Support System Initiating Events Modeling

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Support System Initiating Events (SSIE)

- Events that cause a reactor trip and affect/impair the systems required to mitigate the resulting plant transient.
- SPAR models address loss of service water, loss of component cooling water, and loss of instrument/plant air.
- The SSIE fault tree moves initiating events from the system level to the component level.
  - This is done to better capture the importance of components in these systems.
  - This is done to estimate frequencies that are too low to estimate by direct observation – no system failures have been observed, but component failures are common.
  - This is done to better capture plant-to-plant variability.
- We require a fault tree to predict a system failure frequency, as opposed to a system unreliability or unavailability.

System Failure Occurrence Rate

- SPAR models implement the explicit event method from EPRI report "Support System Initiating Events Identification and Quantification Guideline", 1016741.
- The EPRI method is consistent with NUREG-0492, Equation (XI-28), cut set i contribution to occurrence rate (frequency):

$$w_i(t) = \sum_{i=1}^{n} w_i(t) \prod_{\substack{j \neq i \\ j=1}}^{n} q_j(t)$$

$$= \begin{aligned} & w_{1i}(t) \cdot q_{2i}(t) \cdot q_{3i}(t) \ldots . q_{ni}(t) + \\ & w_{2i}(t) \cdot q_{1i}(t) \cdot q_{3i}(t) \ldots . q_{ni}(t) + \\ & w_{3i}(t) \cdot q_{1i}(t) \cdot q_{2i}(t) \ldots . q_{ni}(t) + \\ & . \\ & . \\ & w_{ni}(t) \cdot q_{1i}(t) \cdot q_{2i}(t) \ldots . q_{ni-1}(t) \quad . \end{aligned}$$

System Failure Occurrence Rate

- Component unconditional failure intensity

$$w_{ni}(t) = [1 - q_{ni}(t)]\lambda_{ni}(t) \approx \lambda_{ni}$$

- Component unreliability (failure with no repair)

$$q_{ni}(T) = 1 - e^{-\lambda_{ni}T} \approx \lambda T$$

where T is some mission time.

- T typically represents the post-trip mission time. 24 hours by default
- Realistic modeling requires the use of unavailability instead of unreliability; repair of components in the target systems if a fact of normal operation.
- q_{ni} provides a good approximation of unavailability when component repair times are 24 hours.

System Failure Occurrence Rate

- If a 24 hour repair time is not sufficient, then we need to introduce new basic events that use the alternate repair time, or LCO.
- The component technical specification limiting condition for operation (LCO) provides a reasonable upper bound. Typically about 72 hours.
- Observe that we can reuse a basic event meant to represent failure of a component to run (unreliability) post-trip as an event meaning a component is in repair (unavailable) when an initiating event occurs!
  - Doing so is redundant if -TM- cut sets are also present.
  - May be hard to convince users of this point.
  - May be better to include the redundant cut sets and frequency contributions than to argue about it (FTR is often negligible when actual TM data is included so point becomes moot).

Initiating Events vs Enabling Events

- SPAR modelers distinguish between component-based “Initiating events” and “Enabling Events”.
- Enabling events put the system in a critical state for the initiating event.
- A critical state is a state that allows the system to transfer from an operating state to a failed state when the initiating event occurs.
- The probability of a critical state for a given component in an unreliability or unavailability model is the Birnbaum of the component.
- SSIE enabling events include routine maintenance and repair that post-trip unreliability models represent as -TM- events.
- Crediting repair or recovery of fail-to-run events may actually be redundant to cut sets involving the -TM- events.

SPAR Application

- Consider the following cut set for two trains operating in active parallel

  {A, B} .

- The SPAR approach is to modify the fault tree giving the above cut set to produce the following cut sets instead

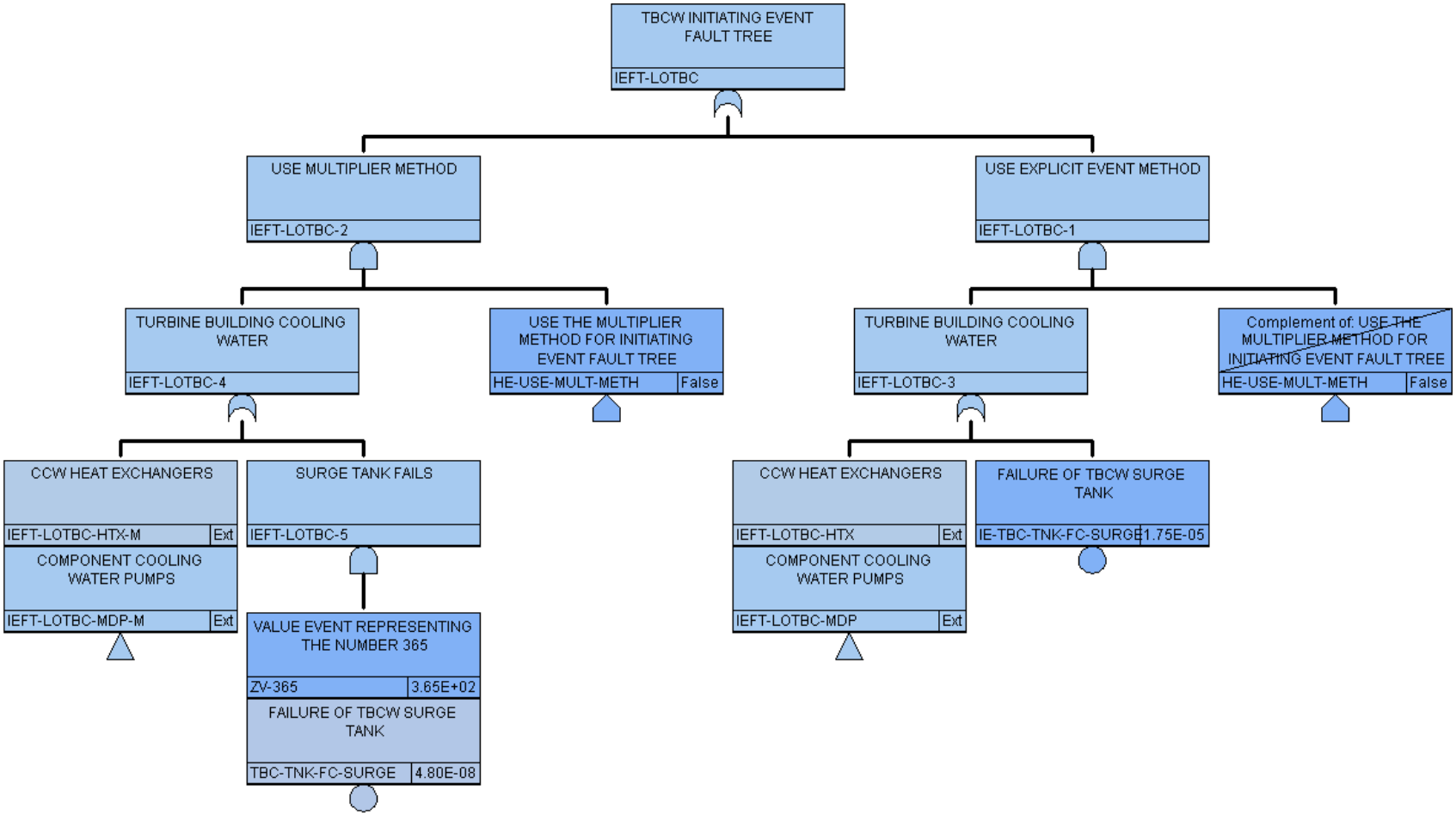
  $\{I_A , B\} ; \{I_B , A\}$

  which are quantified as

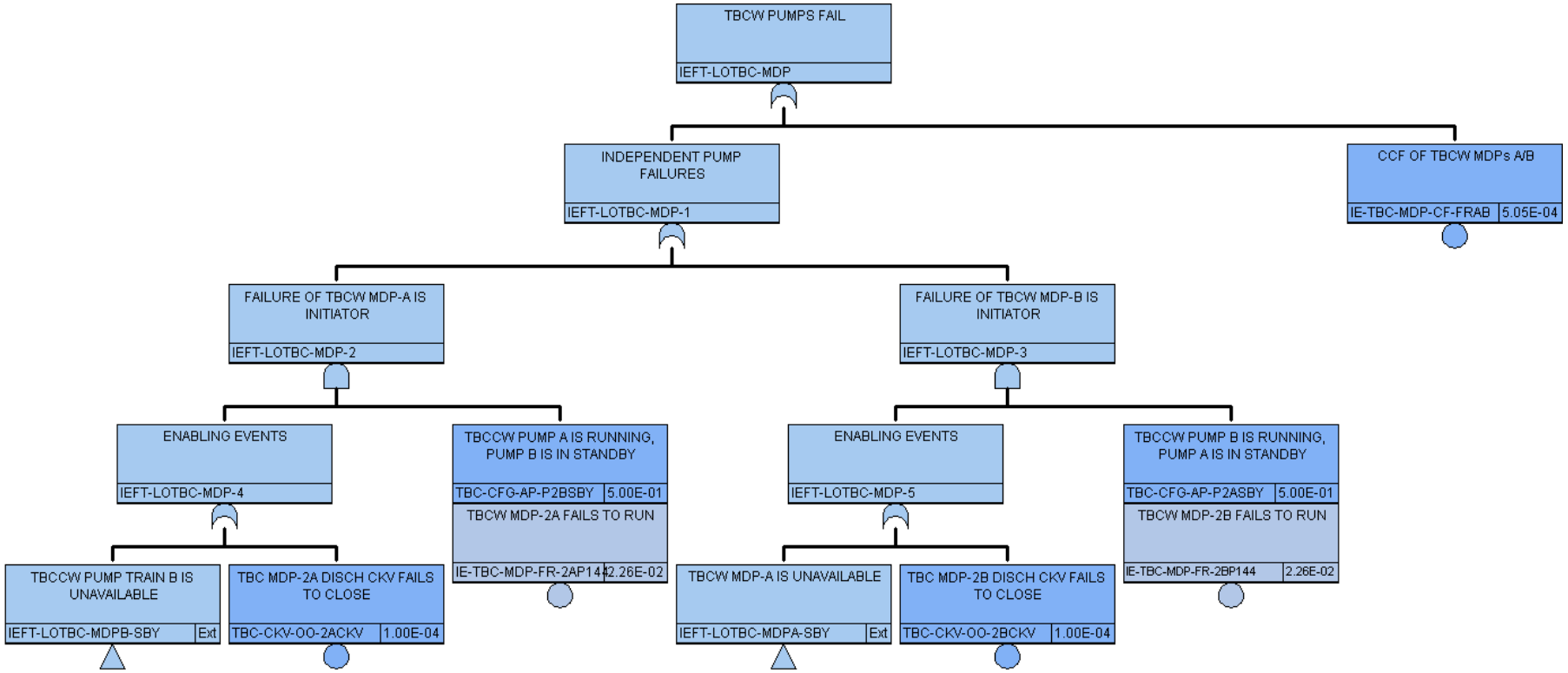
  $$w = w_A \, q_B \; + w_B \, q_A \; .$$

- The expansion required by NURGE-0492 is therefore done in the SSIE fault tree.
- The following slides show what this looks like in a SPAR model.

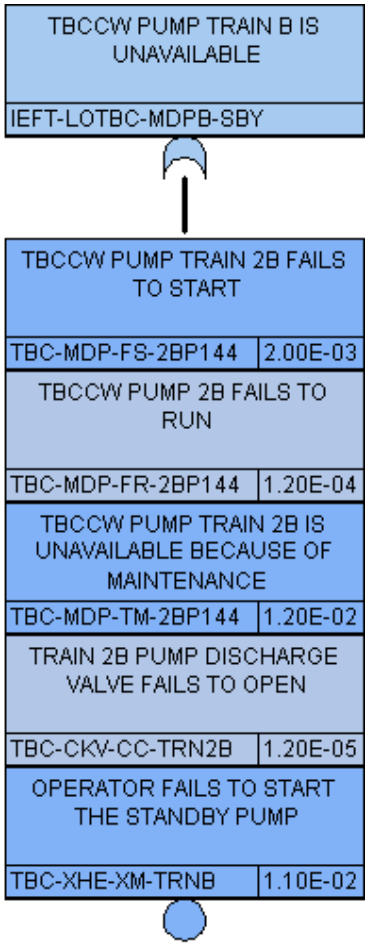
SPAR Model Example



SPAR Model Example (cont.)



SPAR Model Example (cont.)



Common Cause Failure

- Consider a three-train system operating in active parallel. One train is required for success. The cut sets are

  {A, B, C} ; {A, CCF_{BC}} ; {B, CCF_{AC}} ; {C, CCF_{AB}} ; {CCF_{ABC}} .

- Expansion of the second cut set gives

  $w_2 = w_A \, q_{BC} + w_{BC} \, q_A$.

- Need values for both w_{BC} and q_{BC} .
- SAPHIRE has special basic event calculation types, Q and R, that calculate these terms from component total failure rates and alpha factors.
  - Q for initiating event types
  - R for enabling event types

Common Cause Failure (cont.)

- SAPHIRE calculation types implements equation (5.7) from NUREG/CR-5485. Non-staggered testing formulation is used for SSIE applications.
- Initiating and enabling event contributions for CCF_{BC} , CCF_{AC} , CCF_{ABC} are applicable even if train C is in standby.
- Automatic calculation of conditional CCF values for event assessment is not functional.
- ECA requires manual manipulation of events responding to Q_2 , Q_3 , etc. in NUREG/CR-5485.
- Preliminary guidance:
  - Set enabling event to TRUE.
  - Set corresponding initiating event to FALSE.
  - Hand calculate conditional CCF values and apply manually.

Intake Structure Modeling

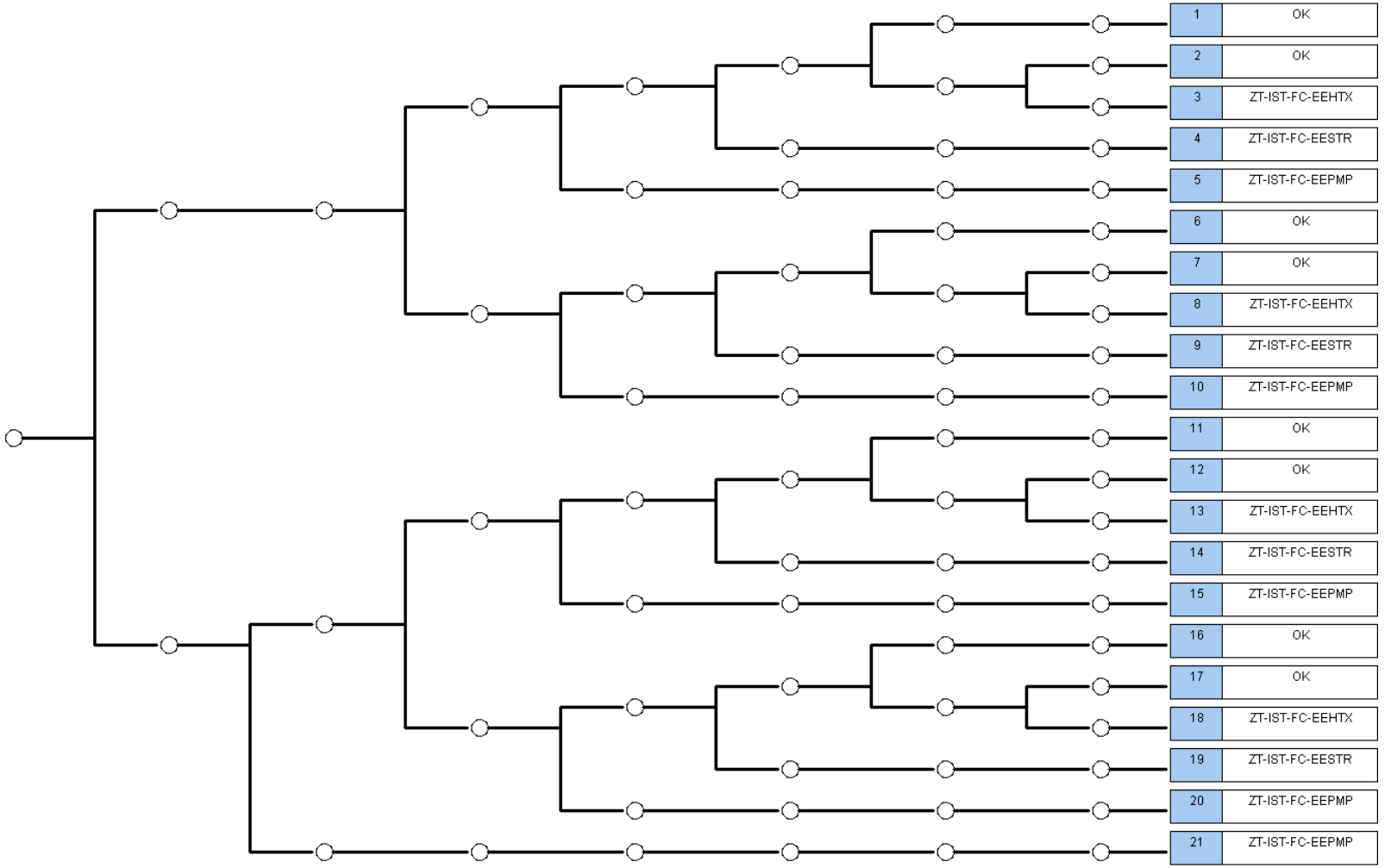
- Event tree resolves component failure rates.
- Rate of occurrence of environmental events (EE) is plant specific.
- Conditional probability of component failure given EE event is not plant specific, or event specific to the type of environmental event.
- Event tree end states are used as templates to quantify basic events in SSIE fault tree for service water systems.
- Linked intake structure event tree model can cause nonsensical output in ECA reports. This does NOT affect the event importance calculation!

Intake Structure Modeling (cont.)

- Intake structure logic is still under development.
  - Subject to collaborative development with EPRI.
  - Environmental impact data not published and may be subject to change as feedback is received from EPRI and it's contractors.
  - Preliminary logic and data are in place and will be used when SSIE logic is enabled.

Intake Structure Modeling (cont.)

EXTREME ENVIRONMENTAL EVENT	TSA FLOW	INTAKE STRUCTURE LEVEL	TSA FILTRATION	PUMP FLOW	STRAINER FLOW	STRAINER FILTRATION	HEAT EXCHANGER SWS SIDE FLOW	#	End State (Phase - CD)
ZT-IST-IE-EE	ZF-TSA-PG	ZF-IST-LV	ZF-TSA-BP	ZF-PMP-FR	ZF-STR-PG	ZF-STR-BP	ZF-HTX-PG	1	OK
								2	OK
								3	ZT-IST-FC-EEHTX
								4	ZT-IST-FC-EESTR
								5	ZT-IST-FC-EEPMP
								6	OK
								7	OK
								8	ZT-IST-FC-EEHTX
								9	ZT-IST-FC-EESTR
								10	ZT-IST-FC-EEPMP
								11	OK
								12	OK
								13	ZT-IST-FC-EEHTX
								14	ZT-IST-FC-EESTR
								15	ZT-IST-FC-EEPMP
								16	OK
								17	OK
								18	ZT-IST-FC-EEHTX
								19	ZT-IST-FC-EESTR
								20	ZT-IST-FC-EEPMP
								21	ZT-IST-FC-EEPMP



Current Status of SSIE Model Implementation

- **BWRS:**
  - The following BWR models still require updates:

Browns Ferry 1
Browns Ferry 2
Browns Ferry 3
Brunswick 1
Grand Gulf
Peach Bottom 2
Peach Bottom 3

  - Currently reviewing the previously completed models to ensure consistency.
- **PWRS:**
  - All PWR models have been completed.
  - San Onofre and Kewaunee are not getting SSIE models since they are shutdown.
  - Currently reviewing the previously completed models to ensure consistency.
- **All models will be completed and ready for use at the end of August 2015, and should be posted for general NRC use in 2016.**