US NRC Activities in the Area of Dynamic Level 2 Probabilistic Safety Assessments

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Project genesis and objectives

- Level 2 PSA identified in 2007 as fertile area for research
- Objectives:
  - Explore methods capable of evolving the state-of-the-art
  - Quantitatively demonstrate the potential benefit and feasibility for future needs (> 5 years)
- Scoping study performed in 2009 to investigate spectrum of approaches
  - Dynamic event tree class of methods selected for further R&D
- Tool development effort initiated at Sandia National Labs in 2009 (ongoing)
  - Includes active participation by: Dycoda, University of Maryland, and the Ohio State University

High-level motivations

- Reduce reliance on unnecessary modeling simplifications and surrogates
  - e.g., directly analyze plant response (e.g., RCS pressure) on a sequence-specific basis
- Improve model realism in specific areas identified by the US NRC’s SOARCA project
  - e.g., more realistic treatment of source term retention mechanisms
- Improve treatment of human interaction and mitigation
  - e.g., include accident management guidance (e.g., SAMGs) in to the Level 2 PSA in an HRA context

High-level motivations (2)

- Make process and results more scrutable
  - e.g., explicitly include timing (quantitatively) in the event sequence characterisation (e.g., event tree)
- Leverage advancements in computational capabilities and technology developments
  - e.g., directly couple the accident sequence development (e.g., event tree) to the plant response simulator (e.g., MELCOR)
- Allow for ready production of uncertainty characterization
  - e.g., directly integrate treatment of Level 1 to Level 3 PSA uncertainty

Why dynamic event trees rather than direct-sampling simulation?

- DDET approach is a hybrid between traditional PSA and direct-sampling simulation
  - More readily conceptualized by PRA and deterministic audiences
- More opportunities for leveraging others' work
- Judged to be more computationally efficient at this time
  - Smart sampling, input correlation, and aggregation techniques have not been sufficiently developed
- Branching rule development / monitoring demands active user involvement (no 'black box' syndrome)

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Other considerations

- The project is expected to:
  - Promote near and long-term technical advancement
  - Inform related activities (e.g., new Level 3 NRC PSA)
  - Inform regulatory activities (e.g., assessment of severe accident mitigation alternatives)
- Long-term development effort, with focus on near-term demonstration
  - Current plan is to perform a dynamic PSA for a PWR station blackout branching on a small set of system / operator action / phenomenological events
- Viewed as complementary to traditional methods (not a replacement)

Leveraging of past work

- Investigation of domestic and international efforts
  - e.g., MCDET (GRS)
  - e.g., uncertainty quantification techniques
- Leverage prior tool development:
  - IDAC cognitive operator response model and code
  - ADAPT and ADS dynamic event tree codes
  - MELCOR accident simulator code
  - MACCS2 offsite consequence code

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Tools at a glance

MELCOR (not an acronym) – a NRC-developed computer code that deterministically models the progression of severe accidents in nuclear power plants

MACCS2 (MELCOR Accident Consequence Code System 2) – a NRC-developed offsite consequence computer code that models the atmospheric transport and dispersion of radioactive material and the associated health effects

ADS-IDAC (Accident Dynamics Simulator using Information, Decisions, and Actions in a Crew Context) – a discrete dynamic event tree computer code developed by the University of Maryland that dynamically treats accident evolution, in concert with a simulator such as MELCOR, with a focus on the cognitive representation of the operators

ADAPT (Analysis of Dynamic Accident Progression Trees) – a discrete dynamic event tree computer code developed by The Ohio State University that dynamically treats accident evolution, in concert with a simulator such as MELCOR, with a focus on component and phenomenological behavior

Probabilistic treatment

- Single-loop approach (i.e., combination of epistemic outer loop and aleatory inner loop)
  - Decision driven by practical considerations
  - Means that aleatory and epistemic uncertainties are treated similarly (i.e., both treated by branching rules)
- Selection of key uncertainties as branching candidates:
  - Systems (e.g., time to battery depletion)
  - Phenomena (e.g., hydrogen deflagration/detonation)
  - Operator actions (e.g., actions to align alternate steam generator injection)

Probabilistic treatment (2)

- For each branching candidate, develop a cumulative distribution function
  - Probability versus a calculable quantity
    - e.g., probability of operator opening a valve versus time since procedure step reached
    - e.g., probability of structure failure versus creep rupture index
- Cumulative distribution functions are discretized to give branching points

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Example of sampling scheme

Procedures and Guidance

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Operator response

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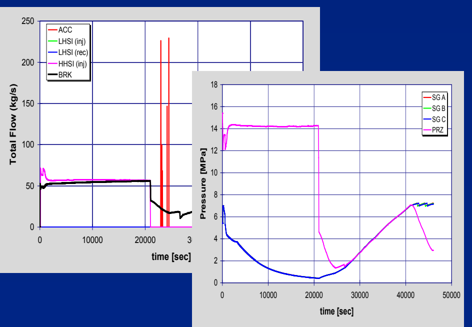
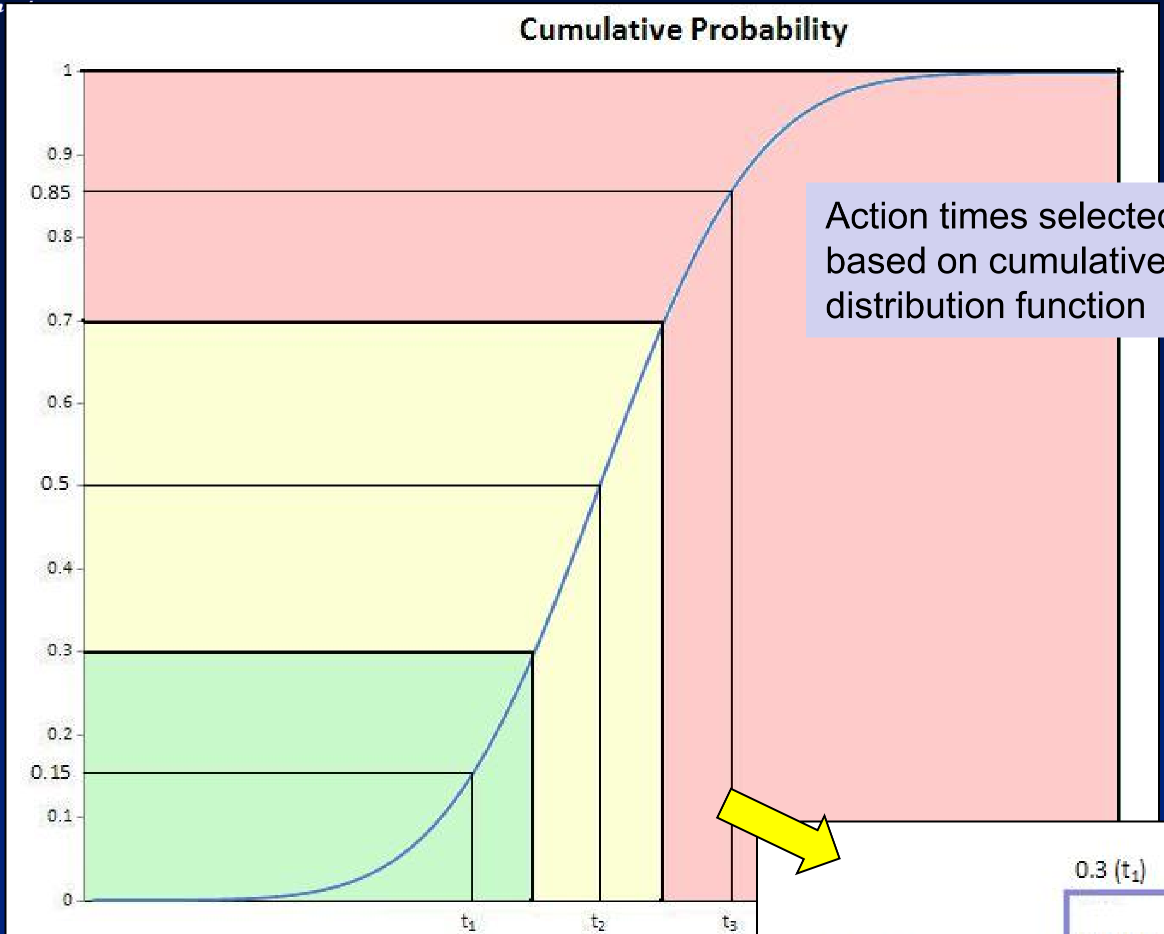
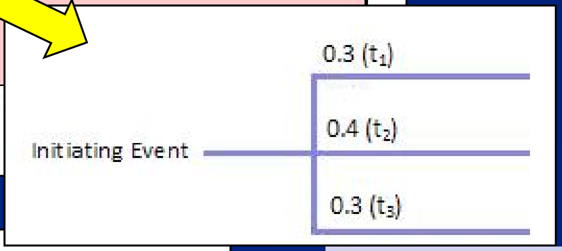
Plant response (via MELCOR)

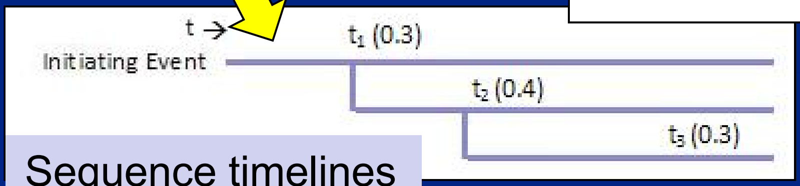




Action times selected based on cumulative distribution function



Event tree



Sequence timelines

New challenges for modeling operator response in Level 2 PSA

- Different operator aids / activities:
  - Guidelines rather than procedures
  - Mitigative strategies under Title 10 *Code of Federal Regulations* Part 50.54(hh)
- Additional types of decision-making
  - Pro and con based decisions (for SAMGs)
  - Addition of the Emergency Plan (EALs) to the picture
- Additional players:
  - Emergency response facilities: technical support center and emergency operations facility
  - Offsite resources
  - Interactions with local and regional decision-makers (E-Plan)

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Example of accident management and emergency preparedness interplay

Control room responds using EOPs

Transition to SAMGs

TSC assumes decision-making responsibility, once it is staffed

Initiating event occurs

↑ Accident Management Guidance

- - - - - - - - - - - - - - - - - - → time

↓ Emergency Plan

Control room assesses Emergency Action Levels

Alert

TSC (onsite) is staffed

Site Area Emergency declared

General Emergency declared

Protective actions are taken

Emergency Notification System activated

Offsite EOF is staffed and interfaces with TSC, state, NRC

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Code coupling

- Key interfaces needing development:
  - IDAC and MELCOR
  - IDAC and ADAPT
- Interfaces requiring enhancement
  - ADAPT and MELCOR
  - ADAPT and MACCS2
- Codes do not all use the same programming language
- Cross-platform issues also have to be addressed (Linux versus Windows)

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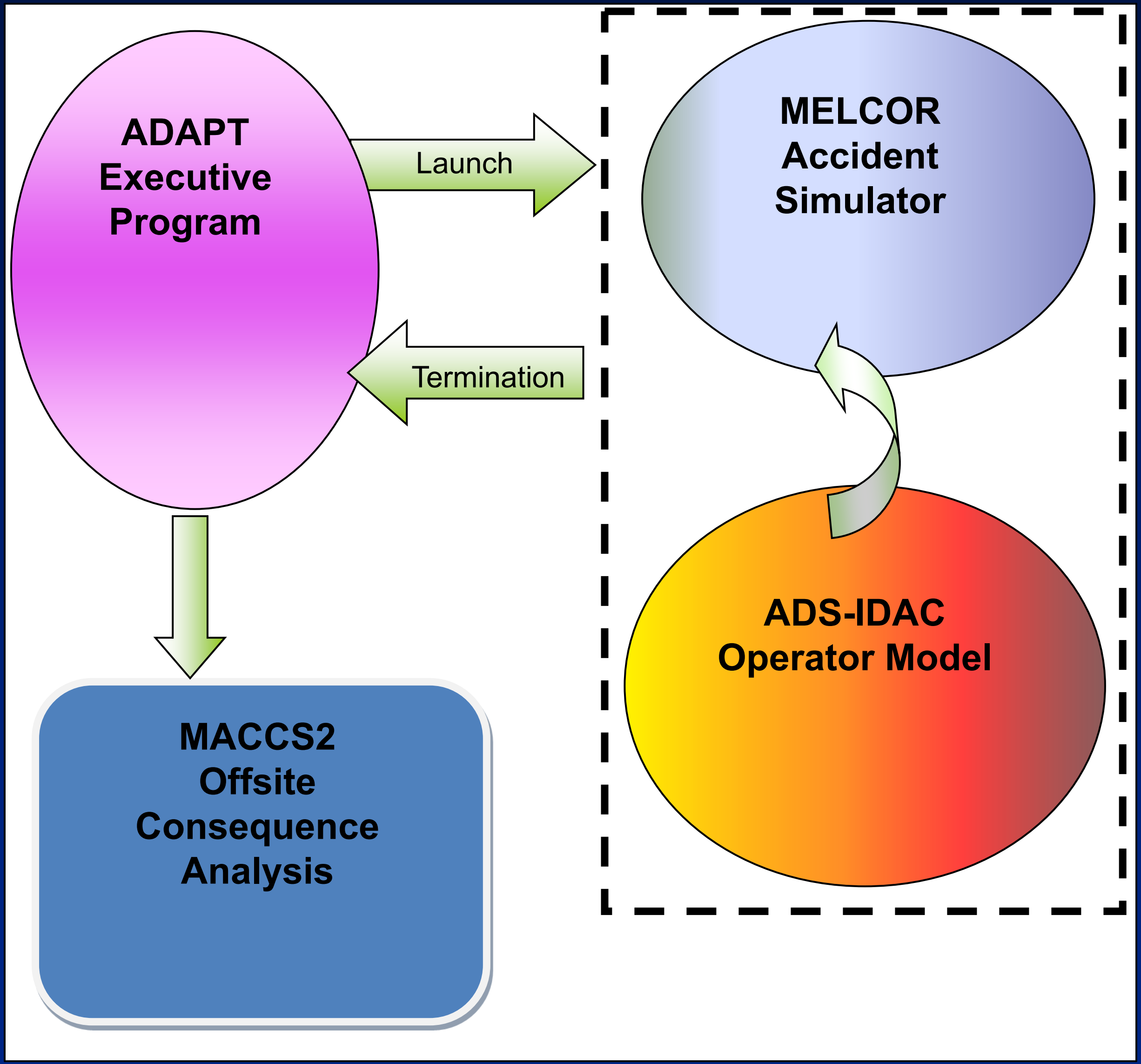
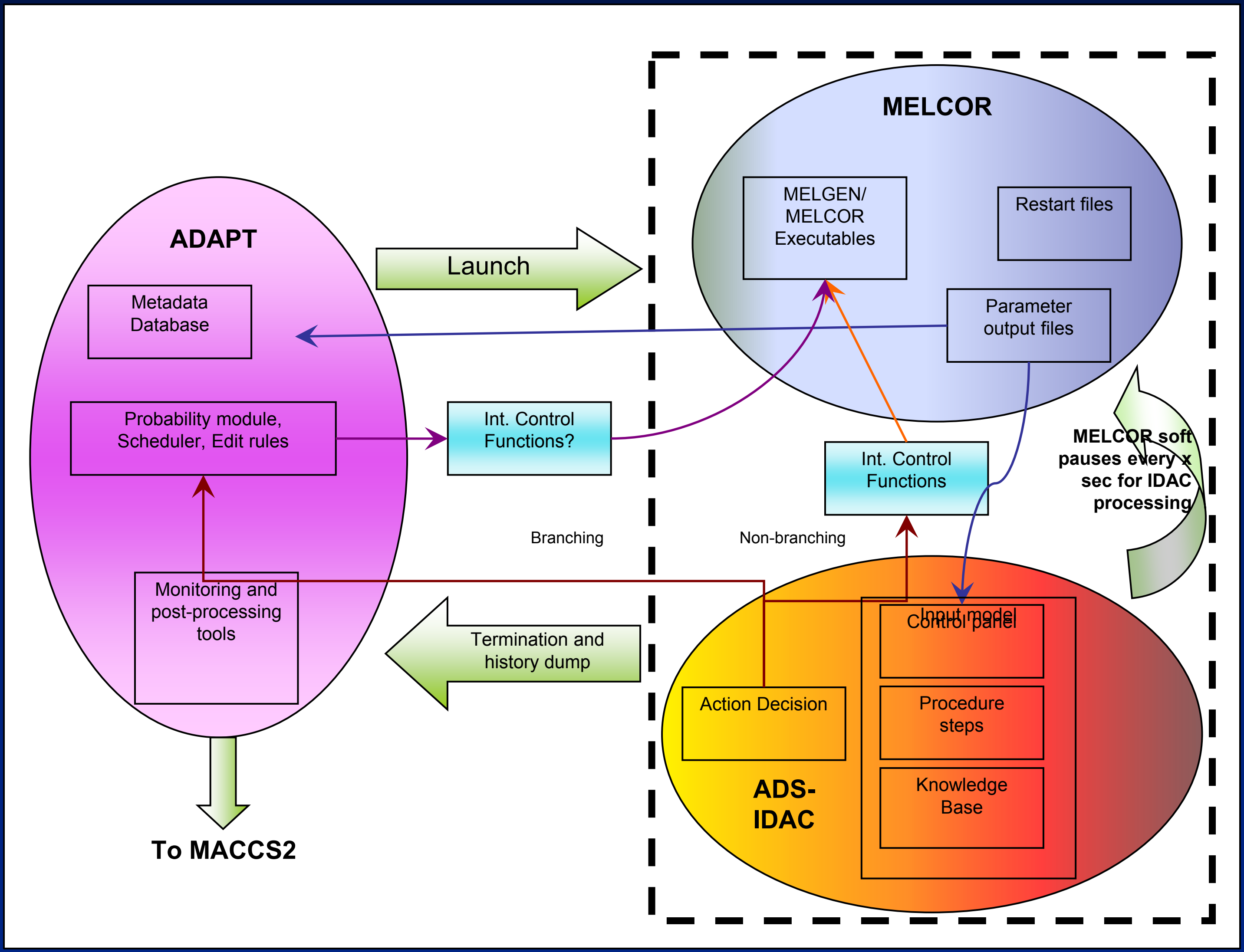
Simplified code coupling scheme



More detailed code coupling scheme



Next steps (Through Summer 2011)

- Addressing basic code coupling issues
- Developing near-term and longer-term development and deployment strategies
- Near-term demonstration of tool use for a PWR station blackout

- Questions?

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Acronyms

ADAPT	Analysis of dynamic accident progression trees
ADS	Accident dynamics simulator
DDET	Discrete dynamic event tree
EAL	Emergency action level
EOF	Emergency operating facility
EOPs	Emergency operating procedures
E-Plan	Emergency plan
GRS	Gesellschaft für Anlagen und Reaktorsicherheit
HRA	Human reliability analysis
IDAC	Information, decision, and actions in a crew context
MACCS2	MELCOR accident consequence code system 2
MCDET	Monte Carlo dynamic event tree
MELCOR	not an acronym
NRC	US Nuclear Regulatory Commission
PWR	Pressurized water reactor
R&D	Research and development
RCS	Reactor coolant system
PSA	Probabilistic safety assessment
SAMG	Severe accident management guidelines
SOARCA	State-of-the-art reactor consequence analysis project
TSC	Technical support center