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Swedish Radiation Safety Authority

NKS Seminar on the Fukushima Accident
and Perspectives for Nordic Reactor Safety and Emergency Preparedness
Finlandshuset, Stockholm, 8-9 January 2013

Source Term Estimation

Improving the Assessments

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Accident Management

- Defence-in-depth approach requires that severe accident management measures, including assessment of plant status and source term prognosis, should be possible to perform even in situations with severely damaged infrastructure and limited information about plant parameters.
- The loss of AC and DC power in Fukushima accident resulted in complete loss of instrumentation thus making the execution of accident management actions and release evaluations extremely difficult.
- In Sweden, dedicated severe accident instrumentation was installed after TMI-2 accident, with own batteries which should provide power during at least 24 hours and with the possibility for recharging the batteries using mobile equipment.

The first release may come relatively early

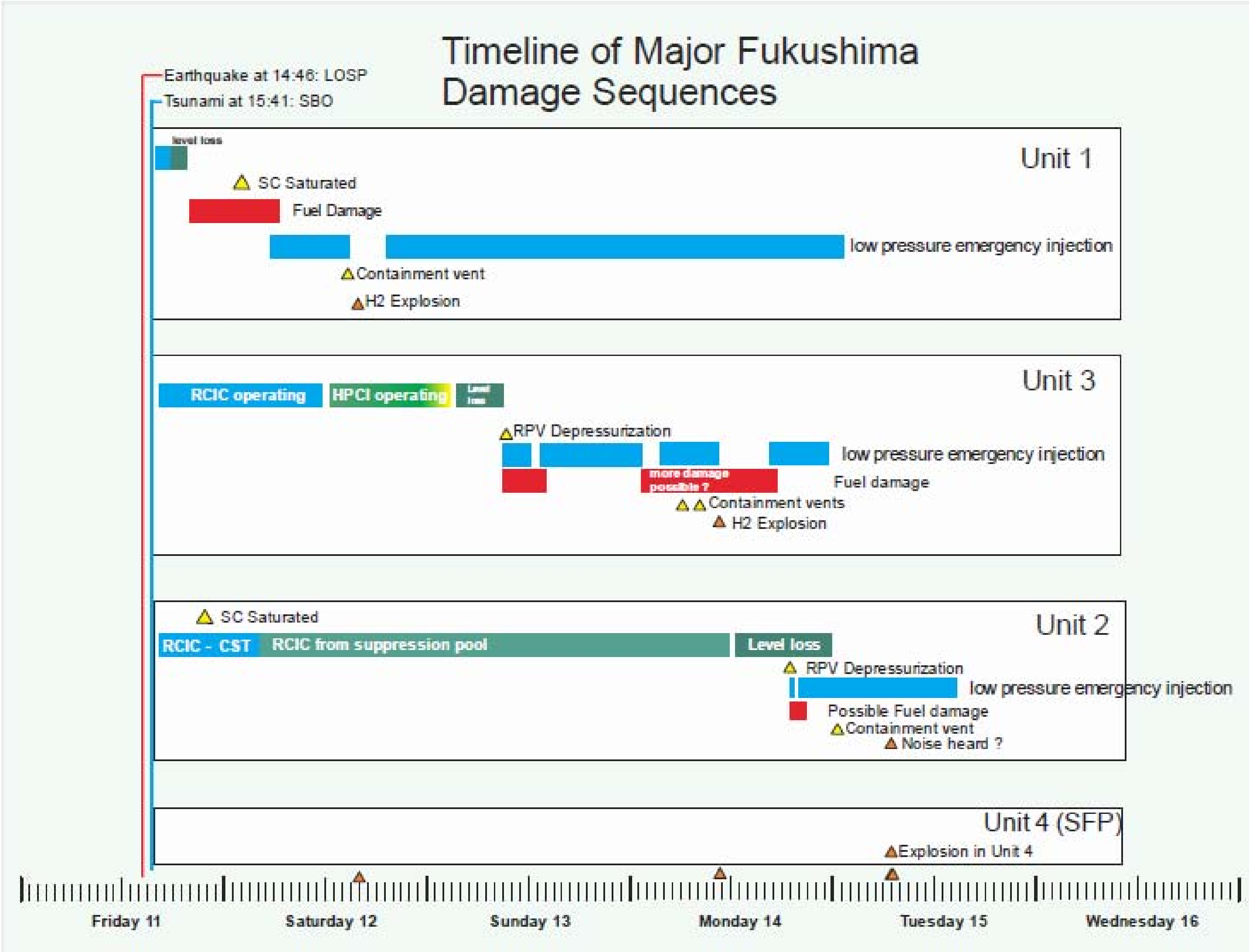
(the times stated below apply to Station Blackout scenario
for Swedish reactors and are approximate)

- Core uncovery
  - 10 minutes in BWR, more than 1 hour in PWR
- Core melt begins
  - 40 minutes in BWR, a couple of hours in PWR
- Reactor vessel melt-through
  - 4 to 5 hours in BWR and PWR
- Automatic activation of filtered containment venting
  - After 4 hours, at the earliest
- Early, unfiltered large release can not be excluded, for example in connection with vessel melttrough (considered as residual risk, subject of research and continuous reassessments)

The need for rapid source term estimation system

- The source term is the quantity, characteristics and timing of the release of radioactivity to the environment through available release paths (including height and thermal energy of the release).
- Today the assessment of plant status and of initial source term are often based on relatively simple tabulations and handbooks (robust, relatively easy to use, conservative source term, limited possibility of diagnostics of plant status).
- Recent developments in Decision Support Systems for emergency response have been predominantly concerned with improvements of models for dispersion, radiological consequence assessment or countermeasures planning.
- A rapid source term estimation system is increasingly desired by off-site emergency planning and response personnel.

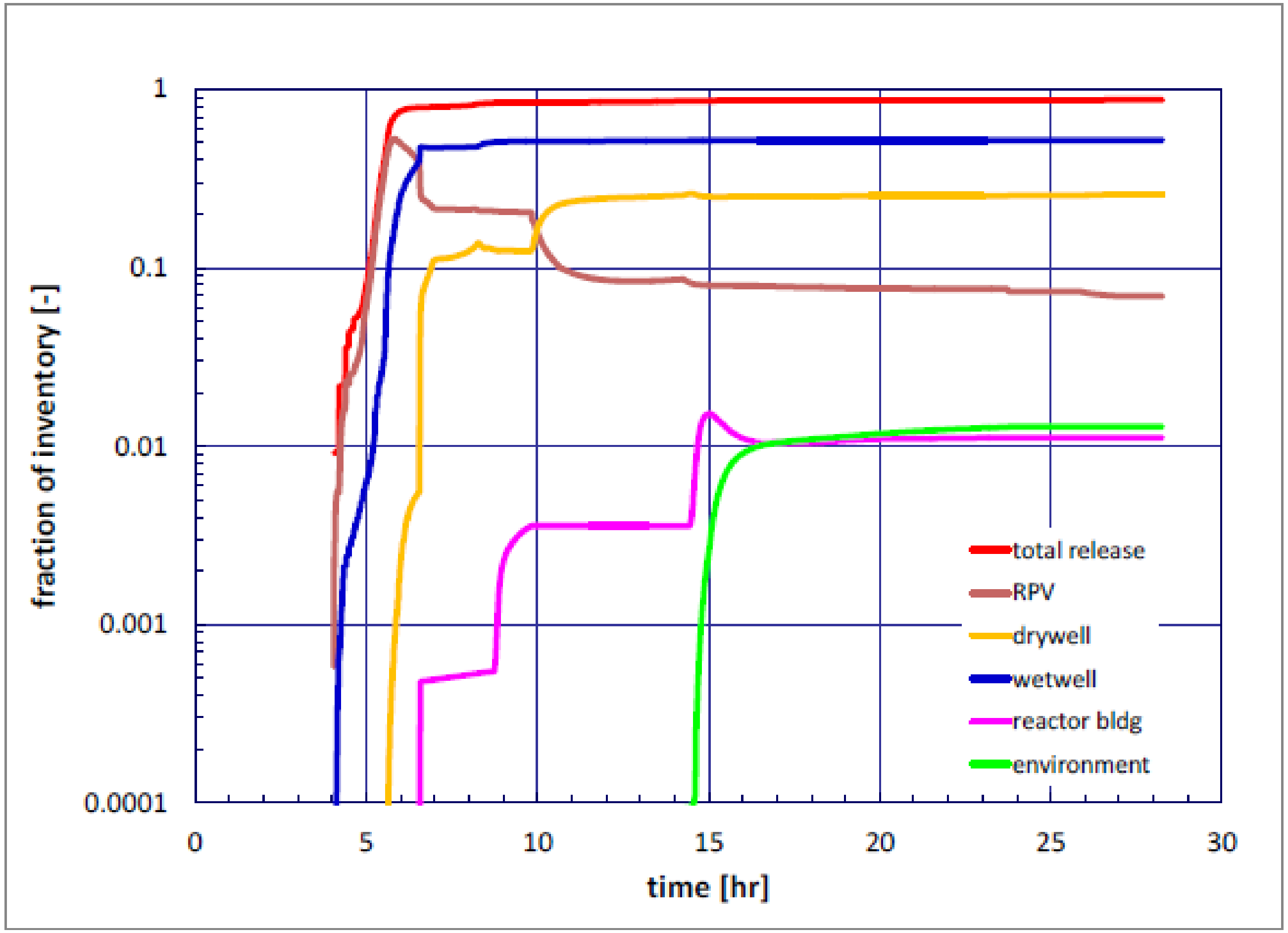
The warning time for evacuation will vary significantly depending on reactor design



MELCOR predicted CsI distribution in Fukushima Unit 1

(Release to environment from the reactor building explosion is not reflected in this distribution)

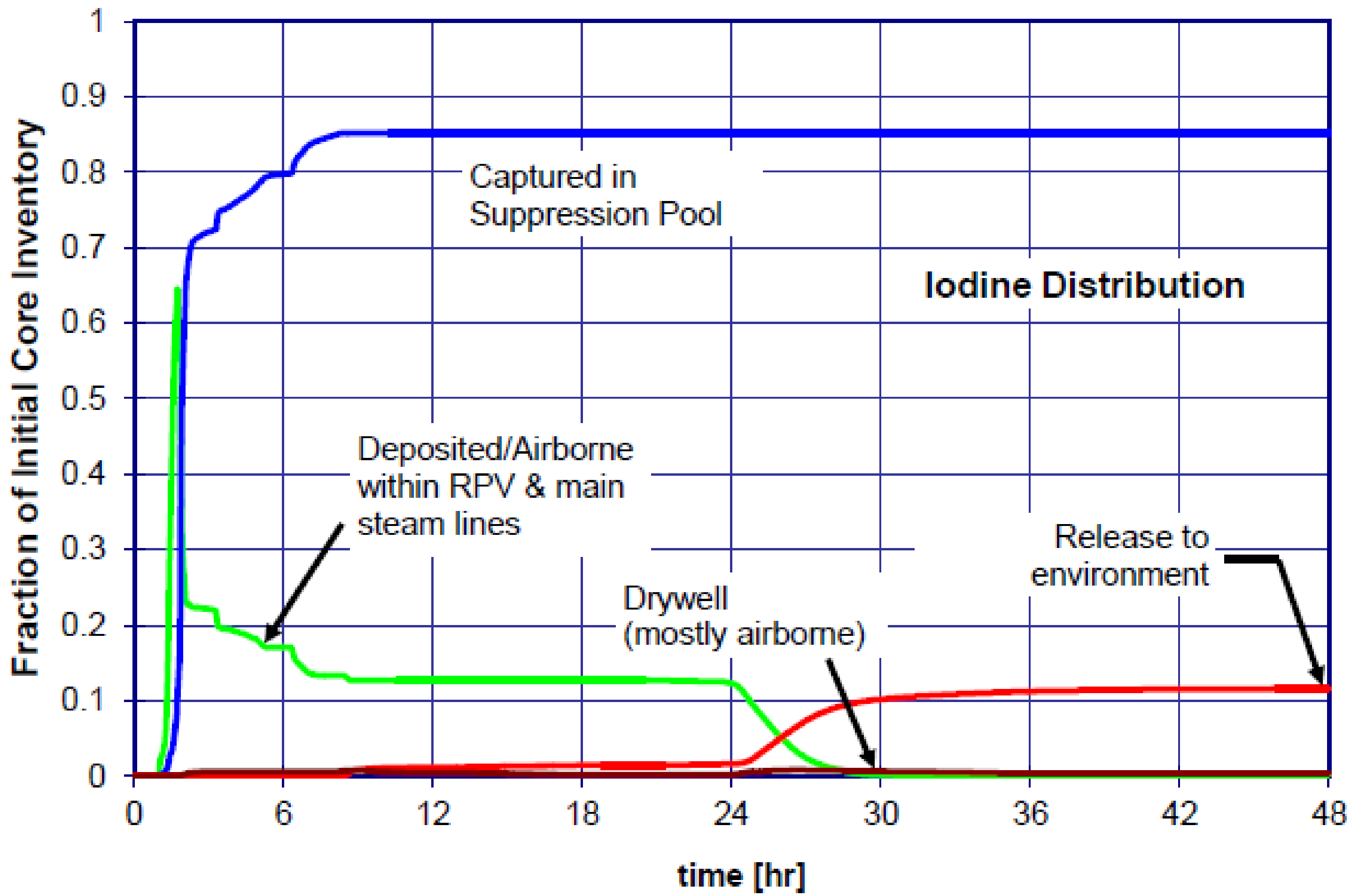
Ref.: R. Gauntt et al., Fukushima Daiichi Accident Study, SAND 2012-6173, August 2012.



Peach Bottom BWR Station Blackout Scenario: Spacial distribution of iodine

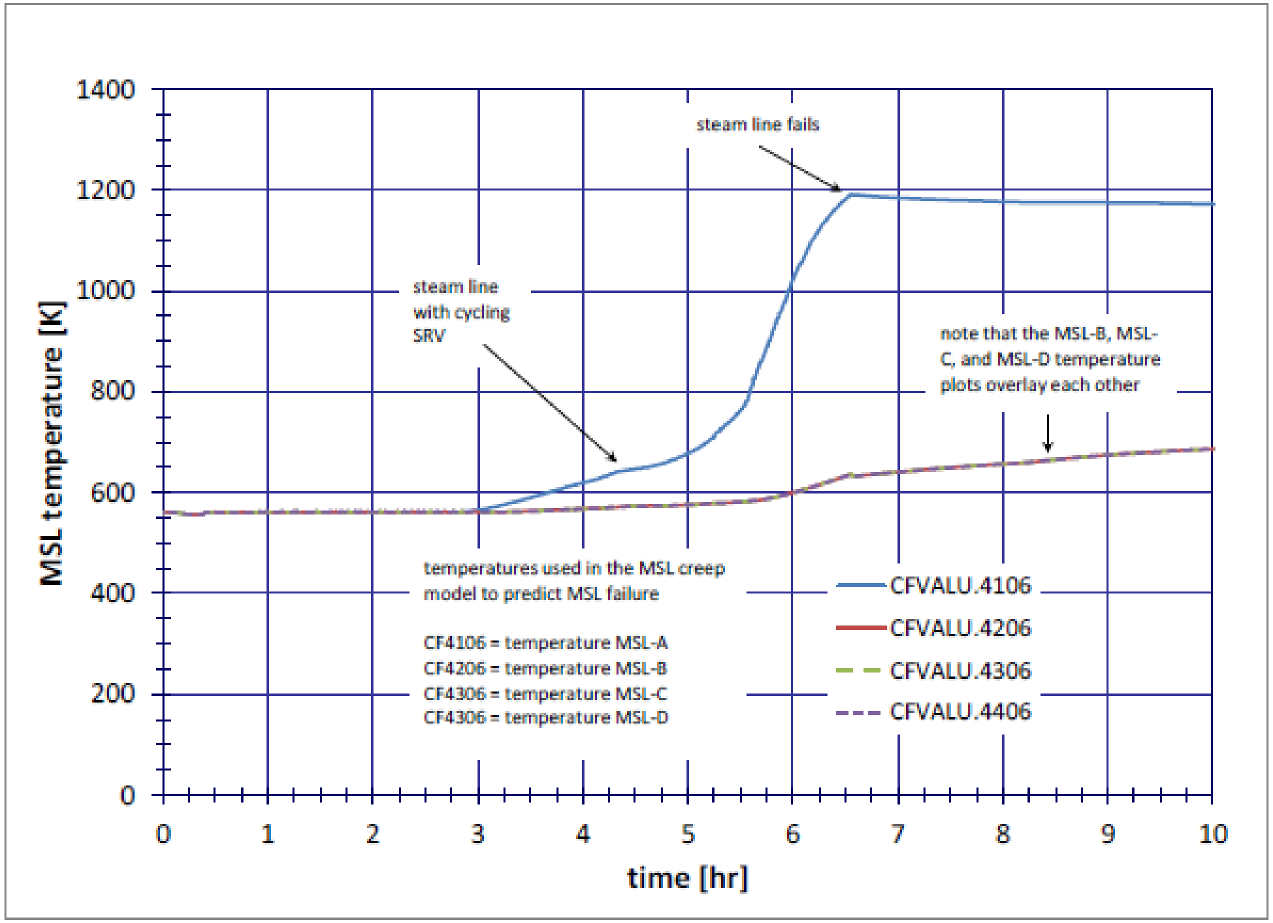
Note late release as a result of revaporization of CsI initially deposited on surfaces within the reactor coolant system

Ref.: State-of-the-Art Reactor Consequence Analyses Project, NUREG/CR-7110, Vol. 1, January 2012



MELCOR-predicted failure of steam line due to high gas temperature in Fukushima 1 (high pressure in RPV) results in fission products release directly to the drywell

Ref. R. Gauntt, CSARP-meeting, September 2012



SSM's tool for rapid source term prediction (1)

- SSM is developing, by contract with Scandpower AB, a computerized tool RASTEP (RApid Source TErm Prediction) for fast, online accident diagnosis and source term prediction, for practical use in severe accident situations, including interfaces to the LENA and ARGOS off-site dose calculation tools.
- RASTEP will be primarily tailored to the needs of SSM's emergency preparedness organisation but it could also be used at the Technical Support Centre at the nuclear power plants.
- As a starting point the project has used the outcome of EU project STERPS (Source Term Indicator Based on Plant Status).

SSM's tool for rapid source term prediction (2)

- The methodology is based on developing a plant model using the Bayesian Belief Network (BBN) technique, making extensive use of Probabilistic Safety Assessment (PSA) information.
- The BBN model is based on prior information from the plant PSA model which is iteratively updated based on plant observables.
- Source term definition and severe accident progression uses information from deterministic severe accident analysis tools, e.g., MELCOR and MAAP.
- The tool shall interface with commonly used off-site dose calculation tools, e.g., LENA and/or ARGOS.

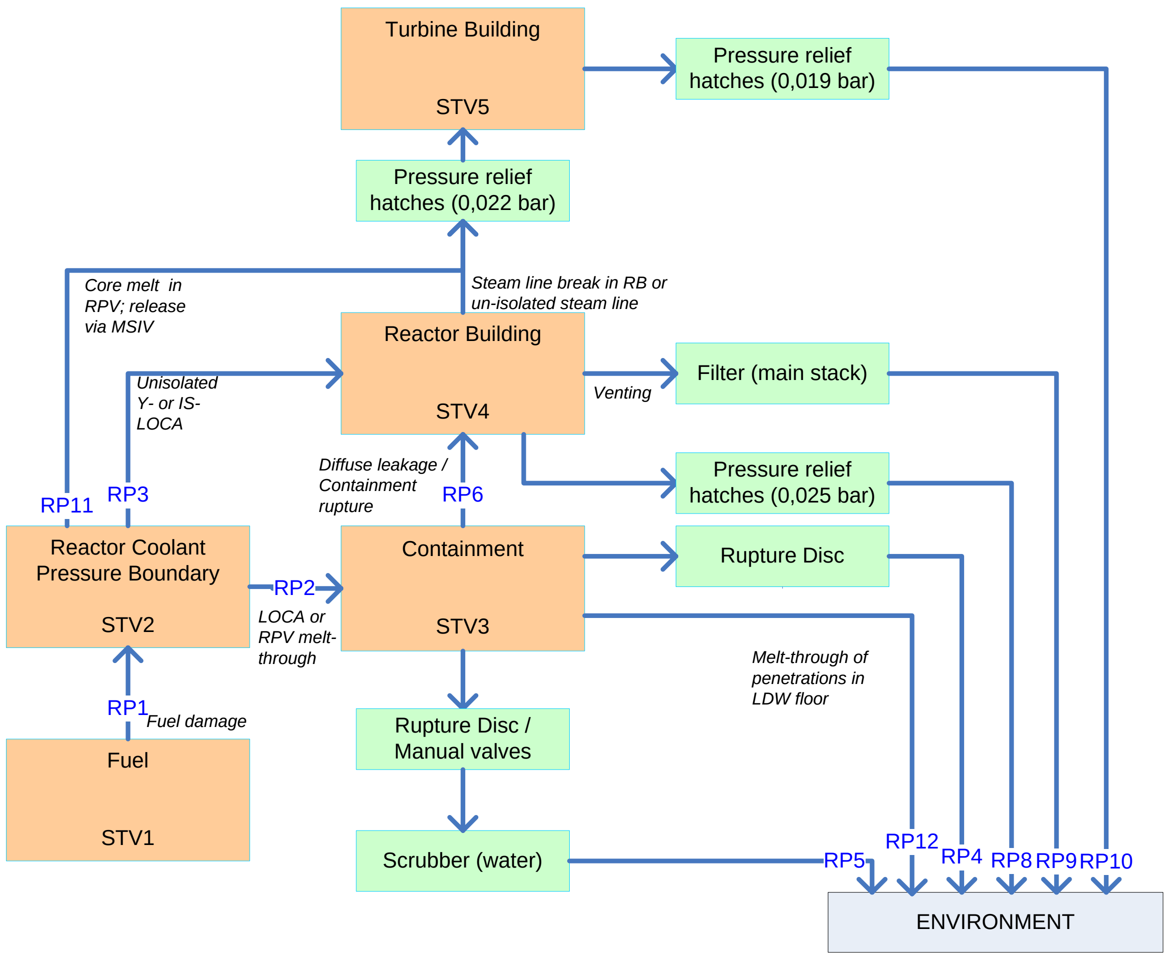
Desired features of the RASTEP tool (1)

- Should provide a rapid indication of possible environmental source term based on the status of the plant.
- Functions in Beyond Design Basis conditions where the instrumentation may not be operating in its designated range, e.g.
  - conflicting / unreliable reading
  - complete failure, i.e. no readings
- Does not require expert knowledge of severe accident analysis or fission product behavior.
- Is suitable for use in high stress conditions and should only require the user to make a minimum number of decisions.
- Provides results rapidly (e.g. before any airborne monitoring data is available).
- Does not require complex computing facilities.

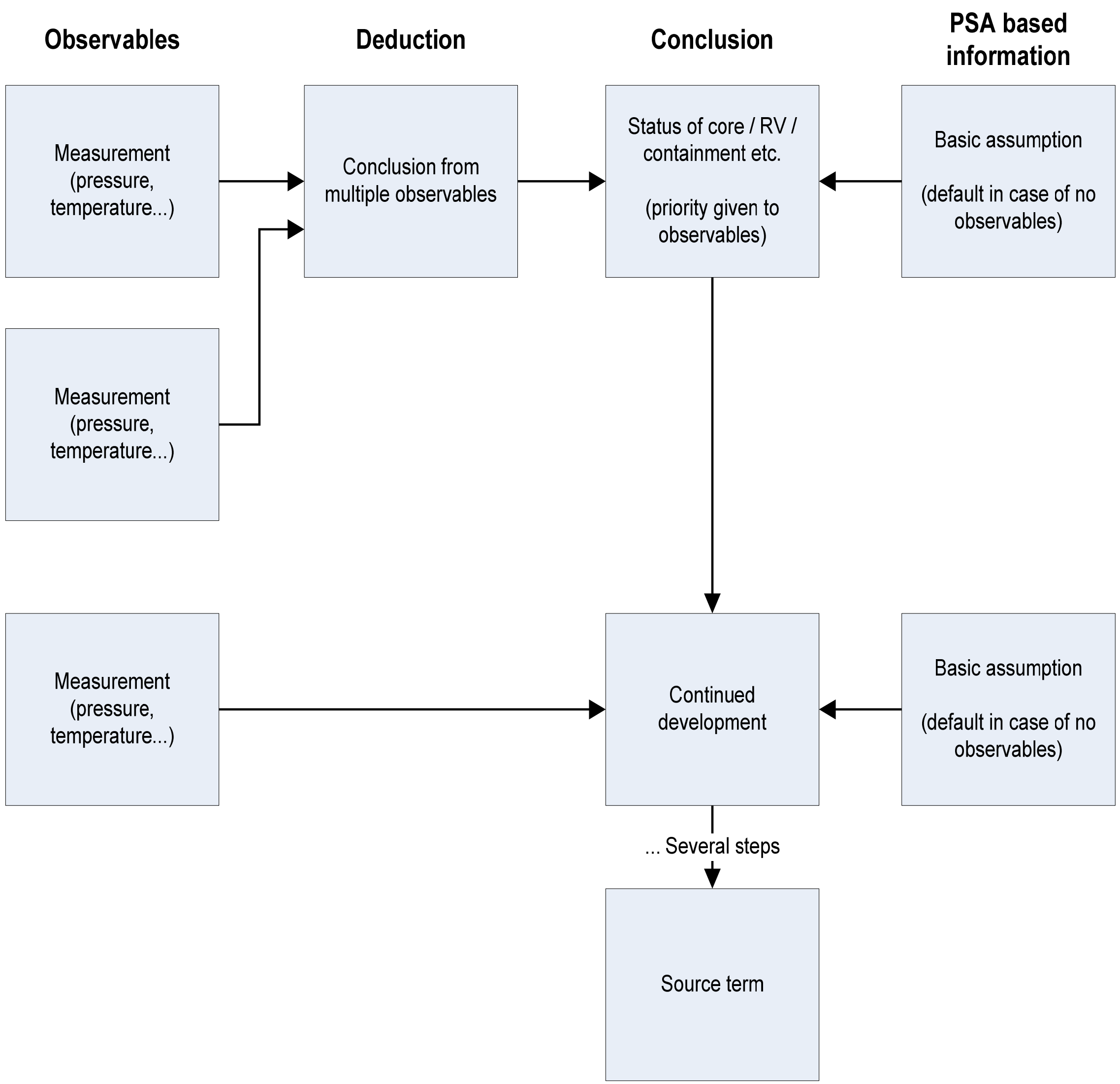
Desired features of the RASTEP tool (2)

- The input data required should be limited to that which is easily available from plant instrumentation or observations.
- The module should be interactive to allow the user to update the input information as it becomes available and therefore to refine the source term estimate.
- The output should be a range of potential source terms, with an associated probability, based on the user´s response to initial key questions and any subsequent updates.
- Gives an indication of relative likelihood and characteristics of potential plant states / environmental releases of radioactivity
  - the main benefit of this approach is that, in diagnosing reactor faults, it alerts the user to the existence of other possible final plant states, based on the known and unknown plant parameters.

RASTEP plant volumes and transport routes for fission products for Oskarshamn 3 BWR

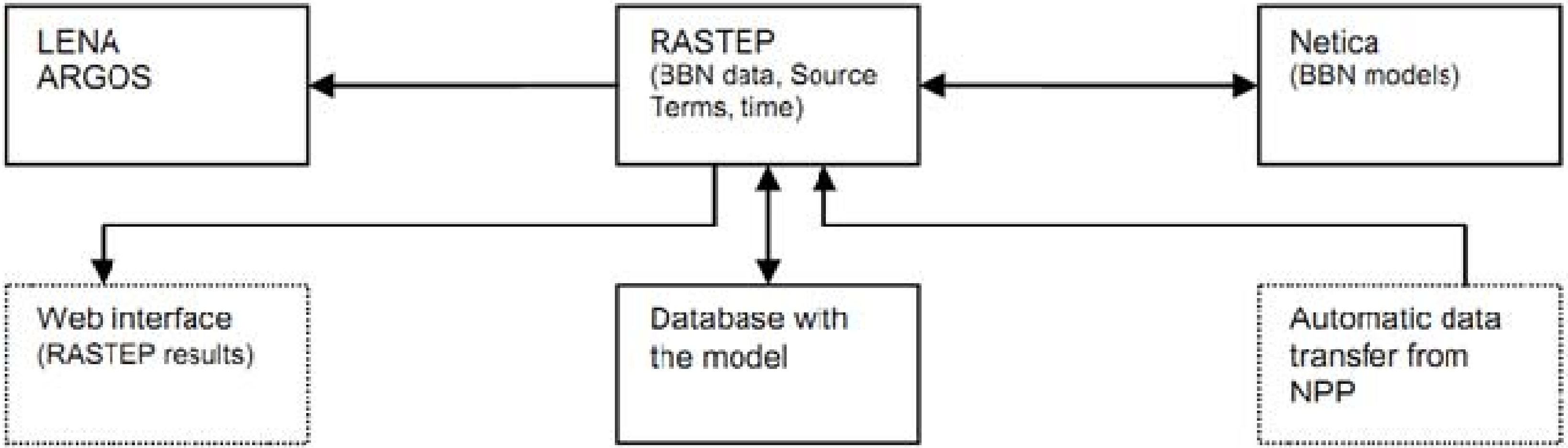


Basic principle for the general structure of the BBN model

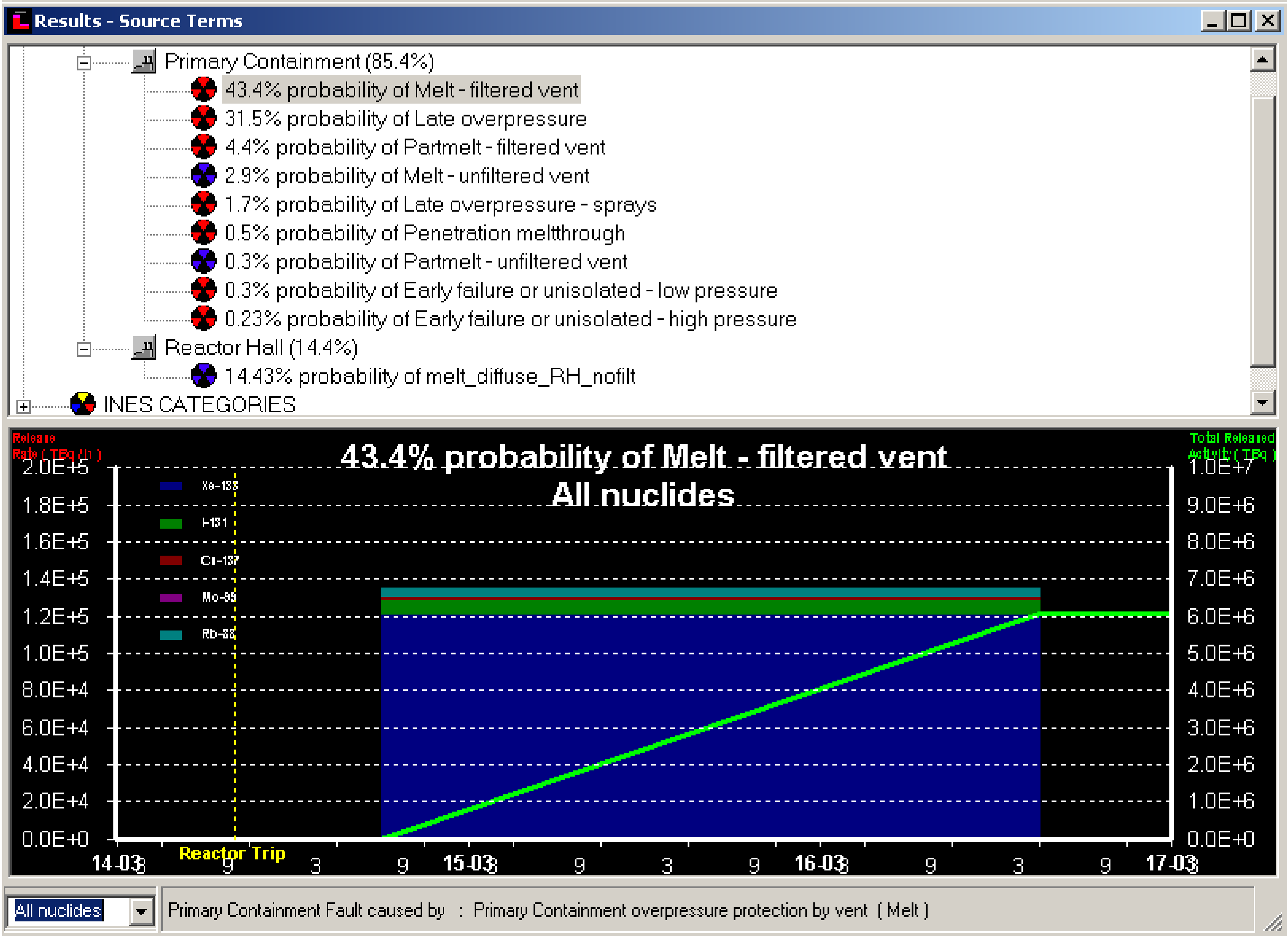


RASTEP interface and functionality

On-line data transmission from the NNP's together with a flexible user interface will ensure correct and timely input information



An illustration of the current presentation of source term in RASTEP



Severe accident early containment threats

Containment failure in the early phase of an accident, e.g. in connection with reactor vessel meltthrough, could result in large radioactive releases to the environment. The following physical phenomena must be considered:

•*Ex-vessel steam explosions/steam spikes (early threat)*

•*Hydrogen combustion (early threat)*

•*High pressure melt ejection/Direct containment heating (early threat, very low risk for large dry PWRs and Swedish BWRs)*

•*Recriticality during refloodling of degraded core (early threat, but low probability, late threat)*

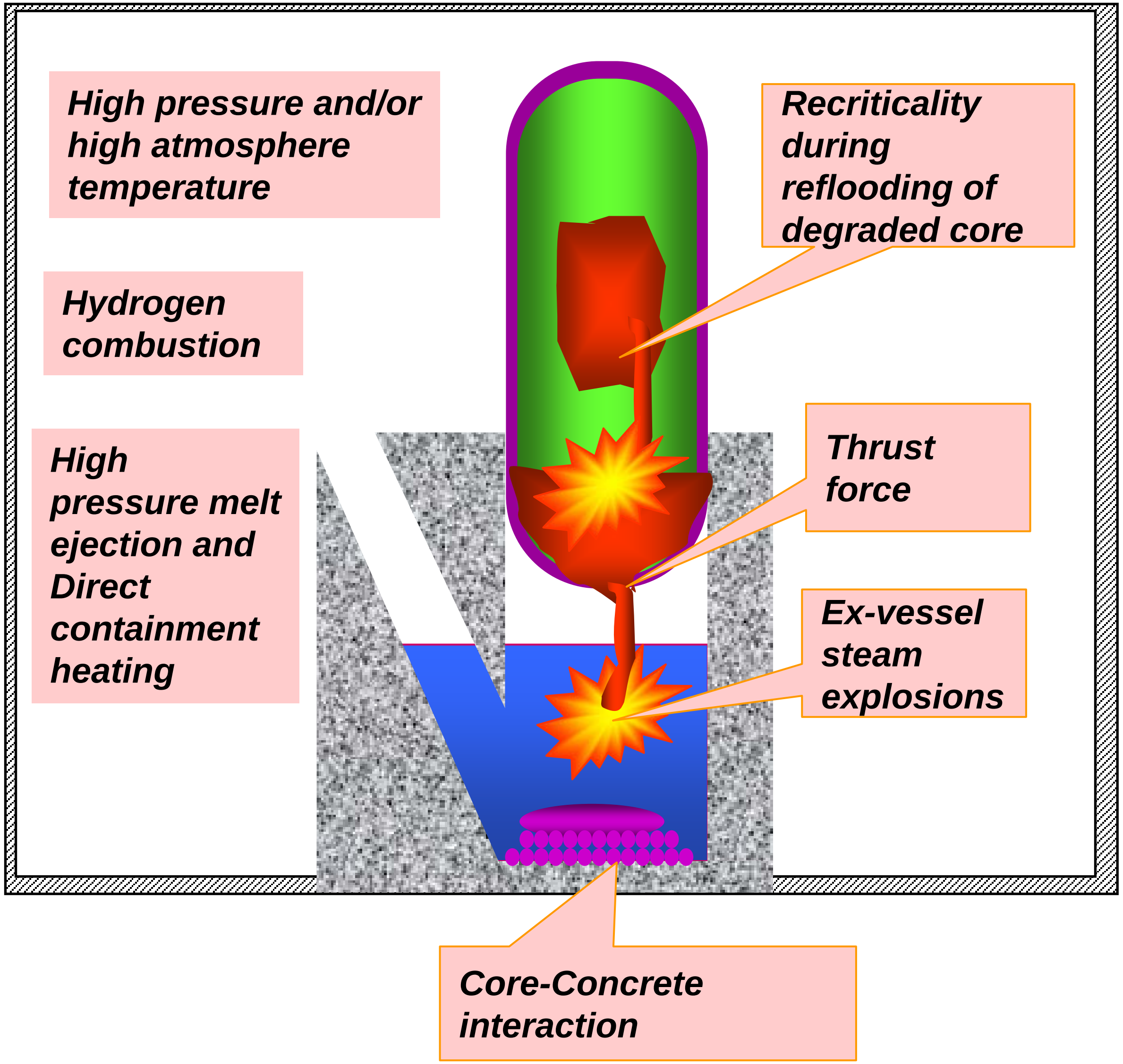
•*Thrust force on reactor vessel at high pressure vessel melt-through (early threat)*

•*Core-concrete interaction (late threat)*

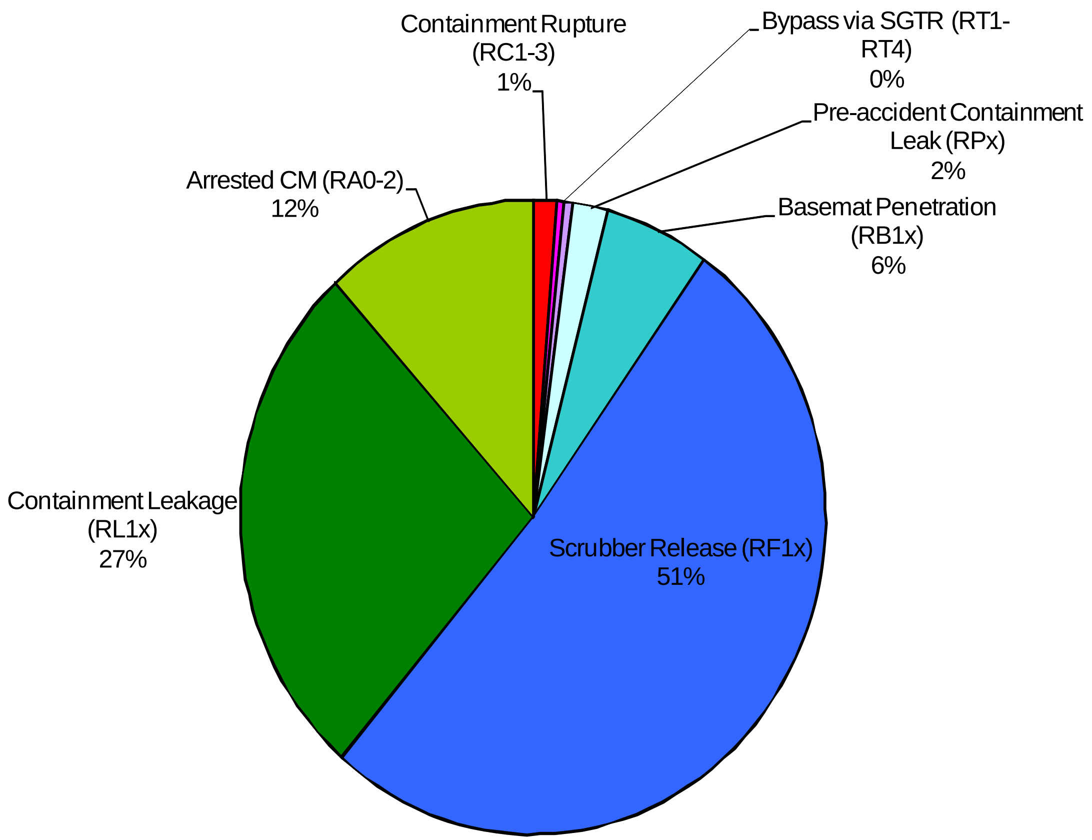
•*Pressure (late threat, slow increase due to decay heat and/or generation of non-condensable gases, will be mitigated by Filtered Containment Venting)*

•*High temperature (late threat)*

Severe Accident Containment Threats



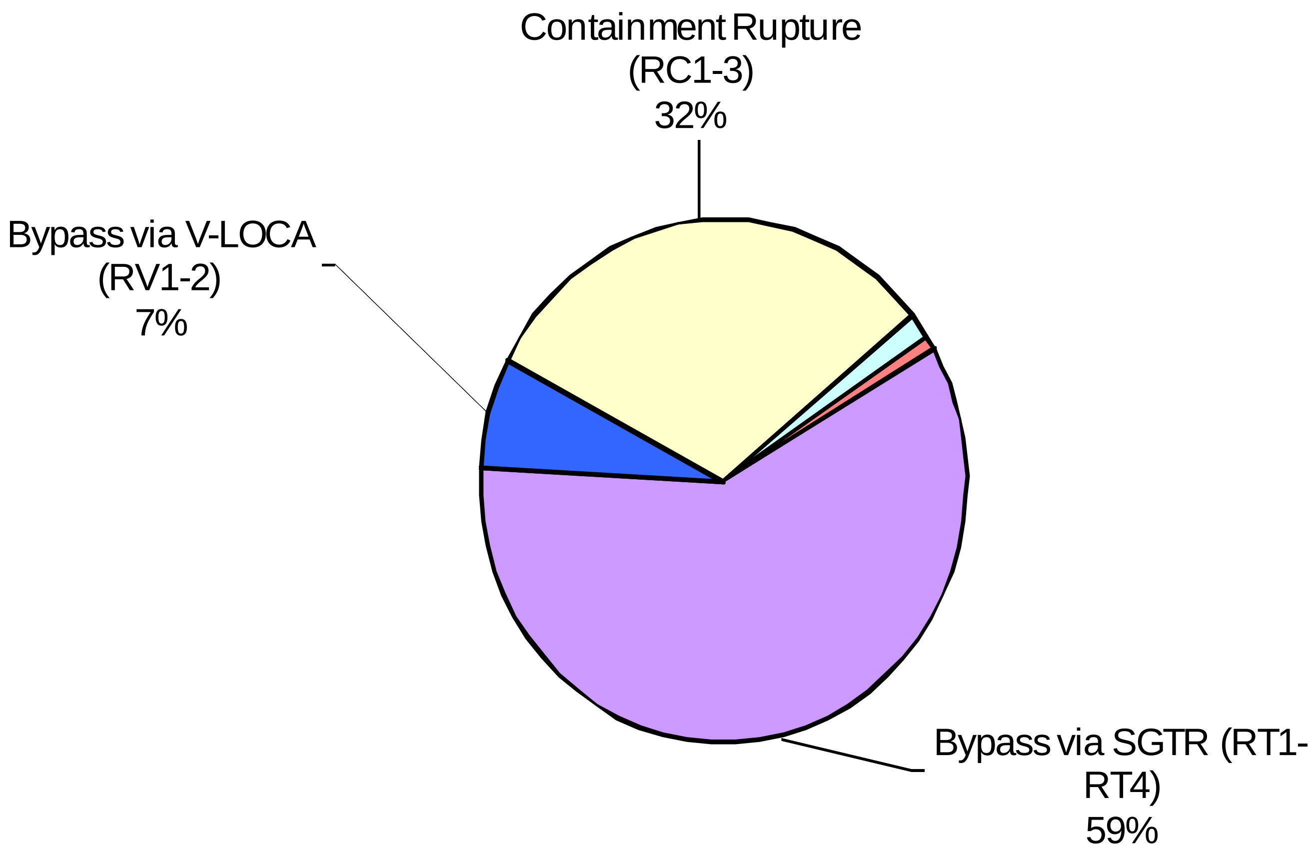
PSA Level 2 results for Ringhals 2
Relative frequencies for various release categories
Ref.: A. Henoch, Ringhals AB, IBC Kärnsäkerhet 2012



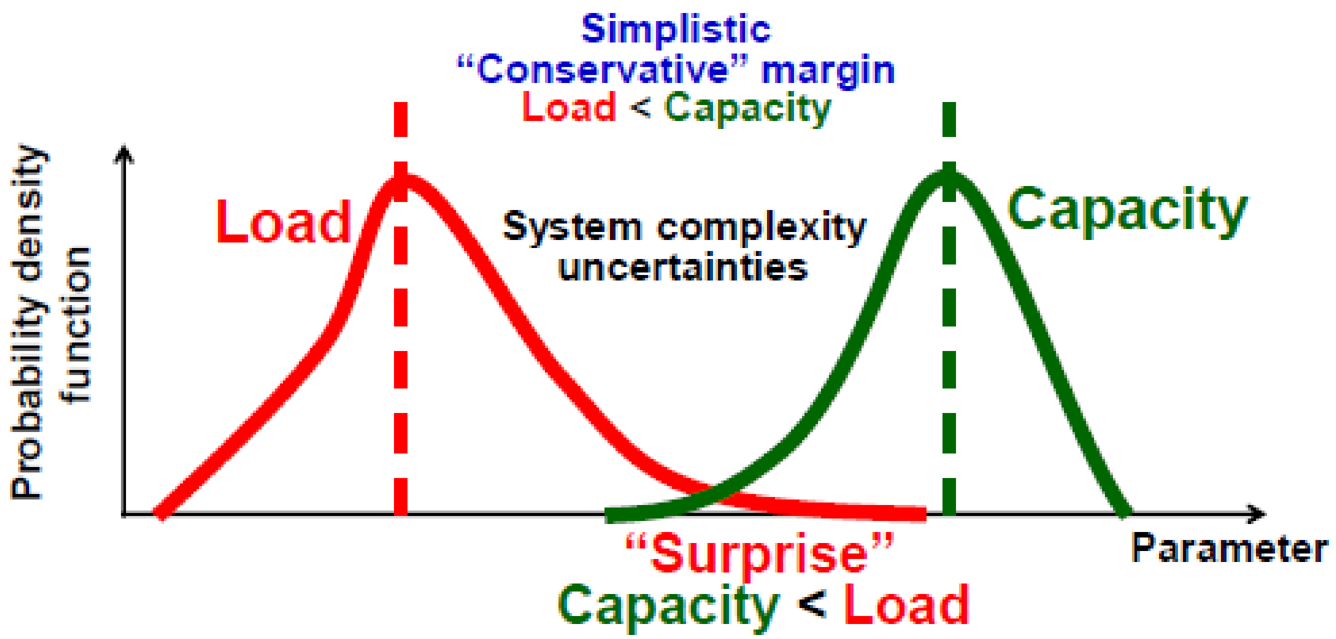
Source term risk (release x frequency)

Scrubber release gives a negligible contribution to the source term risk in comparison with by-pass sequences and containment rupture

Ref.: A. Henoch, Ringhals AB, IBC Kärnsäkerhet 2012



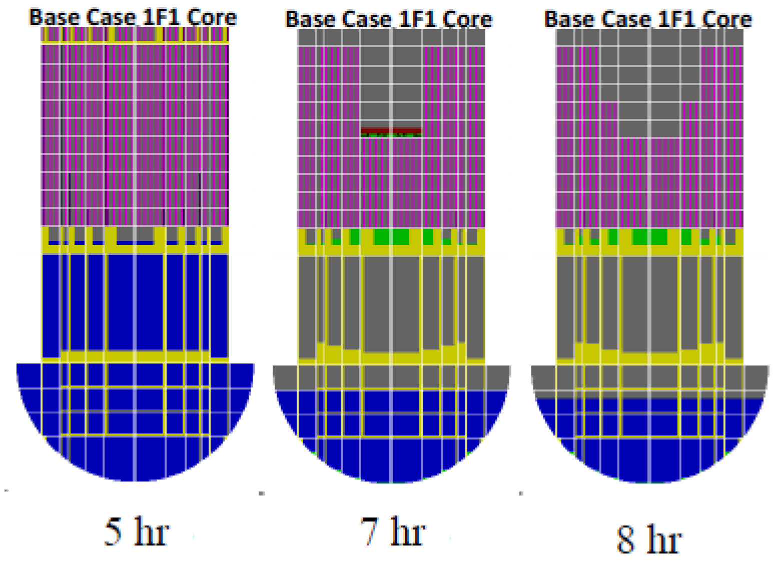
Risk-informed safety analysis
Deterministic vs probabilistic safety margin

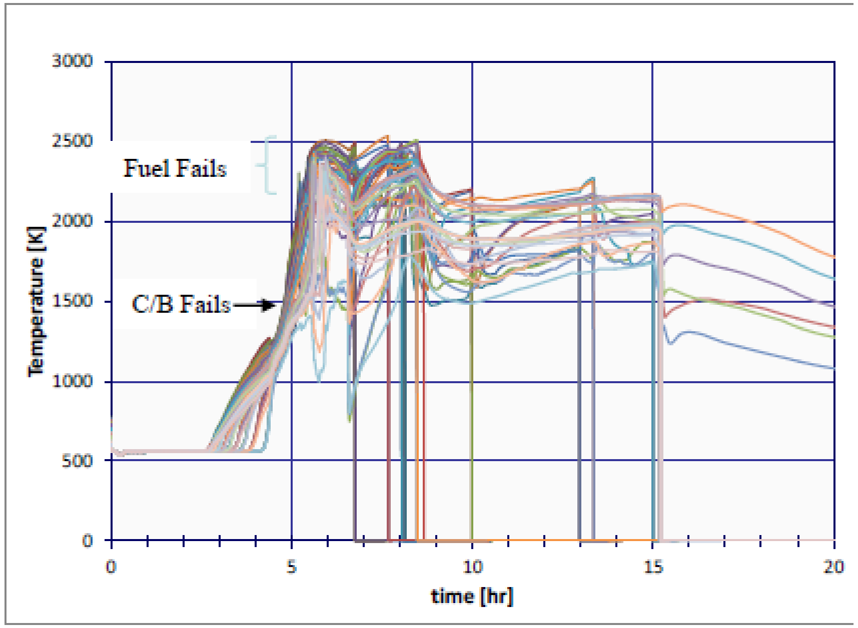


MELCOR 2.1 analyses of Fukushima Unit 1 accident

Recriticality is possible due to early melting and relocation of control blades

Ref.: R. Gauntt, Sandia National Laboratories, CSARP meeting, September 2012

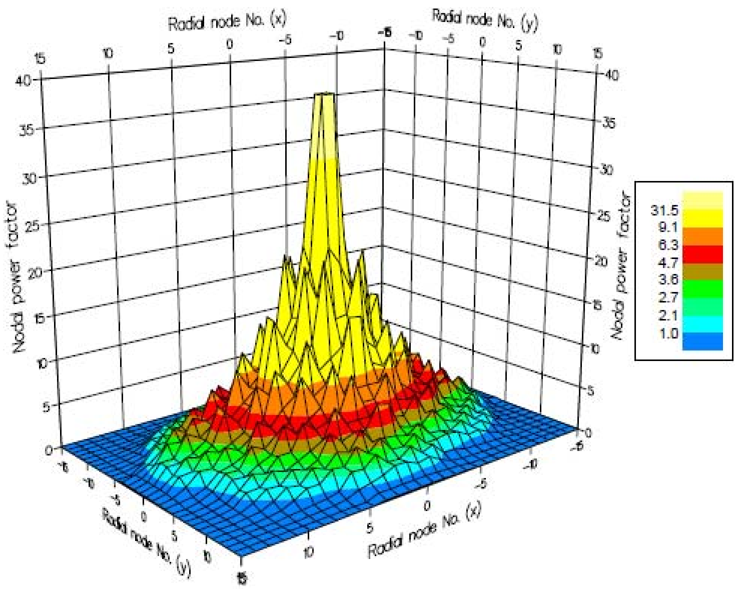




- Core damage starts at ~ 4 hours – control blades fail first
- Progressive fuel damage after 6 hours
- Core exit temperatures very high

Recriticality

Oskarshamn 3 analysis with the Simulate-3K code.
Nodal power factors at recriticality for reflooding with 500 kg/s
(stabilized power level for this case is 11.4 % of nominal power)
and timing of containment events for different stabilized power levels.



Time from first recriticality to:	Stabilised power relative to nominal power due to recriticality			
	8 %	10 %	14 %	19 %
Suppression pool starts to boil	1.3 h	1.0 h	38 min	34 min
Containment venting begins	3.0 h	2.2 h	1.4 h	1.0 h
Containment failure (at 10 bar)	4.2 h	3.0 h	1.8 h	1.3 h

Containment threats in the light of Fukushima accident (1)

- So far no information on new threats and phenomena (no unknown unknown).
- We hope that in the near future more information will be available which will improve our understanding of accident progression and contribute to validation and further development of severe accident codes, as well as to improved accident management.

Containment threats in the light of Fukushima accident (2)

Understanding and modeling of the following phenomena could be improved by information from the Fukushima accident:

- Hydrogen combustion
  - Hydrogen distribution
  - Deflagration-to-detonation transition (DDT), detonation (?)
  - Combustion in stratified layer (?)
- Reactor vessel melt-through
  - In-vessel melt coolability
  - Local vs. global
  - Hole ablation
  - Melt composition (maybe)

Containment threats in the light of Fukushima accident (3)

- MCCI
  - Melt coolability
  - Concrete erosion (anisotropy i.e. radial vs. axial)
- Containment pressure response
- High temperatures in containment
- Temperature loads on structures
- Steam line failure due to high temperatures (?)
- Stratification in suppression pool (?)
- Fission product release to containment

Thank you for your attention!