Post Fukushima PSA

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Properties of an advanced PSA code

- PSA must cover longer periods after an initiating event
  - These periods may differ strongly dependent on time
  - Some effects involving shut down states and the fuel element pool are slow.
  - Recovery and repair after the initiating event appear feasible in such cases.
- Hence, we should consider modeling of
  - Phased mission, and
  - Periods of grace.
- Boundary conditions:
  - As simple as reasonably acceptable
  - Reasonable computational costs
  - Use as much as possible from existing PSA models
Component models

- Quality of existing component models
  - In principle adequate
  - But they assume an initially intact component at \( t=0 \).

- Basic requirement
  - Unavailability before a mission phase change should be equal to unavailability after the mission phase change.

- Strategy
  - Develop component models with given unavailability at an arbitrary starting time \( t_0 \)
  - Define a data structure compatible with existing PSA models and which allows the component model including its parameters to change at times of mission change.
Component models (examples)

- Non repairable component
  \[ U(t) = 1 + (U_0 - 1) \exp(-\lambda(t - t_0)) \]

- Repairable component
  \[ U(t) = \frac{\hat{\lambda}}{\hat{\lambda} + \rho} + \left( U_0 - \frac{\hat{\lambda}}{\hat{\lambda} + \rho} \right) \exp\left(-\left(\lambda + \rho\right)(t - t_0)\right) \]
Component models (examples)

- Tested component

\[ U_u(t) = 1 + U_{r0} \frac{\lambda}{\rho - \lambda} \exp(-\rho(t - t_0)) \]
\[ - \left( U_{r0} \frac{\lambda}{\rho - \lambda} + 1 - U_{u0} \right) \exp(-\lambda(t - t_0)) \]

\[ U_r(t) = U_{r0} \exp(-\rho(t - t_0)) \]

- After a test, let

\[ U_{r0} = U_u(T_k) + U_r(T_k) \]
\[ U_{u0} = 0 \]
\[ t_0 = T_k \]
Fault tree will contain basic events for phases and sub fault trees for phases.

Use phase basic events to store starting time of the phase.

Allow for one component model per phase in each basic event.
A structure of sub pre-event trees are used to define BC sets for each phase, which are inherited by system event trees to implement phase dependent modifications of the fault trees.

Hence, phased mission is easily possible for PSA, which already make distinctions of phases.
After an initiating event, requirements to the safety system change.
Hence, we need (at least) a mission to start with the initiating event.
In a rudimentary way, such mission phase is implemented in the mission time model in PSA codes.
In slow scenarios, more than one mission phase after the initiating event would be useful (e.g.: possibility to repair in first mission phase, no such possibility later due to adverse conditions)
Assume, that the durations of such post initiator phases are fixed given the initiating event.
Mathematical treatment of random phased missions

- Given the scenario defined the random phased mission system is equivalent to the deterministic one, if the time point of the initiating event is given.
- Then the failure frequency density of the contribution of the initiating event is

\[
h_{as}(t) = h_{i}(t) \left( U_{p}(t) + \int_{t}^{t+D} h_{M}(x) \, dx \right)
\]

- And the failure frequency

\[
H_{as}(t_B) = \int_{0}^{t_B} h_{as}(t) \, dt
\]
Let an initiating event define an initial phase after its occurrence.

If there is more than one phase after the initiating event, use phase basic events as defined above, but with a flag denoting the starting time as relative to the initiating event.
A period of grace is a time a minimal cut set may exist without causing system failure. If repair occurs before the period of grace elapses, there is no failure.

If repair rates for all components in a minimal cut set are given, the probability of repair after this period elapses can be given by

\[ pr\{T_R > T_G\} = \exp \left( - \sum \rho_i \right) \]

If repair on all components in the minimal cut set is not feasible, it is assumed, that the component with the largest repair rate will be repaired

\[ pr\{T_R > T_G\} = \exp \left( - \max(\rho_i) \right) \]
Organizing periods of grace in a PSA code

- A period of grace can be associated to a mission phase and thus to a phase basic event.
- It must be possible to associate different periods of grace to different parts of an event tree (using BC sets exchanging the phase basic event).
Summary and Conclusions

- A large step towards more accurate modeling can result by small changes in the PSA code.
  - Formulate component models which allow to transit between mission phase changes smoothly.
  - Allow for more than one component model per basic event.
  - Implement a phase basic event, which defines a mission phase, its starting point, the relation to a basic event, and possibly a period of grace for the system.
  - Modify time dependent quantification to account for the above.
Summary and Conclusions

- Put this into OPSAMEF?