# Post Fukushima PSA

RISA Sicherheitsanalysen GmbH

Dr. G. Becker

# Contents

- Desired properties of an advanced PSA code
- Component models
- Phased mission before an initiating event
- Phased mission after an initiating event
- Periods of grace
- Summary and Conclusions

# 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

$$U(t) = 1 + (U_0 - 1)exp\big(-\lambda(t - t_0)\big)$$

- Repairable component

$$U(t) = \frac{\lambda}{\lambda + \rho} + \left(U_0 - \frac{\lambda}{\lambda + \rho}\right) exp\big(-(\lambda + \rho)(t - t_0)\big)$$

# Component models (examples)

- Tested component

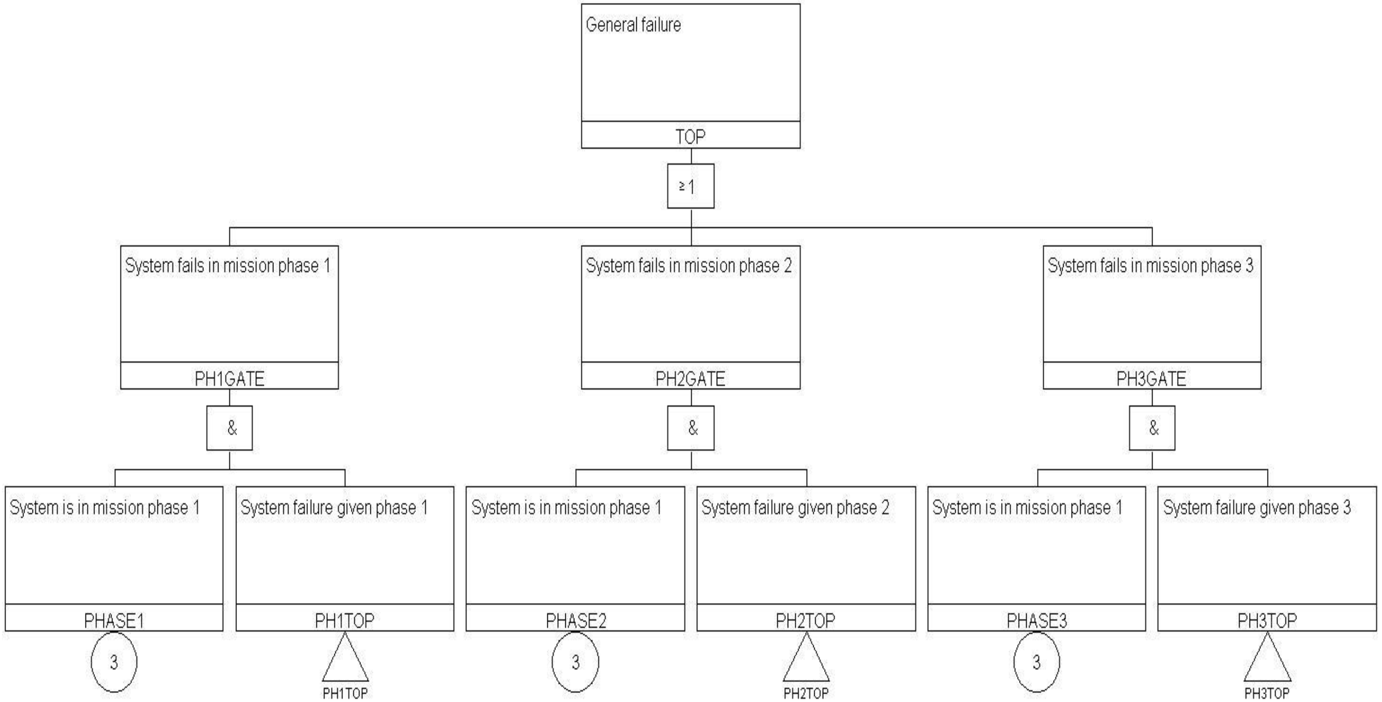
$$U_u(t) = 1 + U_{r0}\frac{\lambda}{\rho - \lambda} exp\big(-\rho(t - t_0)\big) - \left(U_{r0}\frac{\lambda}{\rho - \lambda} + 1 - U_{u0}\right) exp\big(-\lambda(t - t_0)\big)$$

$$U_r(t) = U_{r0} exp\big(-\rho(t - t_0)\big)$$

- After a test, let

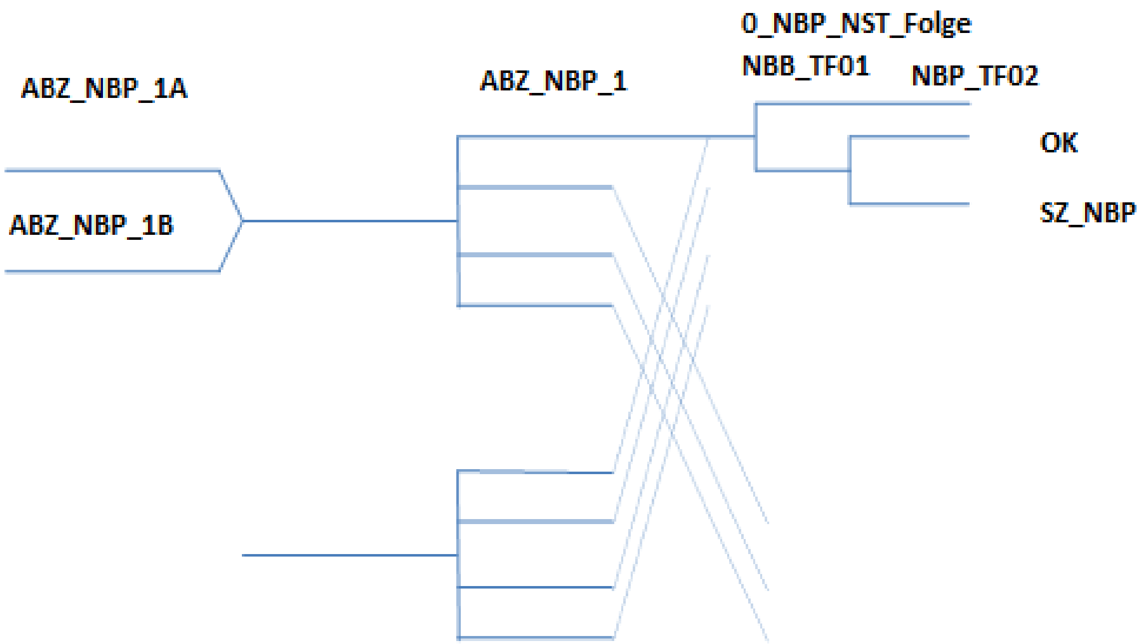
$$U_{r0} = U_u(T_k) + U_r(T_k)$$
$$U_{u0} = 0$$
$$t_0 = T_k$$

# Phased mission fault trees




- 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.

# Phased mission event tree




- 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

# Phased mission starting at a random time point

- 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

RiSA Sicherheitsanalysen GmbH

- 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

$$H_{as}(t_B) = \int_0^{t_B} h_{as}(t)dt$$

# Organizing random phased mission in the PSA code

RiSA Sicherheitsanalysen GmbH

- 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.

# Periods of grace

- 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

$$pr\{T_R > T_G\} = exp(-max(\rho_i))$$

## 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

RiSA Sicherheitsanalysen GmbH

- 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?