Source Term Prediction Software in Case of Severe Accidents: FaSTPro for Shutdown States

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Introduction

- In case of an accident, an early prediction of the expected releases of radioactive materials into the environment (source term) is crucial for a timely decision on short-term plant external protection of the public and civil protection measures

- “Source term”: radioactive release into the environment, characterized by:
  - Amount (activity) of relevant reference nuclides
  - Release height
  - Time course of release

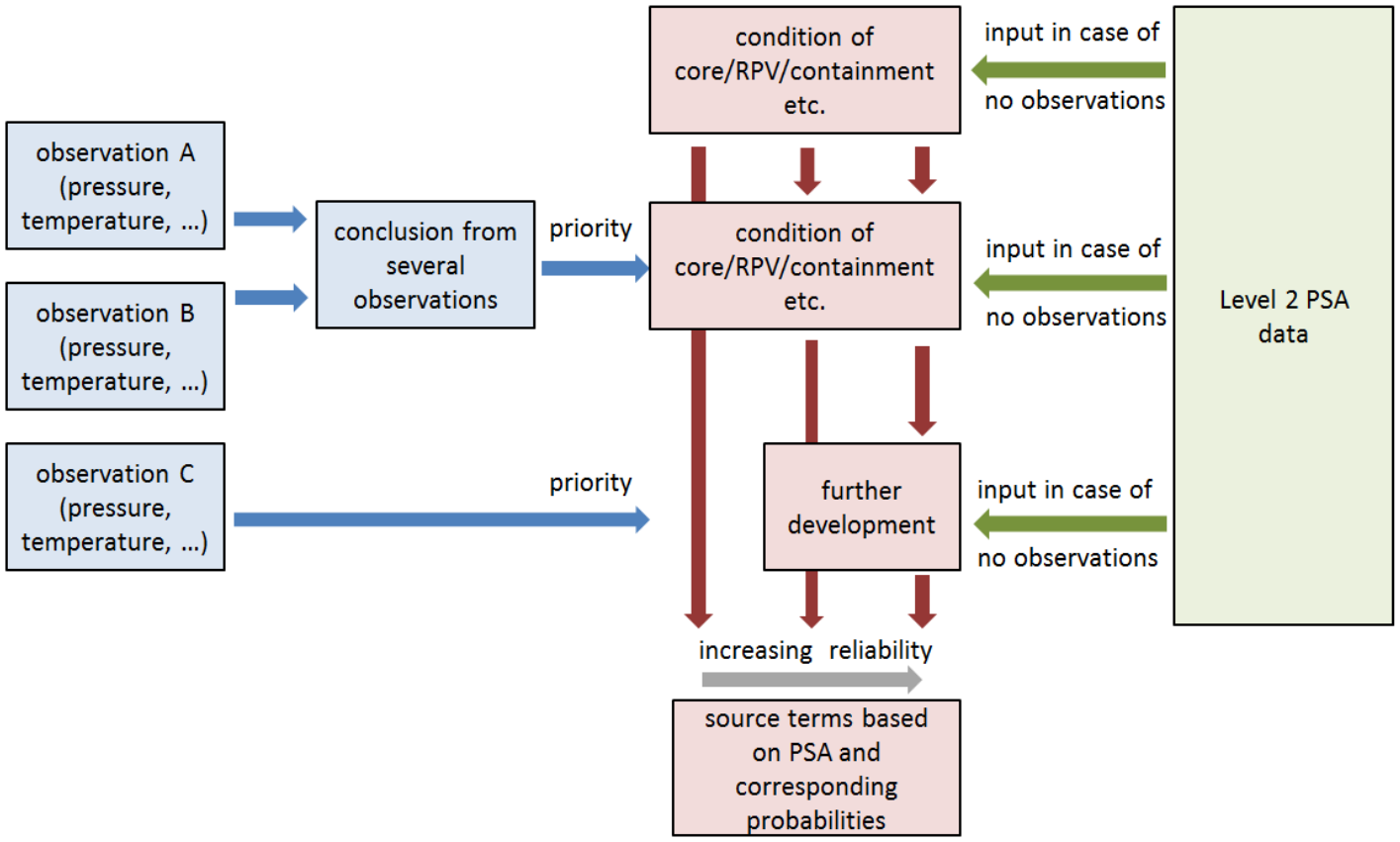
- Computer software to assist the plant crisis team for estimation of radioactive releases is useful and time saving in case of a severe accident

Major Steps of the Source Term Prediction Software

- The following methods are basically available:
  - Calculations of potential accident scenarios in advance, summarized in tables and handbooks
  - Fast-running simulation methods (only for experts, time consuming)
  - Probabilistic methods based on plant specific PSA (Probabilistic Safety Analysis) → source term prediction software by GRS
- GRS source term prediction software is based on the probabilistic methods approach.
- In Germany, a source term prediction based on Level 2 PSA results and plant specific parameters is recommended by the Commission on Radiological Protection (SSK)

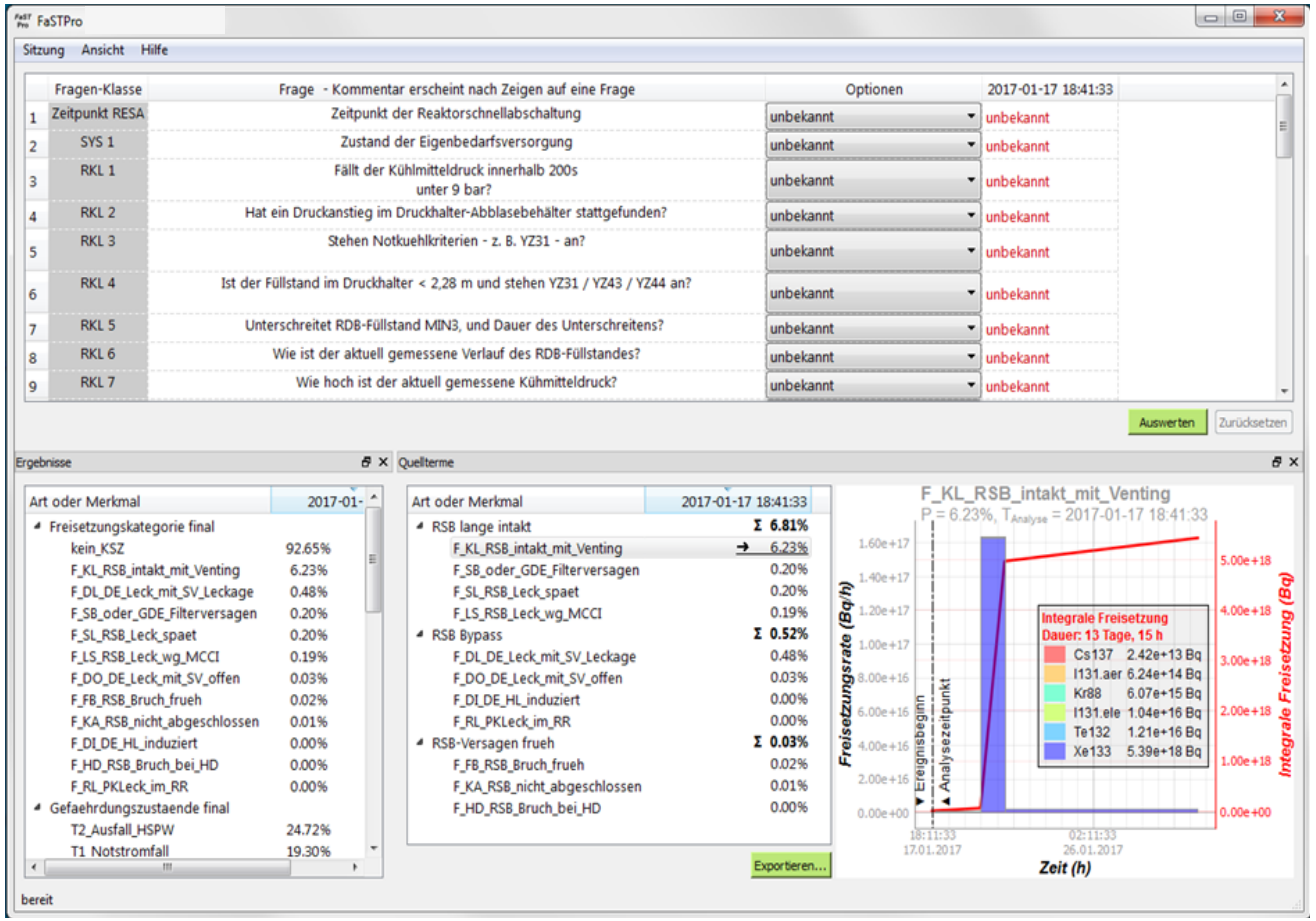
Basic Principles of the Source Term Prediction Software

For each sequence of the accident scenario the result is a synthesis of observations and input from PSA.



Structure of the Bayesian Belief Network (BBN): the combination of observations (blue) and Level 2 PSA (green) result in a prediction for source terms (red)

Basic Principles of FaSTPro



Multiple choice questions for user

Release categories and corresponding probabilities

Predicted time dependent release of radionuclides

Graphical display of the FaSTPro user interface

Use of the Source Term Prediction Software

- Multiple-choice questions to be answered by the user as far as possible (software structure allows the user to dismiss questions)
- Questions about the status of the system, explicit time point information, relevant events or status of the containment
- Prediction software calculates event tree end states of the accident and displays them to the user
- All source terms have been derived or taken from extensive accident simulations performed with MELCOR taking into account different possible accident scenarios

		Question	Option
1	Time point 1	When has the initiating event started?	2016-09-17 12:27:39
2	Containment 1	Has there been a depressurization of the containment without venting?	Depressurization without Venting
3	General 1	Will the severe accident measure be successful?	Unknown
4	PS 1	Is or has the exit temperature of the fuel assembly been over 650°C?	Core damage will be prevented Core damage will not be prevented Unknown
5	Time point 2	When has the fuel assembly temperature been over 650°C for the first time?	

Example of the multiple choice questions asked to the user.

Source Term Prediction Software Features

- Requirements for user skills to apply this software tool are kept deliberately low assuming hardly any user experience in software handling and a stressful situation
- All questions and answers are recorded; therefore the accident sequence over time can be deduced later
- A prepared form is available for the status report together with an export data set for the source terms which can be processed by the decision support system RODOS
- Prediction software is being continuously enhanced and improved by implementing further MELCOR calculations, e.g. with respect to
  - External hazards scenarios
  - Spent fuel pool (SFP)

Integration of Shutdown Plant Operational States (POS)

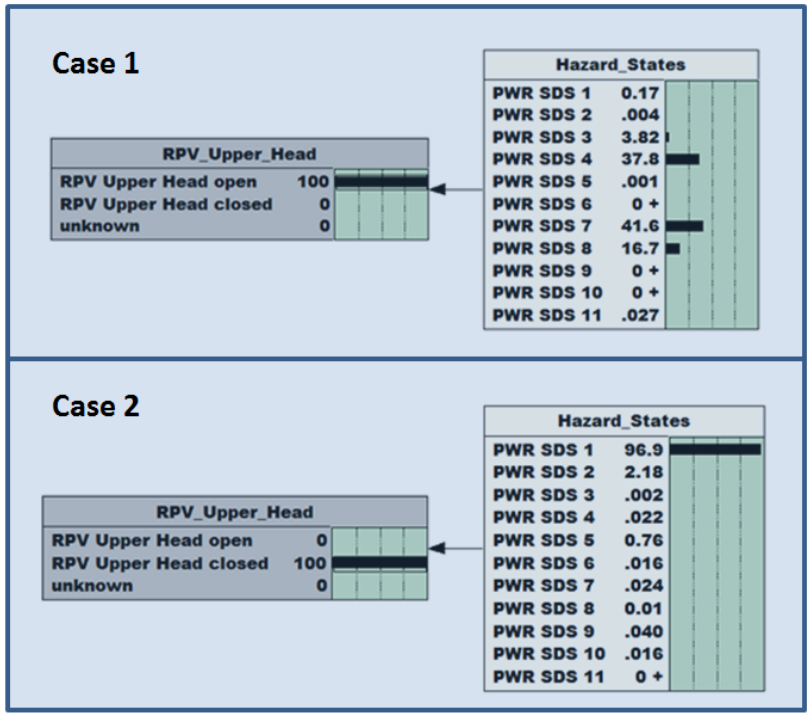
- In previous versions of FaSTPro, the condition of barriers (e.g. the containment or the air lock) has been deduced from plant status observations at the control room, e.g. on the pressure inside the containment.

- In the enhanced version, the BBN has been extended by means of further explicit knots in relation to the shutdown states of the plant. The answers given to these questions affect the calculated probability for certain accident scenarios or release categories respectively.

- The underlying BBN has been extended in order to cover also low power and shutdown plant operational states (POS), e.g. by the integration of deviating barrier conditions for the containment (normal operation or a failure considering the air lock for example) or the primary circuit (upper head of the RPV (*r*eactor *p*ressure *v*essel) sealed or removed).

- These characteristics of the shutdown states affect the possible release paths (e.g., open air lock) and physical phenomena which do not occur during full power operation such as the air ingress to the RPV resulting in a specific chemical reaction with Zircaloy.

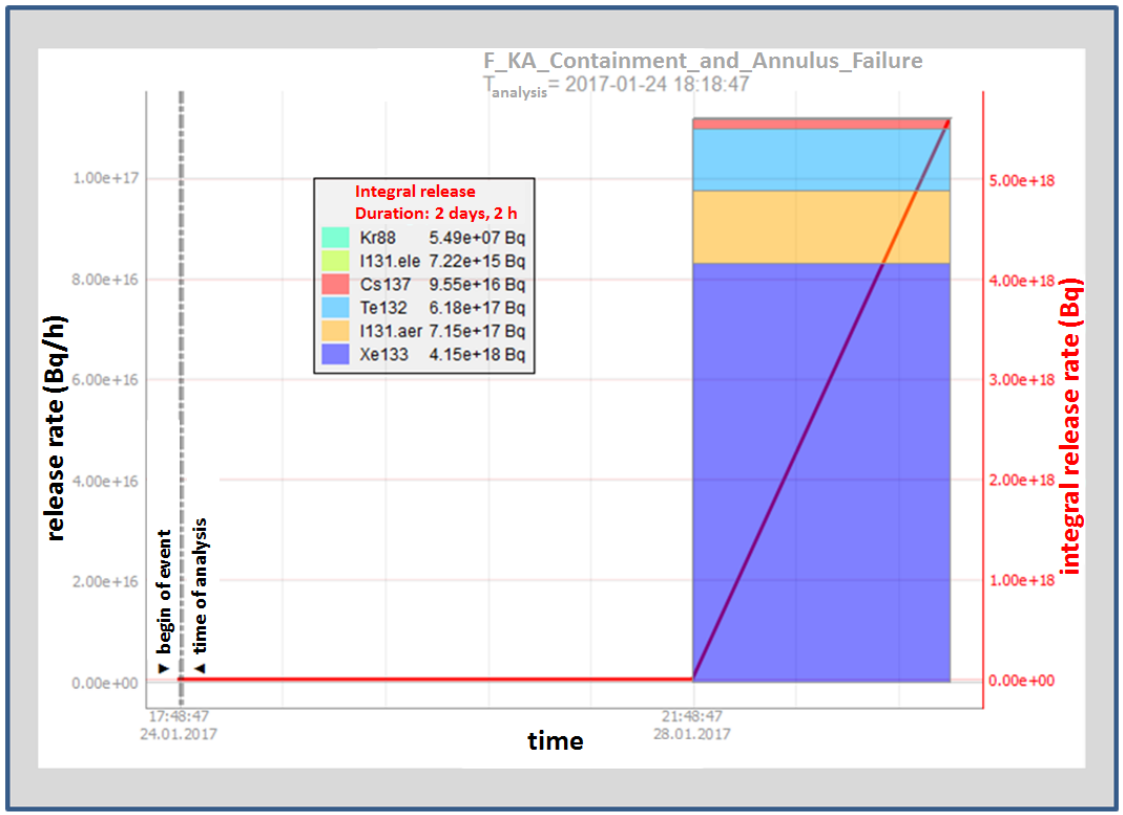
The Bayesian Believe Network (BBN) of the Shutdown States



Example from the shutdown states BBN

- Different probabilities for PWR SDS cases (SDS = Shutdown States) in the “Hazard_State” knot depending on the answer given to the question about the status of the RPV upper head

Example of a Predicted FaSTPro Source Term Distribution over Time



Time dependent release of radionuclides during the scenario „FKA Containment and Annulus Failure“ generated with the GRS prediction software FaSTPro for shutdown states.

Shutdown States Source Terms Generated with FaSTPro

PWR, "F_KA_Containment_and _Annulus_Failure"	Kr-88 [Bq]	Xe-133 [Bq]	I-131 [Bq]	Te-132 [Bq]	Cs-137 [Bq]
Release from begin of containment failure (T_b= 100 h) until the end of release (T_e= 150 h)	$5.5 \cdot 10^{7}$	$4.2 \cdot 10^{18}$	$7.2 \cdot 10^{17}$	$6.2 \cdot 10^{17}$	$9.6 \cdot 10^{16}$

Example for a shutdown state source term generated with FaSTPro

- The release category describes an accident sequence without a containment bypass but with a release via containment failure and an annulus failure opening a path for the radionuclides into the environment.
- Within the release over 90 % of the noble gas core inventory is released to the environment; for I-131, Te-132 and Cs-137 the release fraction values vary between 20 % and 35 %.

Summary and Outlook

- The GRS prediction software for shutdown states was introduced, showing its underlying probabilistic approach to predict a possible radioactive release into the environment during a severe accident
- By combing user given answers concerning the status of the NPP and a basic Level 2 PSA, the software predicts the most probable accident scenario and the corresponding release
- The use of such prediction software has been recommended by the German Commission on Radiological Protection (SSK) in Germany
- The prediction software is a tool to help and support the crisis team in an emergency center during a severe accident
- Further shutdown states MELCOR calculations, in order to calculate the amount of release of radioactive nuclides more precisely, are foreseen
- Enhancements of the software regarding the implementation of more severe accident measures are intended
- It is foreseen to perform an uncertainty analysis of the probabilistic network

Thank you for your attention!