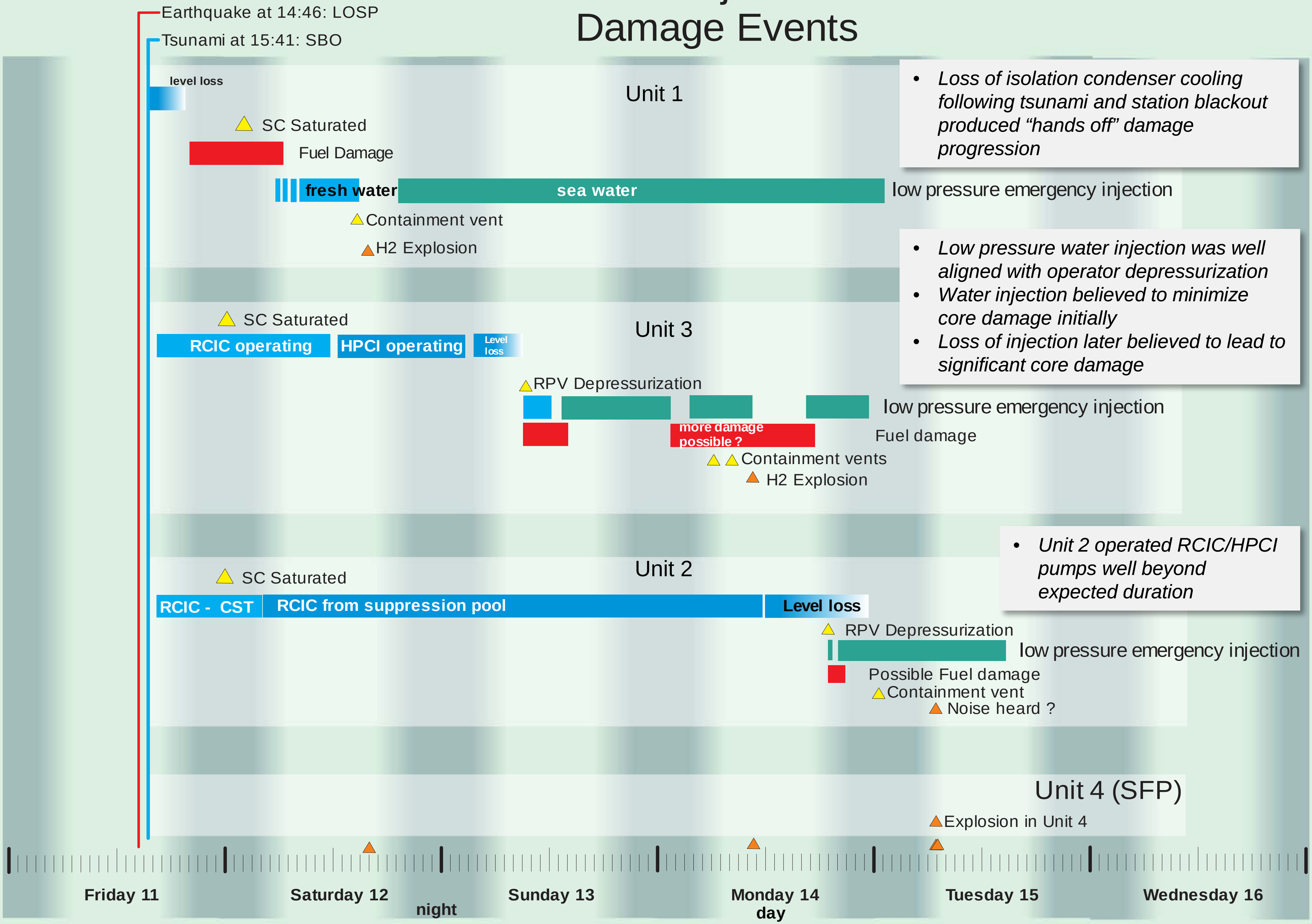
The Fukushima Accident Reconstruction

U.S. DEPARTMENT OF ENERGY

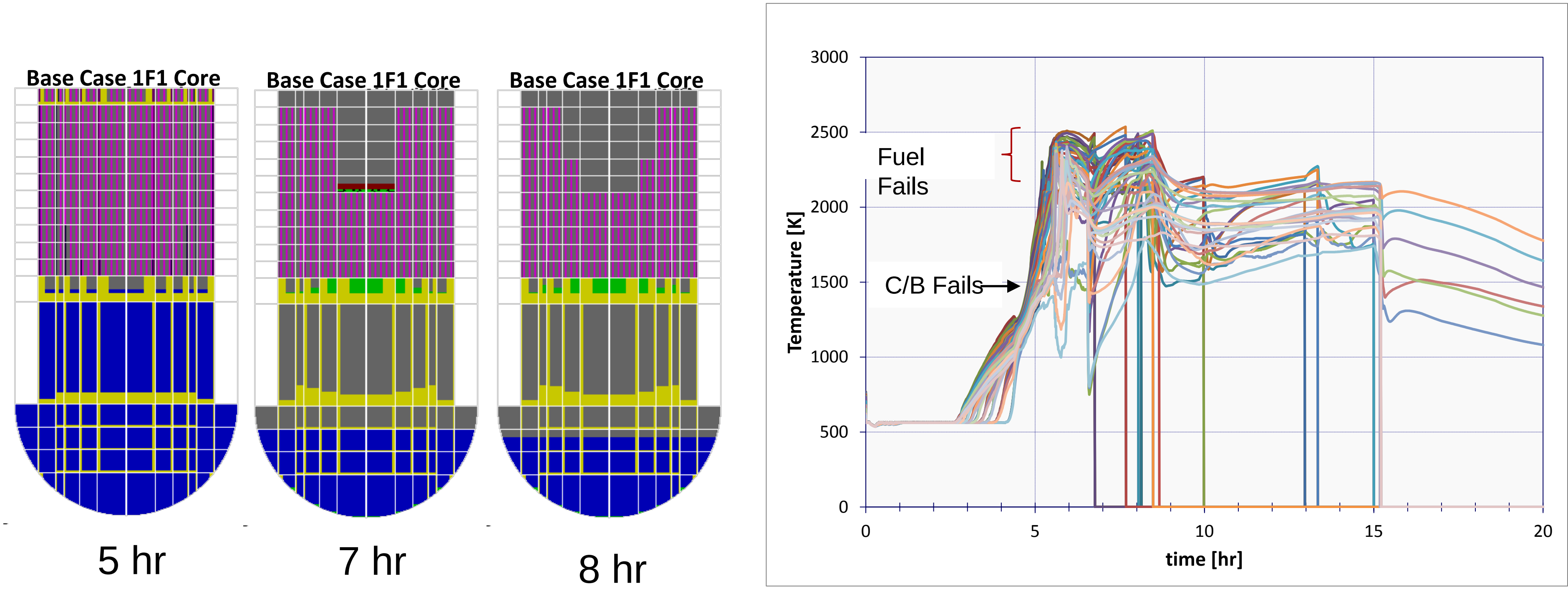
NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Timeline of Major Fukushima Damage Events

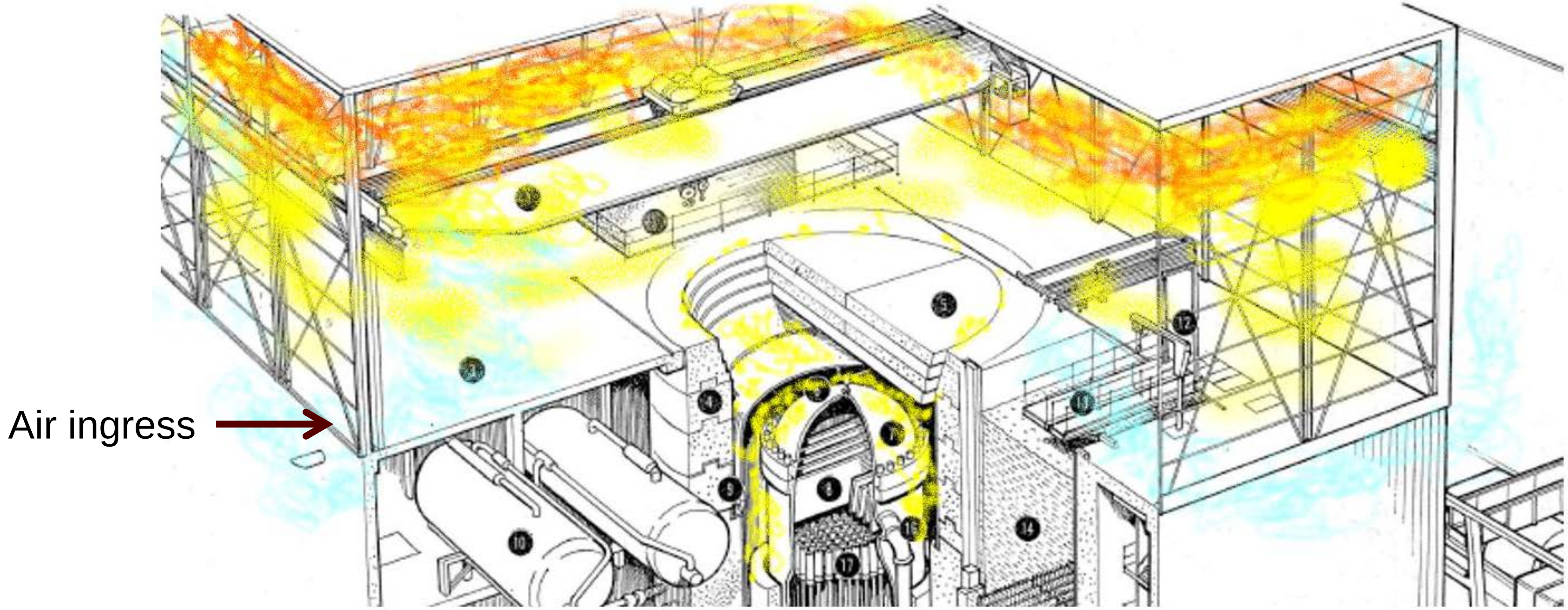


Sequential Degradation of Control Blades and Fuel Rod Geometry



- Core damage starts at ~ 4 hours – Control Blade fails first
- Progressive fuel damage after 6 hours
- Core exit gas temperatures very high

Combustible Conditions Follow PCV Venting in 1F1

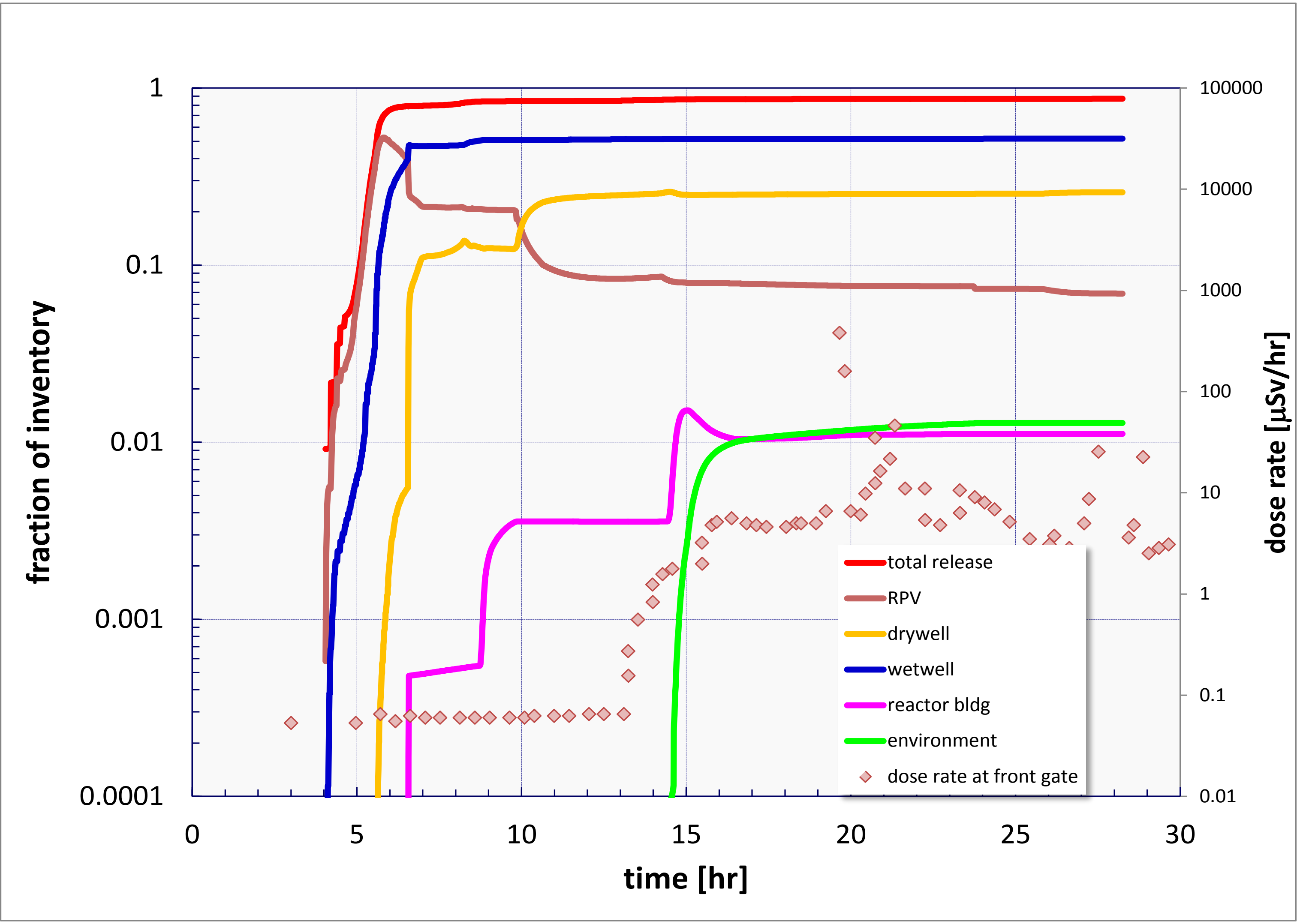


- At around ~23 hours, steam and hydrogen leakage from PCV greatly reduced
  - Water injection was stopped
  - PCV was depressurized by operator venting action
- Continuing condensation without steam source….
  - Reduces steam molar fraction to below 50% in refueling bay, and
  - Produces partial vacuum that draws in outside air
- Air ingress and steam condensation leads to conditions favoring combustion
- Hydrogen stratification produces flammable or detonable concentrations of H_2/O_2

Damage from Explosions

Used by permission from TEPCO
Kenji Tetawa

Cs Release 1F1



Radiation monitors at front gate jump at ~13 hr

Cs Env release about 400,000 Ci

Extended legacy in Probabilistic Risk Assessment

Sandia National Laboratories

Foundations

Establish basis for assessing and managing risks

Evolutionary PRA

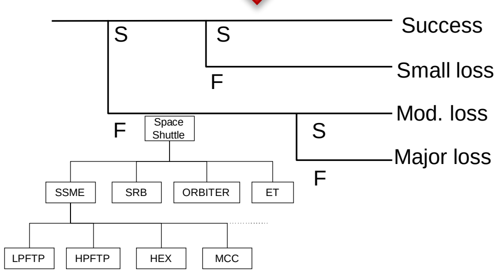
Address gaps in foundational methods

Revolutionary PRA

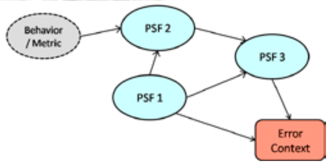
Introduce dynamic elements

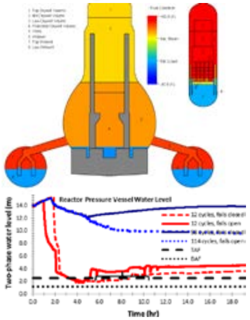
New frontiers

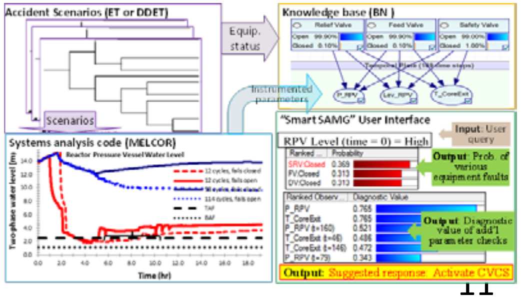
Use foundation to solve problems beyond PRA



$$\text{Risk} \sim \sum_{n} \sum_{j} (f_{nj} \cdot c_{nj})$$

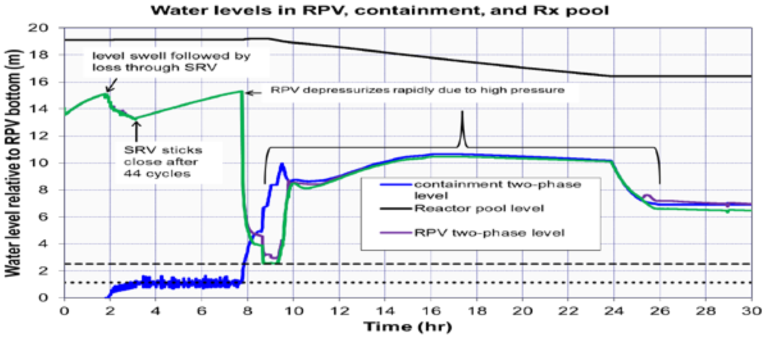


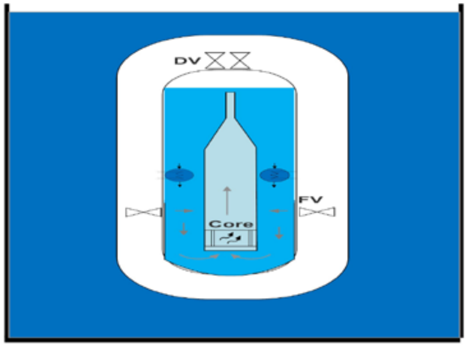


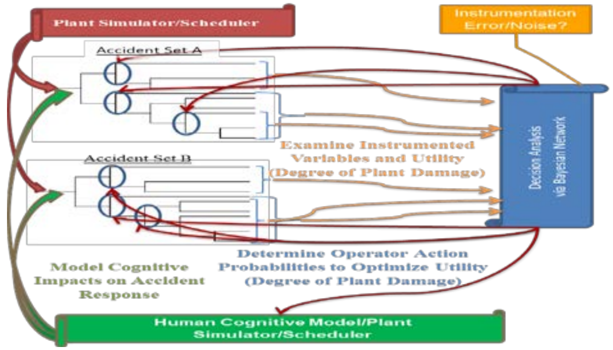


Exceptional service in the national interest

Sandia National Laboratories







New Frontiers

"Smart Procedures"

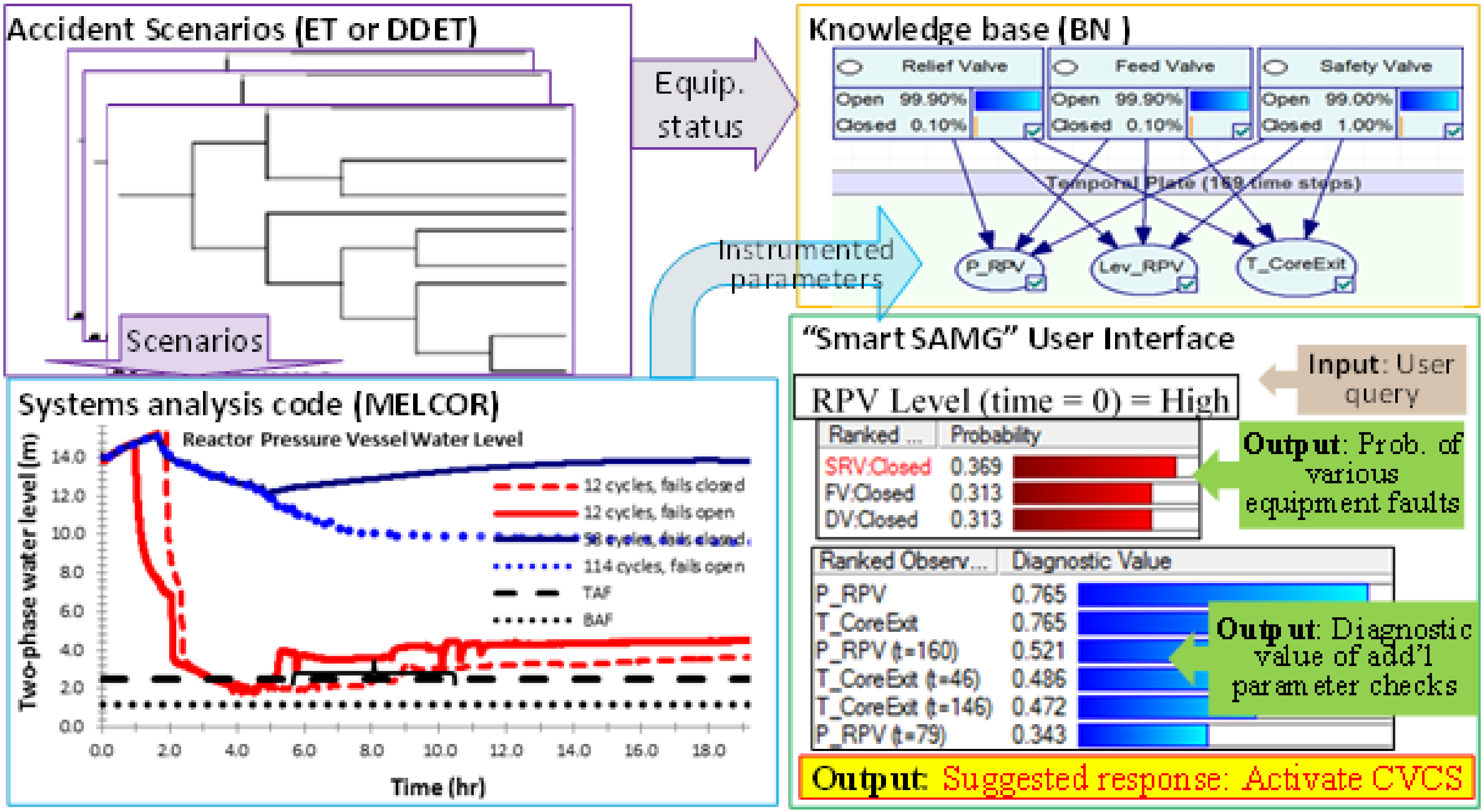
U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

SAND2013-8096C

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

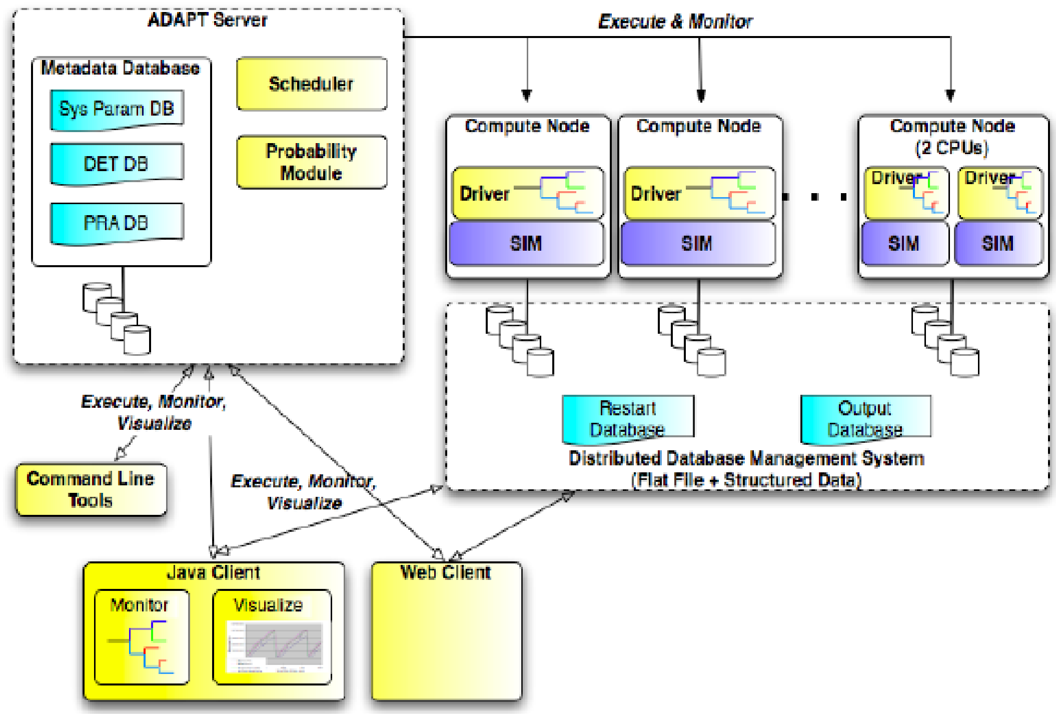
Approach: “Smart Procedures” Model development methodology

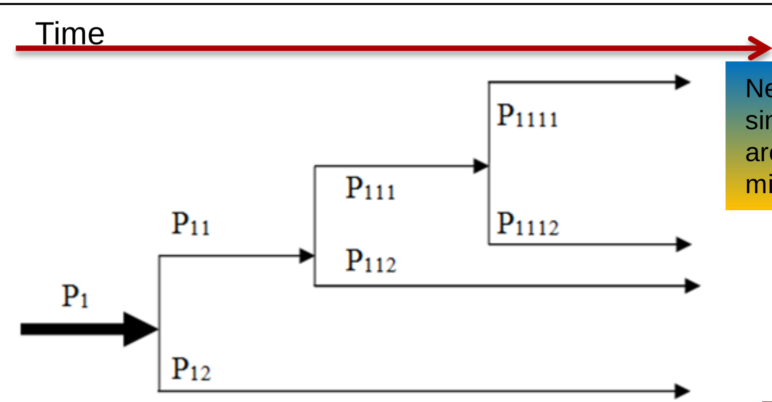


Discrete-Dynamic-Event-Trees (DDET) [Uncertainty Exploration]

Sandia National Laboratories

- DDET is a methodology for exploring large spectrum of possible accident scenarios via **Dynamic Programming**.
  - Simulates multiple accident sequences by branching based on physics calculations.
  - Scheduler (ADAPT) was created by a Sandia LDRD completed in 2008.



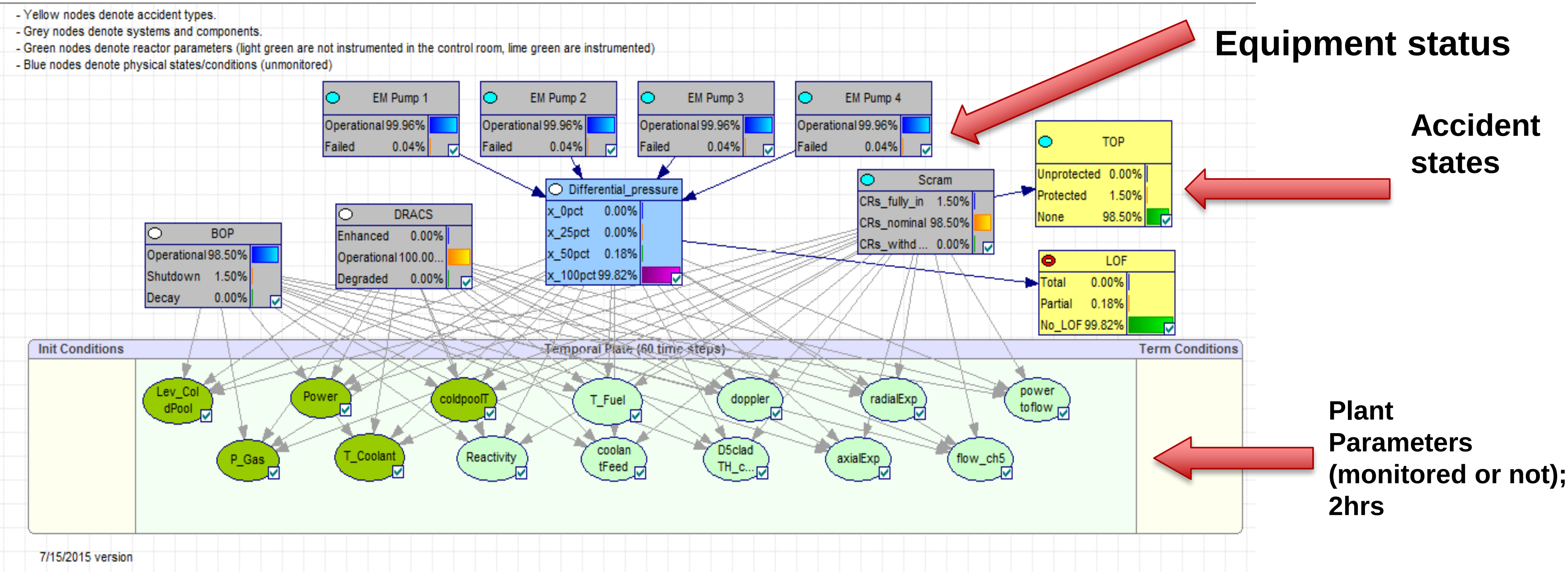


New simulations are branched mid-transient

Evolution of accident sequences is determined by physics and engineering calculations, not a priori analyst decisions.

SAND2013-8096C

Accomplishment: Proof-of-concept model for LOF and TOP diagnosis

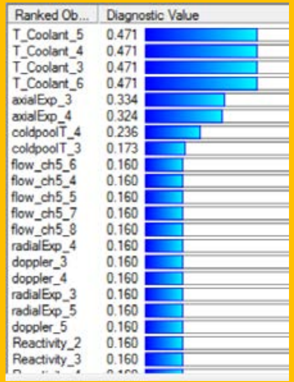


BN-based tool can be used to provide insight into instruments are most essential for diagnosis of specific accidents. This information can provide insight into, reactor design e.g., which instruments need to be hardened for severe accidents.

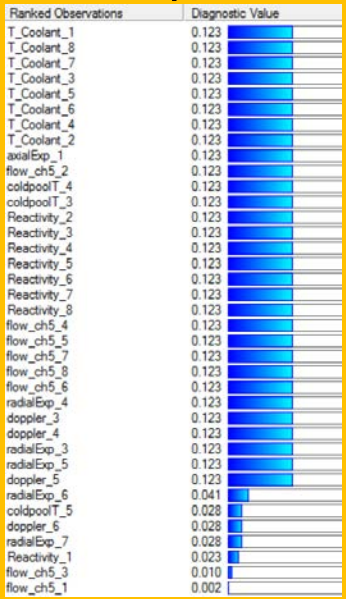
“SMART Procedures” Next steps

- Experiment with model to get insights on value of specific indicators (in progress).
  - Example of insights:
    - Reactivity is a better diagnostic indicator than Power
    - Hot pool temperature (T_Coolant) has high diagnostic value for both LOF and TOP
    - Cold Pool Temperature has better diagnostic value for LOF than TOP
    - Power and Reactivity are redundant
- Expand model scope to cover additional accident sequences
- Conceptualize addressing “failed” instrumentation states
- Test and Validation activities on existing model

Loss Of Flow Diagnosis

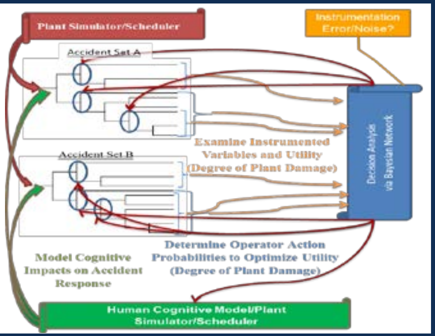


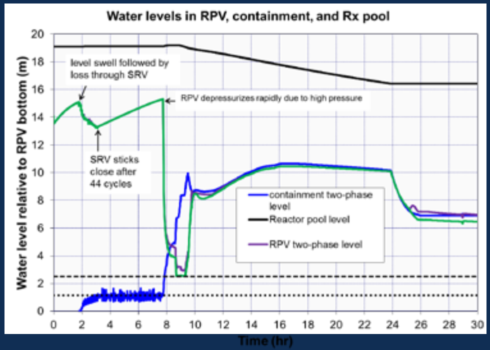
Transient Overpower Diagnosis

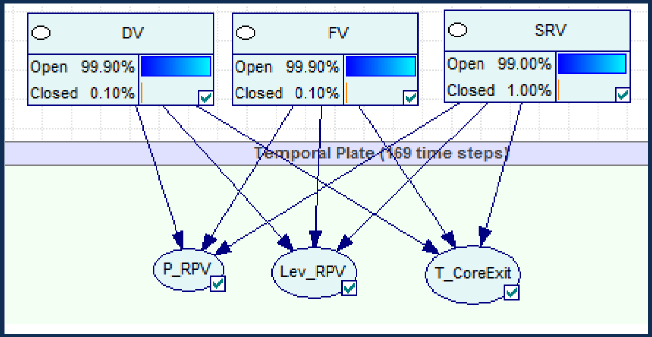


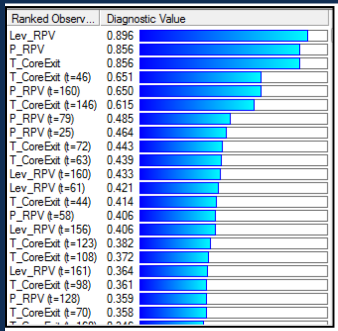
Exceptional service in the national interest

Sandia National Laboratories









Thank you!

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.