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Idaho National Laboratory Advanced Test Reactor Probabilistic Risk Assessment (PRA)

September 2012

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History of PRA for the ATR

- PRA studies began in the late 1980s
- 1989, ATR PRA published as a summary report
- 1991, ATR PRA full report
- 1994 and 2004 various model changes
- 2011, Consolidation, update and improvement of previous PRA work
- 2012/2013, PRA risk monitor implementation

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Purpose/Goal of the ATR PRA

- The PRA supports the ATR Updated Final Safety Analysis Report (UFSAR)
- The PRA provides sufficient information regarding either core or fuel damage (CDF or FDF) to enable ATR personnel to make risk informed decisions
- Improved performance in facility operation, testing, maintenance, training, and emergency procedures
- Ensure cost-effective approaches and the setting of priorities for plant upgrades and modifications, especially for risk reduction/system improvements
- Evaluate multiple overlapping contingent controls and equipment outages

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PRA Applications

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- Assess increases (or decreases) in risk as the plant changes due to equipment failures or maintenance activities (e.g., Risk Monitor)
  - Train Work Week Managers, Operations, and Engineering to use for evaluating work weeks, daily operations, and planning activities performed during operations and shutdown modes.
- Assistance in categorizing Structures, Systems, and Components (e.g. Safety Class, Safety Related)
- Changes to licensing basis (SAR, TSRs) such as completion times
- Inservice inspection and testing

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ATR PRA Modules

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- Power Operations (Includes Power Operations greater than ~3MW)
- Shutdown and Fuel Handling (Includes operating states less than ~3MW)
- Internal Flood
- Internal Fire
- Seismic
- ATR Confinement

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Power Operations Module

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- 40 initiating events (e.g., cask drop, small LOCA)
- 51 system functional criteria (e.g., forced flow for 30 minutes, vessel venting)
- 86 fault trees (e.g., core emergence makeup, secondary heat removal)
- 2680 basic events (e.g., cooling pump fails to run, emergency pump fails to start, operator fails to actuate valve)
- 24 ATR systems modeled (e.g., deep wells, plant protection system)
- Meets ASME/ANS Standard RA-Sa-2009 capability category II criteria (All 6 modules)
- Independently reviewed by highly experienced PRA experts from the commercial power industry (All 6 modules)
- Forms the basis for all other ATR PRA Modules

Shutdown and Fuel Handling Module

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- Replicated Power Operations Module 6 times and modified each to specifically represent each plant operating state.
- Plant Operating States (POSs) modeled (original POSs 5-7 subsumed in other POSs)
  - POS 1, Transition From Pressurized with EFIS in Auto to Depressurized with EFIS in manual
  - POS 2, Depressurized Shutdown, Vessel is Vented, Fuel in the Core
  - POS 3, Depressurized Shutdown, Actively Transferring Fuel Into or Out of the Reactor
  - POS 4, Reactor Defueled
  - POS 8, Transition From Depressurized with EFIS in Manual to Pressurized with EFIS in Auto
  - POS 9, Low Power Operation, Startup and Transition to Power Operations, PCS >100 psig, Automatic EFIS
  - POS 10, Power Operations – Separate Module
- Constructed module such that 1 flag (logic switch) can be set and then solve any individual POS

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Internal Flood Module

- 296 initiating events (e.g., fire protection pipe flood, gland seal spray in pump motor room, demineralized water spray in second basement)
- System functional criteria of power operations module
- Modified power operations module fault trees to consider flood and spray damage
- Calculations to determine time to flood critical equipment depending on the piping system flow and location of the assumed break or spray
- Consideration of penetrations (e.g., ventilation ducts, cable trays, drain gutters, door jam space, stair wells)

Internal Fire Module

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- 150 initiating events (screened many more)
- System functional criteria of power operations module
- Modified power operations module fault trees to consider damage caused by fire (e.g., transient fire, cable tray, running motor, high energy arc faults) and possible fire protection actuation.
- Fires modeled via CFAST considering zones of influence and smoke layers resulting in time to reach combustion of overhead components and fire sprinkler actuation

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Seismic Module

- Site specific seismic hazard curve.
- Specialized event tree for the unique nature of seismic events
- Modified power operations module fault trees to consider damage caused by seismic events (e.g., both random faults and seismic damage – ~ 300 plant specific seismic fragilities are considered)
- Sensitivity studies for the site hazard curve and acceleration specific variations

Confinement Module

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- Initiating events derived from CDF and FDF power operations module results
- Considers timing, material, and component inactions during core melt progression
- Individual sequences resulted in 22 source terms
- Considers the specific initiating event regarding which systems may still be functional (e.g., firewater injection, building spray, power supplies) including whether the initiating event causes a confinement breach (e.g., drop events)
- Release progression throughout the building and evaluates confinement bypass (large early release fraction)
- Sensitivities studies for ventilation failures (e.g., dampers) and whether ventilation fans continue to run when they shouldn't

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Core Damage Frequencies

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ATR PRA Module	Point Estimate of CDF (1/yr)	Mean of CDF (1/yr)
Power Operations	5.1E-06	5.5E-06
Fuel Handling and Shutdown (irradiated fuel in the vessel, in transit, or stored in the canal)		
• Depressurized/vented	2.1E-07	1.8E-07
•Depressurized moving fuel	1.7E-07	1.6E-06
•Reactor Defueled	6.6E-07	5.9E-07
•Transition from depressurized to pressurized	2.5E-05	2.4E-05
•Low power operation	2.1E-07	2.0E-07
Internal Flood	8.4E-06	9.8E-06
Internal Fire	3.0E-05	2.8E-05
Seismic	4.1E-05	2.7E-03
Level 2 (LERF)	1.1E-06	1.1E-06

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Dominant Full-Power Accident Sequences

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Event Description	Frequency/year	% Total
Canal draining from non-cask drop	1.1 E-06 (1 in .9 million)	21.4%
Large LOCA	1.0 E-06 (1 in 1 million)	19.3%
Forklift load drop	9.0 E-07 (1 in 1.1 million)	17.5%
Loss of commercial power	5.1 E-07 (1 in 1.96 million)	10%

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Insights

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- There are no dominant sequence groups indicating mitigation systems are appropriate
- Environmental aspects of important components need to be evaluated to credit their potential safety function (e.g., fire water spray on switchgear and digital systems)
- Operating procedures and training emphasizing the importance of vessel venting and proper operation of firewater injection could be improved
- Replacing open cable trays with solid bottom cable trays above some buses could provide an effective thermal barrier
- Buildings housing support equipment are seismically weak and should be upgraded or equipment moved
- Upgrade unqualified primary piping (completed)
- Confinement release is dominated by load drop events and most large releases are due to stored fuel vs. the core

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Recent Uses of the PRA

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- Modeled secondary coolant system component replacement during operations to show insignificant change in risk
- Evaluated broken firewater valve to determine its importance in reactor startup
- Evaluated various configurations of running diesel generators to determine allowed outage time (completion time)
- Evaluated station blackout (similar to 10 CFR 50.63 and NRC Regulatory Guide 1.155)
- Determined risk significant components in support of system health program
- Ongoing evaluations of various design options for converting plant electrical systems to commercial power with diesel/battery backups

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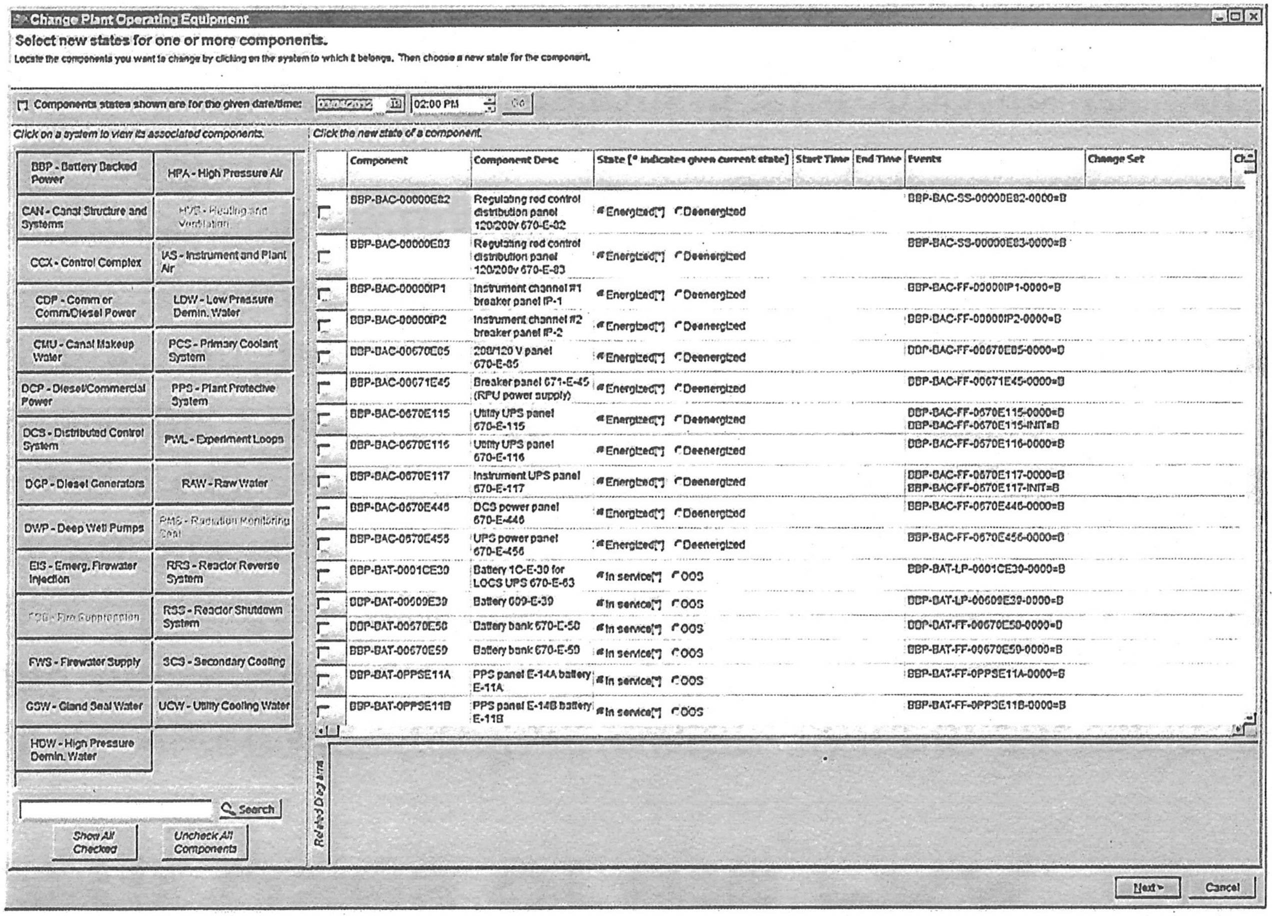
ATR Risk Monitor Equipment Selection



ATR Risk Monitor Cycle Configurations

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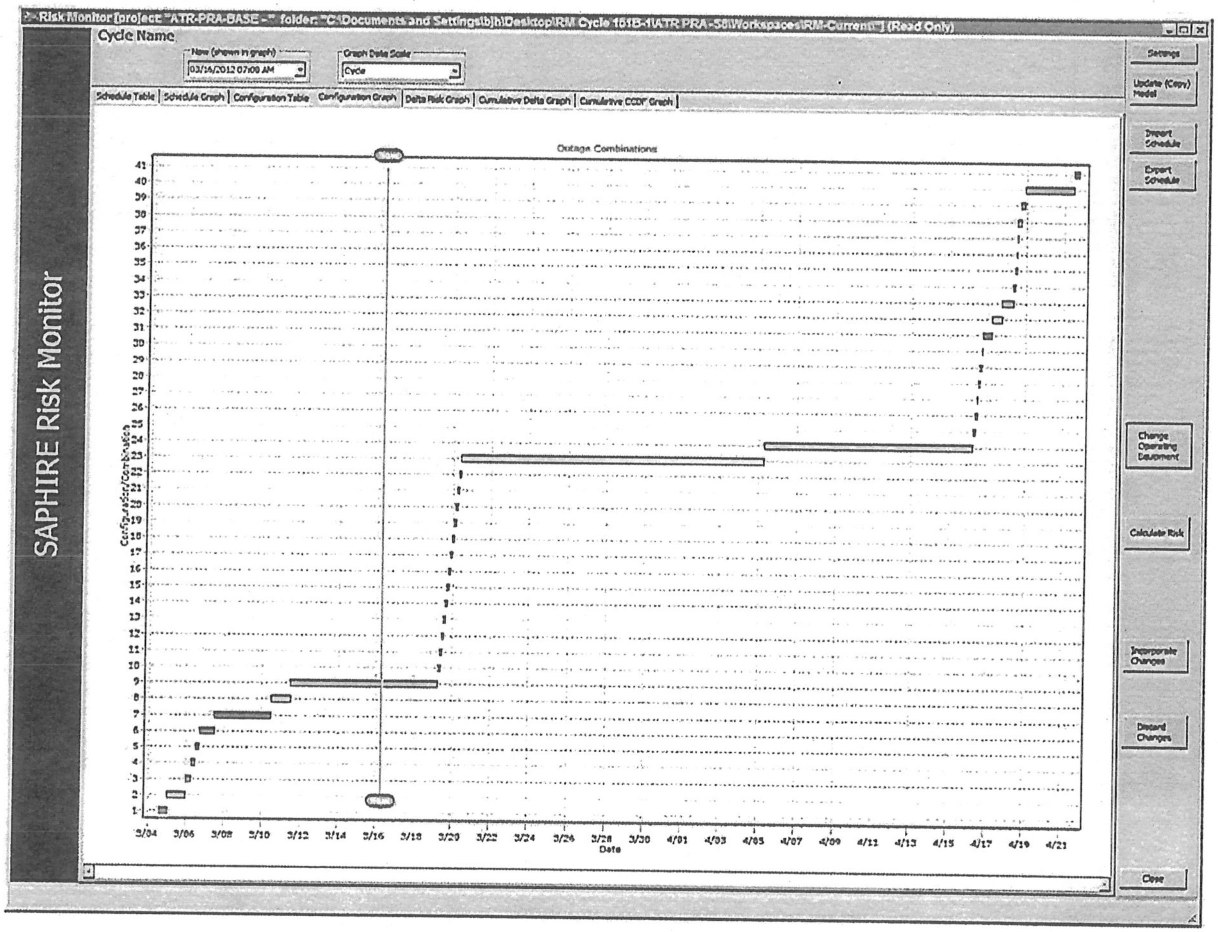

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ATR Risk Monitor Example CCDF

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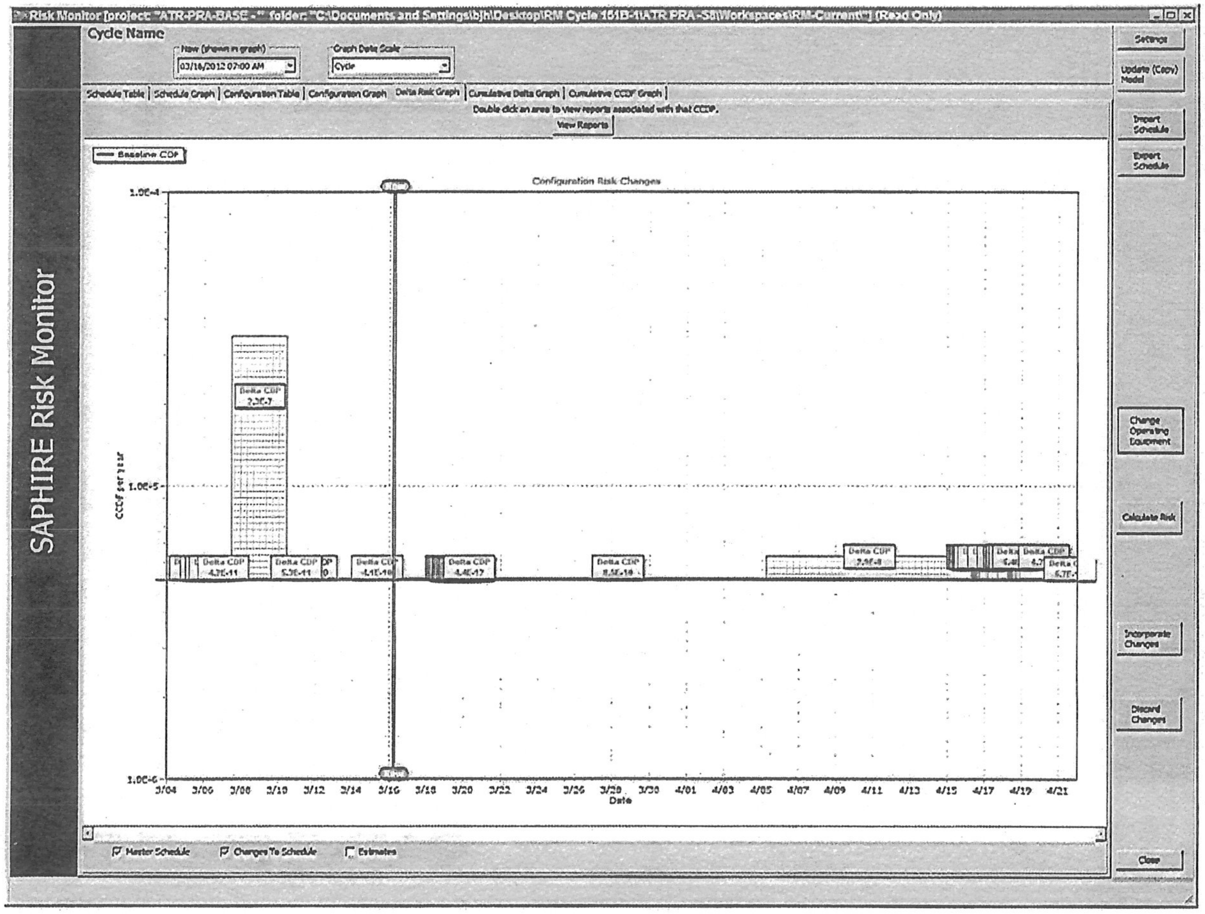

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ATR Risk Monitor Example
Cumulative CDP

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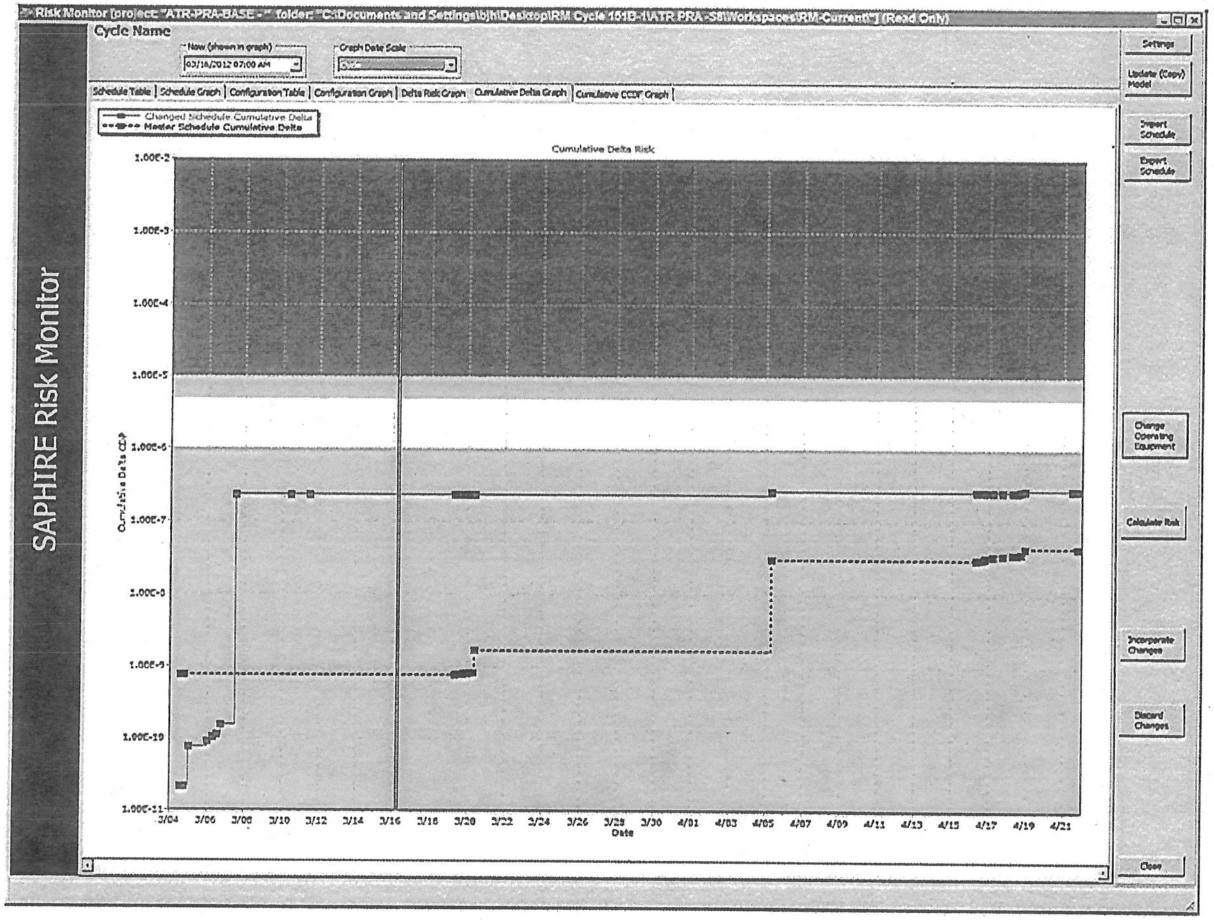

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