Vysus Group

Current Status of RASTEP

An Emergency Preparedness and Response decision support tool

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Ingenuity.
Imagination.
Insight.

PSAM18, Pittsburgh

RASTEP Context

“Normal” situation

Detailed and complex set of assessment criteria

Detailed and complex set of mathematical models

Comprehensive & extensive documentation

Large amounts of information and data available

Not time-critical

RASTEP Context

Emergency situation

Approximately how much?

Approximately when?

Need for quick decisions

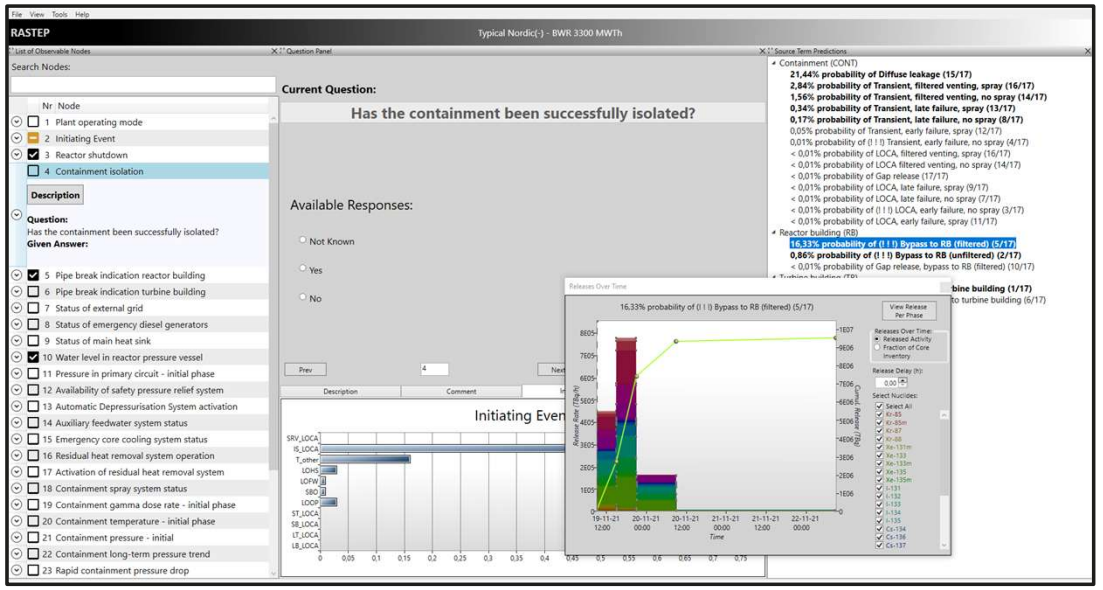
Information and data may be limited, uncertain or delayed

RASTEP Overview – History

2010: The Swedish Radiation Safety Authority (SSM) wanted a radioactive release estimation tool for use during the early stages of a severe accident, when little information would be available.

- The idea was to replace missing information with likelihoods.
- A suitable probabilistic model for taking
  new information into account is a so-called *Bayesian Belief Network.*

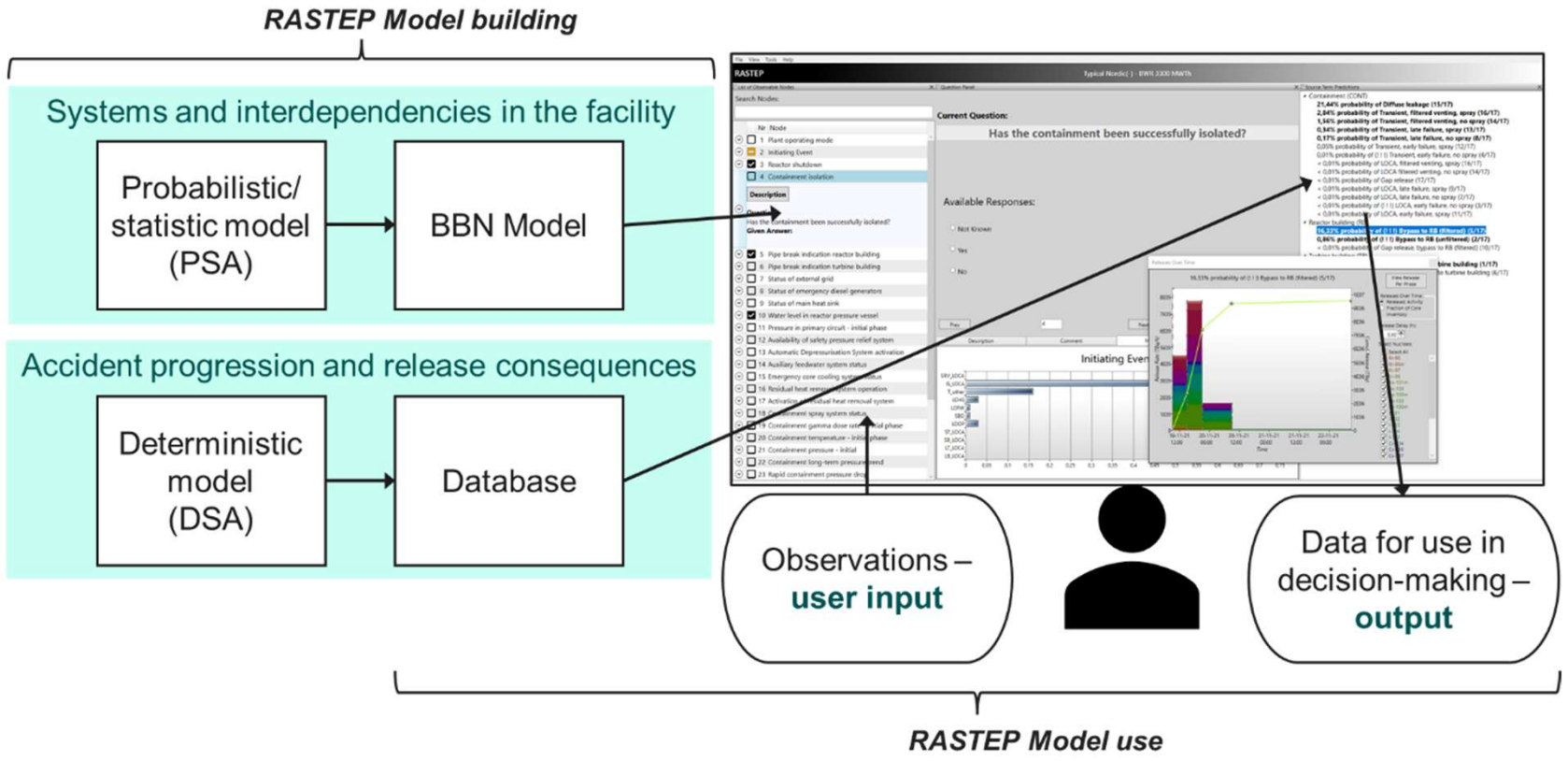
⟶ Vysus Group, previously Lloyd's Register Energy, initiated the development of RASTEP, funded by SSM.



The RASTEP graphical user interface, version 1.4, released 2021.

Strål säkerhets myndigheten
Swedish Radiation Safety Authority

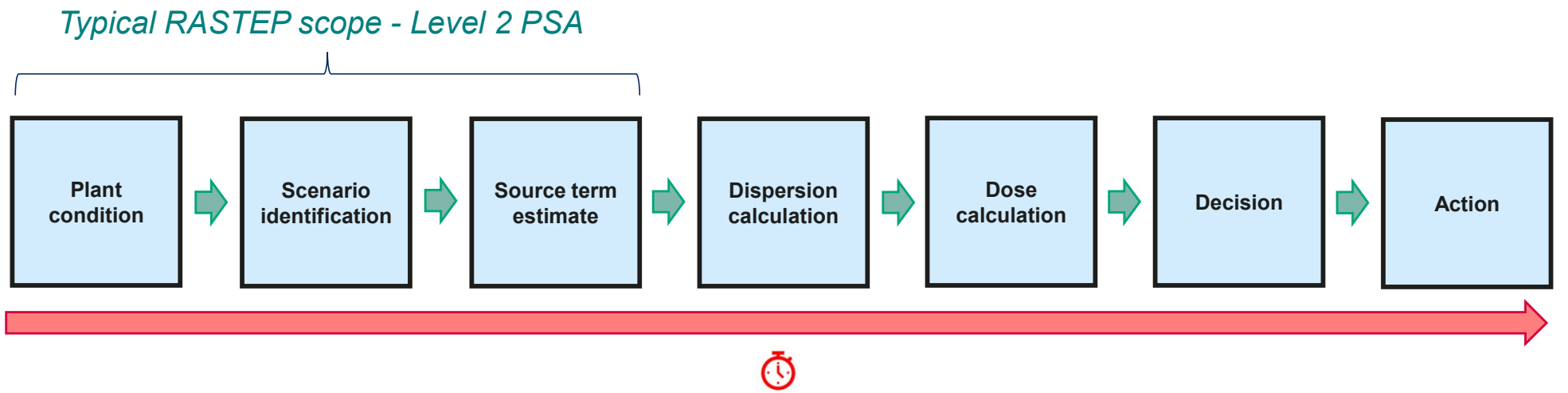
RASTEP Overview – Solution



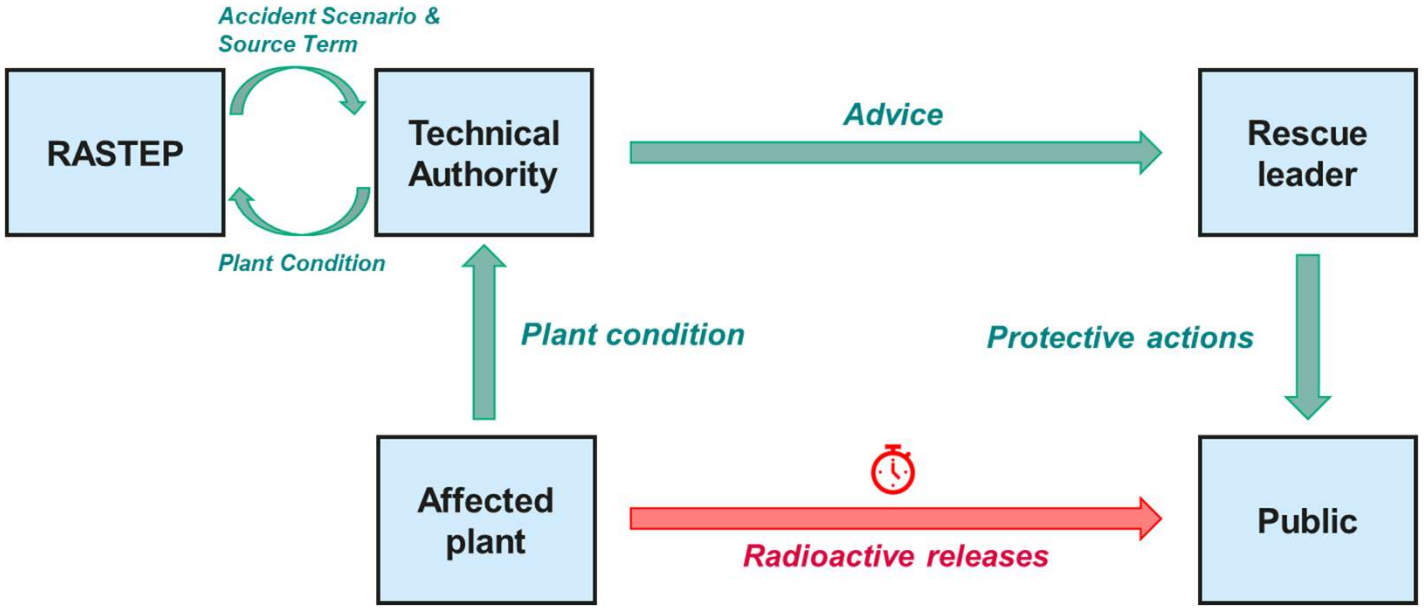
RASTEP overview

- The goal of RASTEP is to provide emergency preparedness organisations with decision support for independent evaluation of severe accident progression and possible off-site consequences.
- User input:
  - Observations of an ongoing event
- Typical output:
  - Likelihood ranking of output categories (release categories for Level 2 PSA).
  - Pre-calculated data for the output category of interest (source term data for Level 2 PSA).
- Method developed since 2009
- Graphical user interface launched in 2015

RASTEP Scope



RASTEP Objectives



RASTEP modelling

(Level 2 PSA Scope)

- Mapping of plant characteristics
  - Source term volumes (STV) to be considered
  - Fission product transport and release paths
  - Relevant plant systems
  - Severe accident management systems and actions
  - Physical phenomena
  - Observable plant state parameters
  - Release categories

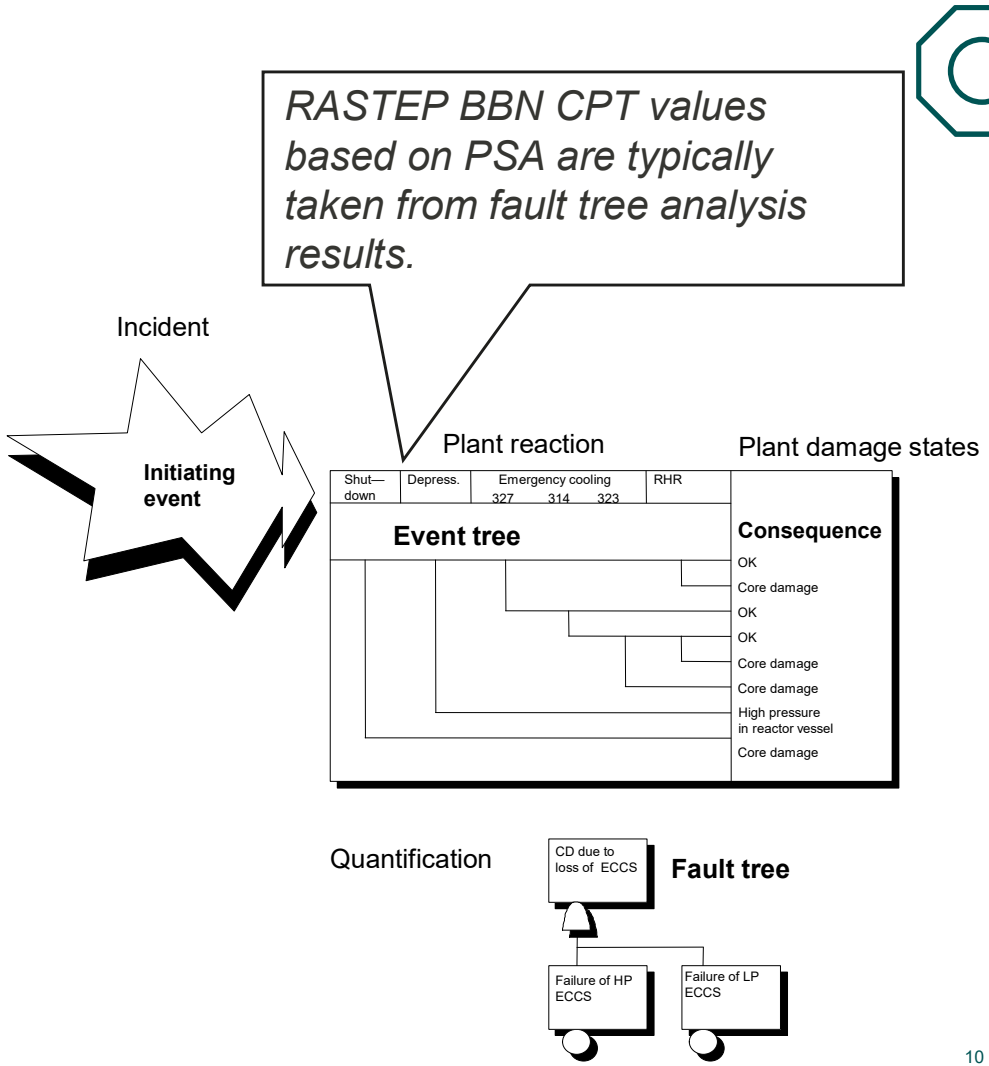
- General development strategy
  1) Model structure
  2) Conditional Probability Tables (CPTs)

RASTEP Scope: PSA L1

Initiating events
- Incident or accident (internal or external event), which initiates a plant shutdown by means of the safety systems functions.
  - RASTEP: Define IE groups in RASTEP and relative likelihoods for different IE groups (CPTs)

Event tree
- Describes the plant reaction caused by the incident, thereby systematically identifying different possible event sequences
  - RASTEP: Define the logical structure of the model and system requirements for different initiating events and boundary conditions.

Fault tree
- Shows the structure of the safety systems, including possible faults and dependencies (power supply, pressurized air, cooling...).
- Logical model which quantifies and can be used to calculate the frequency of events.
  - RASTEP: Define probabilities of safety systems failures given the type of initiating event, system requirements, dependencies, etc. The probabilities are implemented in the BBN CPTs.



PSA L2: Start and end points

Initiating event
= as in PSA Level 1

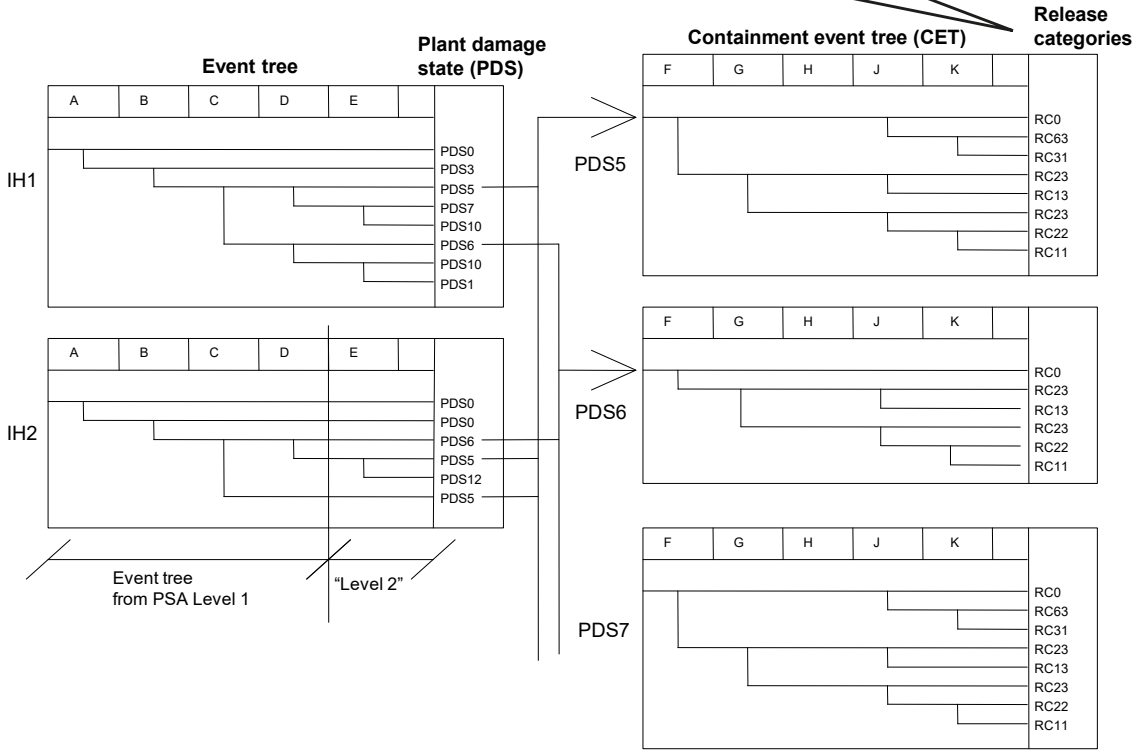
Event tree
~ as in PSA Level 1

Plant damage state (PDS)
- Characterization of the PSA Level 1 final state in a way that is assigned to further analysis within PSA Level 2.

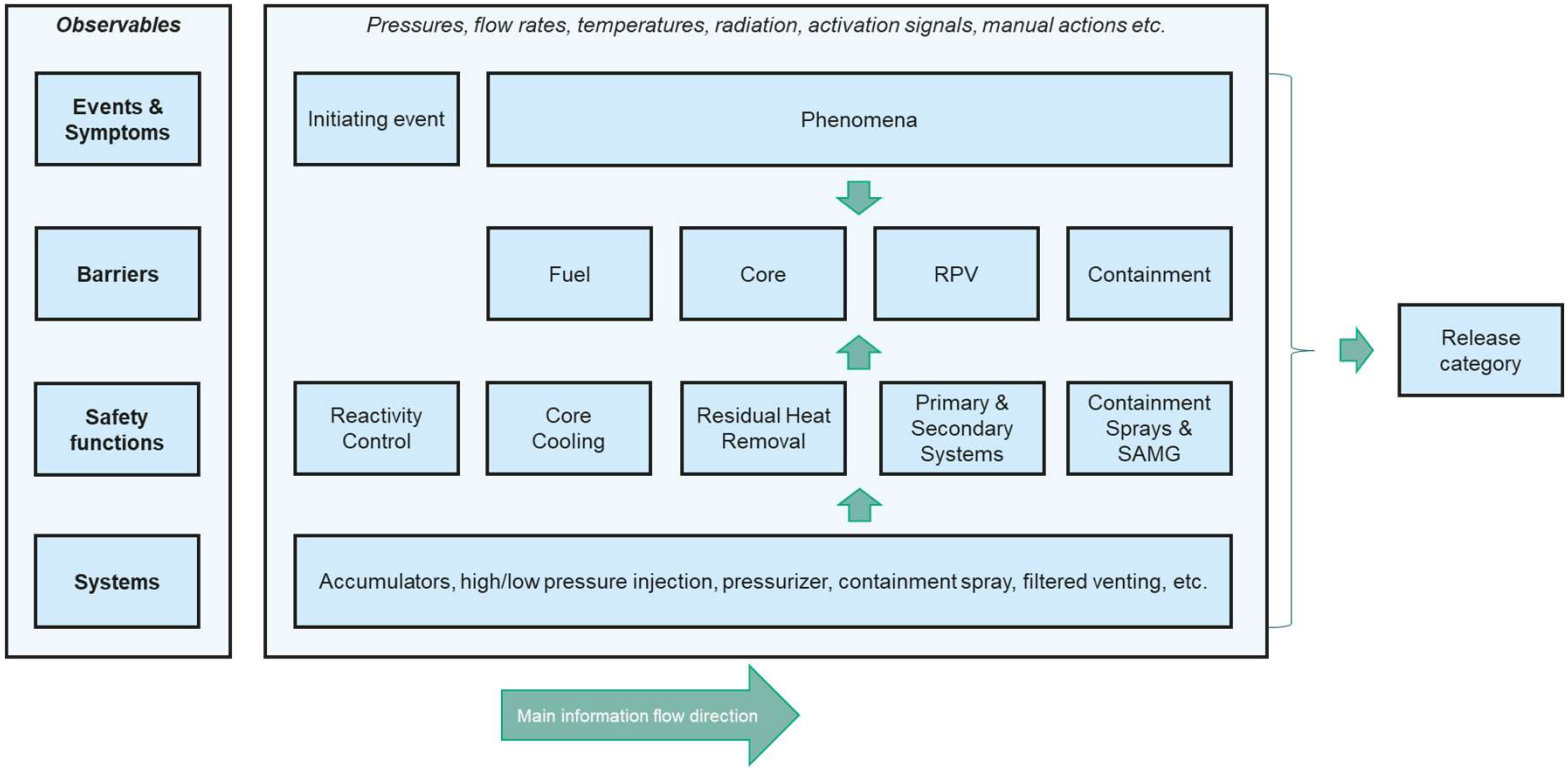
Containment event tree (CET)
- Progression of the incident, including emergency systems, phenomena and severe accident management.

Release categories
- Final state of the CET. Characterization of the release path of radioactive nuclides and events during the sequence.
  - RASTEP: define source terms for different accident sequences.

RASTEP output nodes are typically based on the release categories.



RASTEP Model Structure



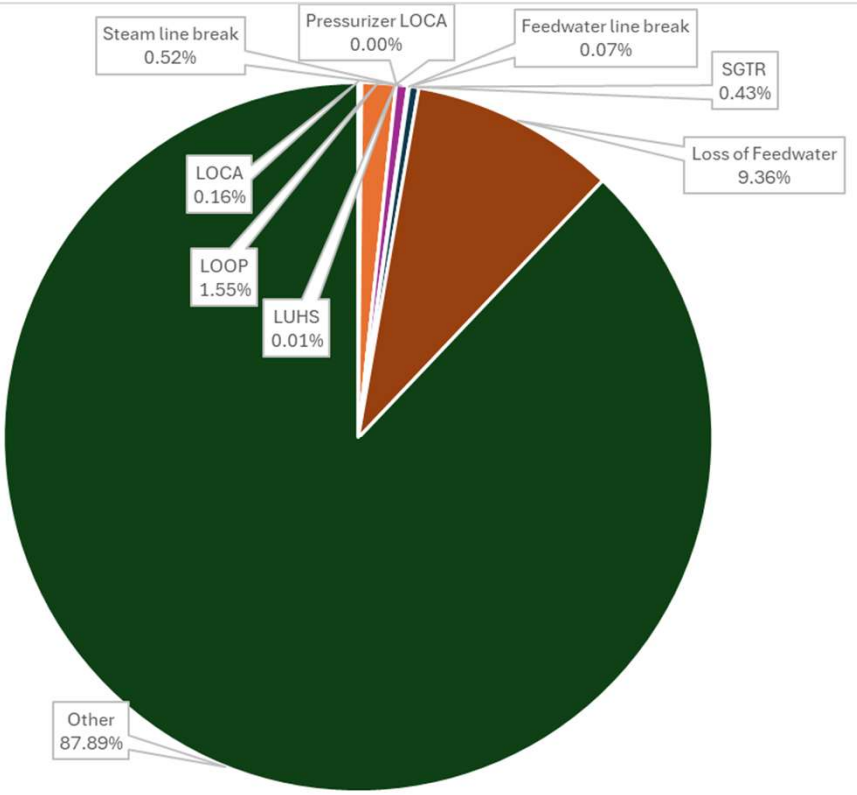
RASTEP: IE groups (example)

Grouping of initiating events

- The scope is typically limited to the internal events during full power operation.

- Initiating events were grouped as it has been judged unnecessary to discriminate between them for severe accident source term estimation.

RASTEP model IE group	Initiating event
Large LOCA	Large LOCA
Medium LOCA	Medium LOCA
Small LOCA	Small LOCA
Small LOCA PRZ	Pressurizer LOCA
Steam line break	Steam line break
Feedwater line break	Feedwater line break
SGTR	Steam Generator Tube Rupture (SGTR)
	Steam line break induced SGTR
Loss of offsite (AC) power	LOOP
Loss of ultimate heat sink	Total Loss of ultimate heat sink
Loss of feedwater	Loss of feedwater Loss of compressed air
Other transients	Spurious reactor trip Transient on primary loop Transient on secondary loop

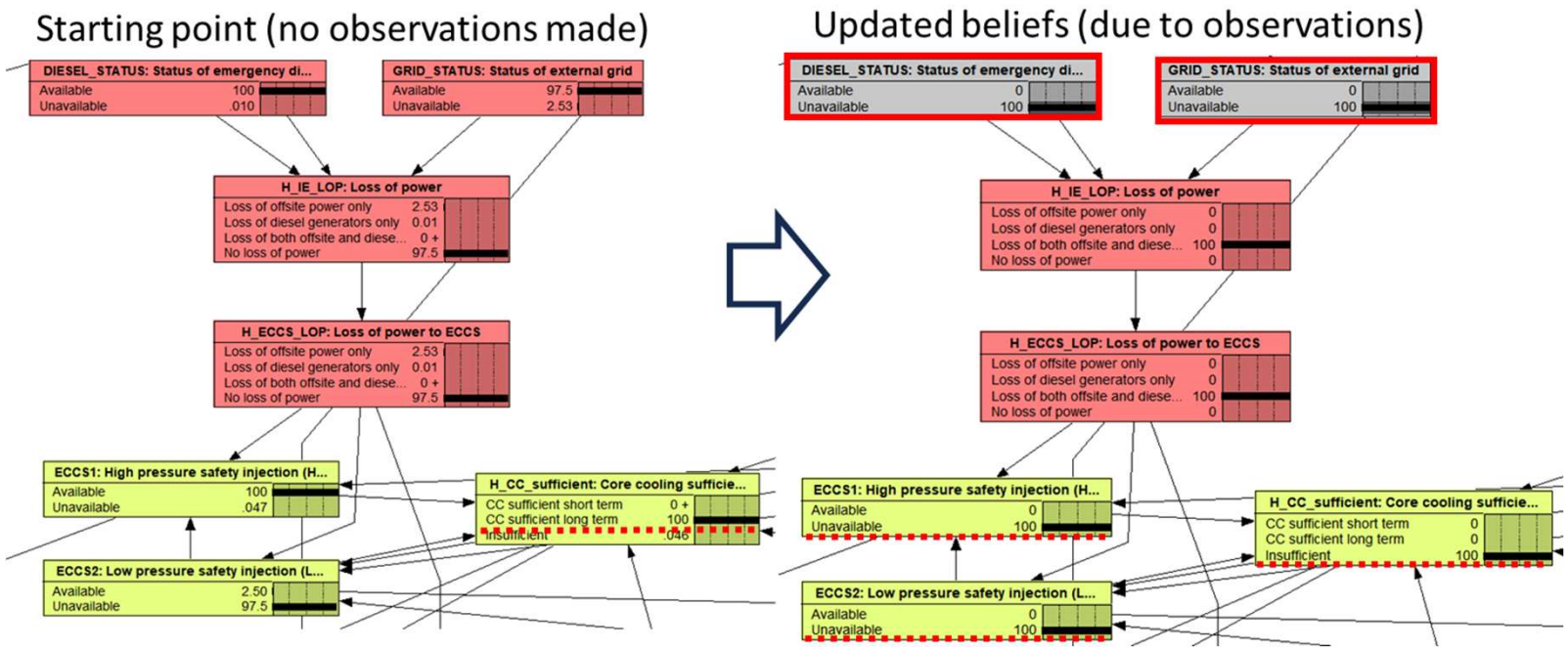


RASTEP model – Safety Function and Systems (Example)

- Selection of safety systems to be included in the RASTEP model was based on the PSA L1 ET and L2 CET.
  - Values in CPTs for different safety systems are based on PSA and include information on:
    - > *System success criteria for different initiating events and boundary conditions.*
    - > *System dependencies.*

Safety Function	Safety System/Equipment
Reactivity Control	Control Rods
	Boron Injection System
Core cooling, primary inventory control	Low pressure injection systems
	High pressure injection system
	Accumulators (3 hydro accumulators are respectively connected to the three cold legs of the RCS)
	Boron injection tank and boron surge tank
	Boron recirculation
	Pressurizer
	RWST
Residual heat removal	High pressure injection system
	RHR heat exchangers
	Primary feed & bleed
Primary depressurization	PORVs
	Pressurizer relief tank
Secondary system isolation	Main Steam Isolation Valves
Secondary system inventory control / heat sink	Condenser
	Atmospheric relief valves
	Feedwater system
	Auxiliary feedwater system

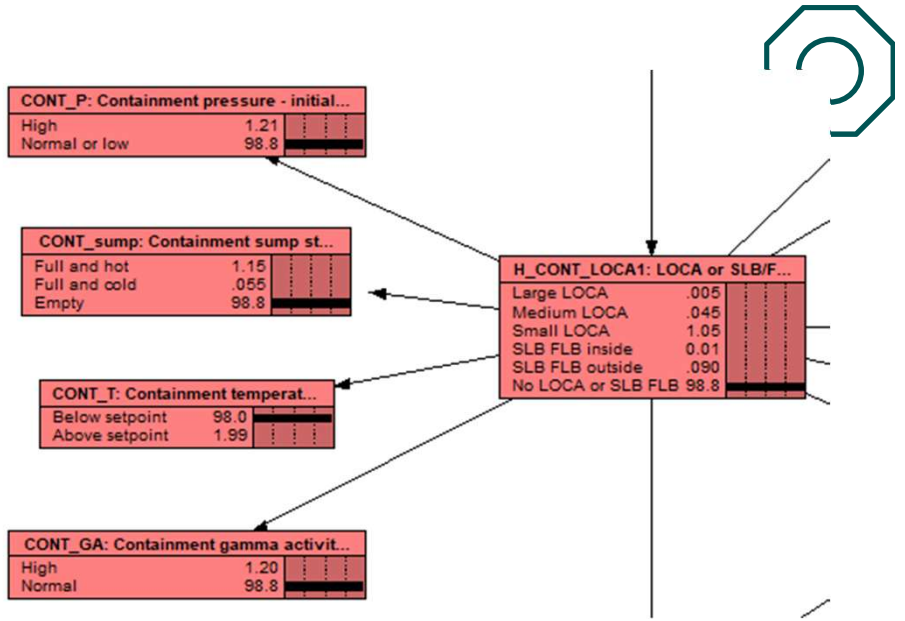
RASTEP Example: ECCS



RASTEP modelling

Organization of nodes into *hidden* and *observable.*

- Observable nodes are assigned a question which is displayed by the RASTEP GUI.
- Hidden nodes are used to group intermediate conclusions, in this example regarding various types of LOCA events.
- Probabilities of false high and false low need to be taken into account in the CPTs of observable nodes representing direct measurements.



Hidden nodes can be either probabilistic or deterministic:

- Probabilistic nodes are based on PSA (system availabilities under different conditions calculated using fault tree analysis, probabilities of phenomena) or expert judgment.
- Deterministic nodes employ 0 or 1 probabilities in the conditional probability tables (CPTs).
  - Typically, model logical relations between other nodes (e.g. system dependencies on other systems or system requirements as in event tree analysis in PSA, where different outcomes represent different branches in the event tree).

RASTEP modelling

A node can be made observable if:

- Its states during an accident can be deduced through observation
- Its conditional probability table can be filled

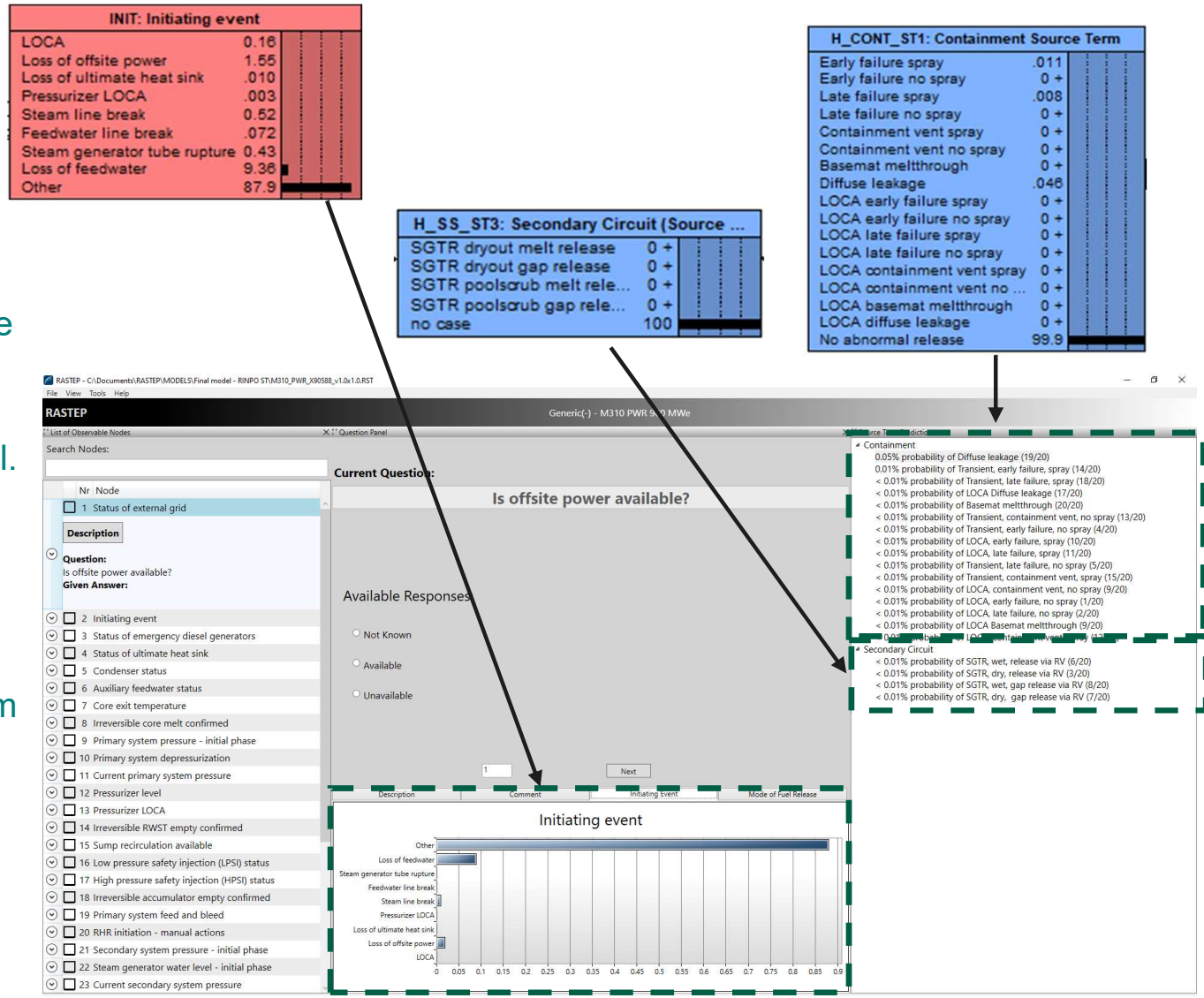
Types of observable nodes:

- Observable nodes of type A *“What we can see or measure”*
  - Temperatures, pressures, dose rates, etc.
- Observable nodes of type B *“What we can do to the system”*
  - Operator (manual) actions
- Observable nodes of type C - *More or less complex qualities.*
  - System response, such as availability.

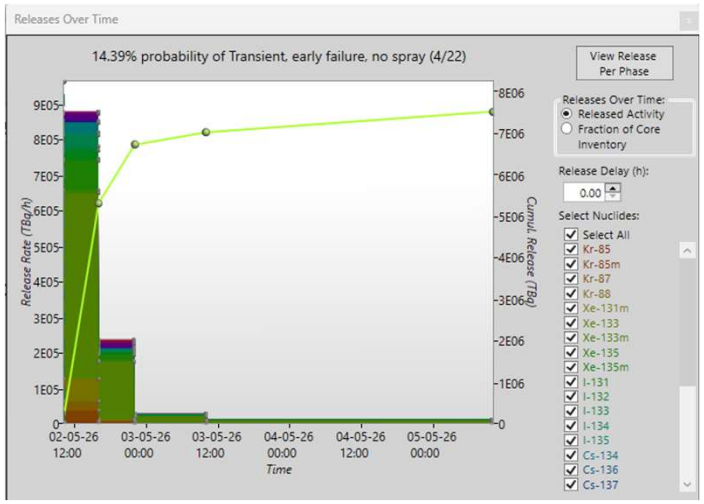
RASTEP modelling

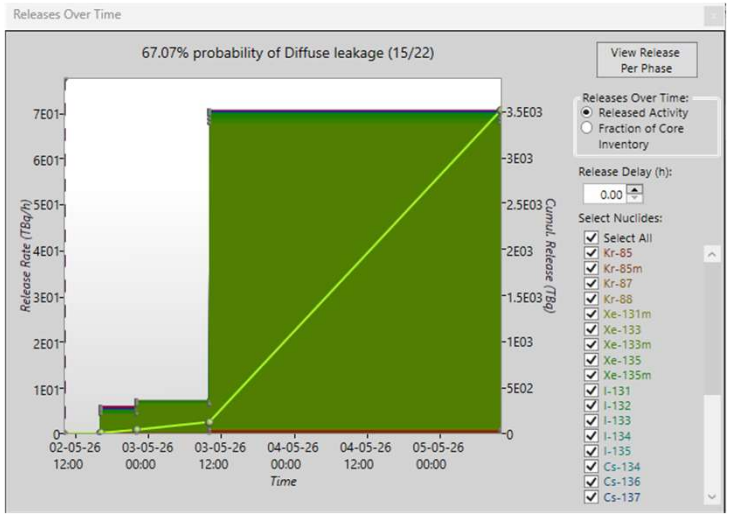
Initiating event and source term nodes

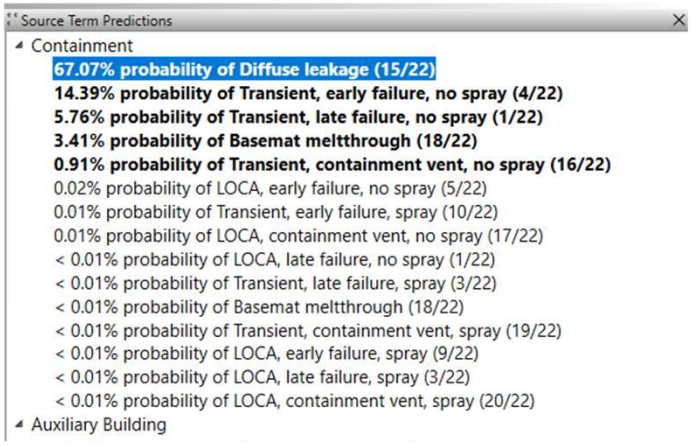
- The initiating event and source term (release category) nodes represent the start and endpoints of PSA L1&L2.
- External and/or area initiating events are not explicitly included in this model. Their effects can still be captured through system availability, but the initiating event guess will be limited to the included internal events.
- Bypass cases are included by using separate building structure source term nodes.



Example of RASTEP Likelihood ranking of Source Terms







Model V&V

Validation activities cover the following aspects:

- Independent expert review using pre-defined checklists;
- Convergence testing showing the model homes in on the correct scenario as observations accrue.
- Out-of-sample validation to check against scenarios through MELCOR/MAAP that were not used to build the model logic, nodal questions and corresponding observations and check whether predicted source-term categories match.

Future improvements:

- VG is developing automated approaches for out-of-sample validation, including the evaluation of the effect of missing evidences (plant measurements or observations).
- PRA and DSA adequacy and the effect of uncertainties.

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Thank you