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Continuous Process of Safety Enhancement in Operation of Czech VVER Units

EUROSAFE 2017

Outline

- Introduction
- Systematic and focused approach to new safety measures
- Examples and case studies of safety assessment
  - Implementation of DEC-A concept
  - Analytical support of severe accident strategies and measure implementation
- Conclusions

Introduction

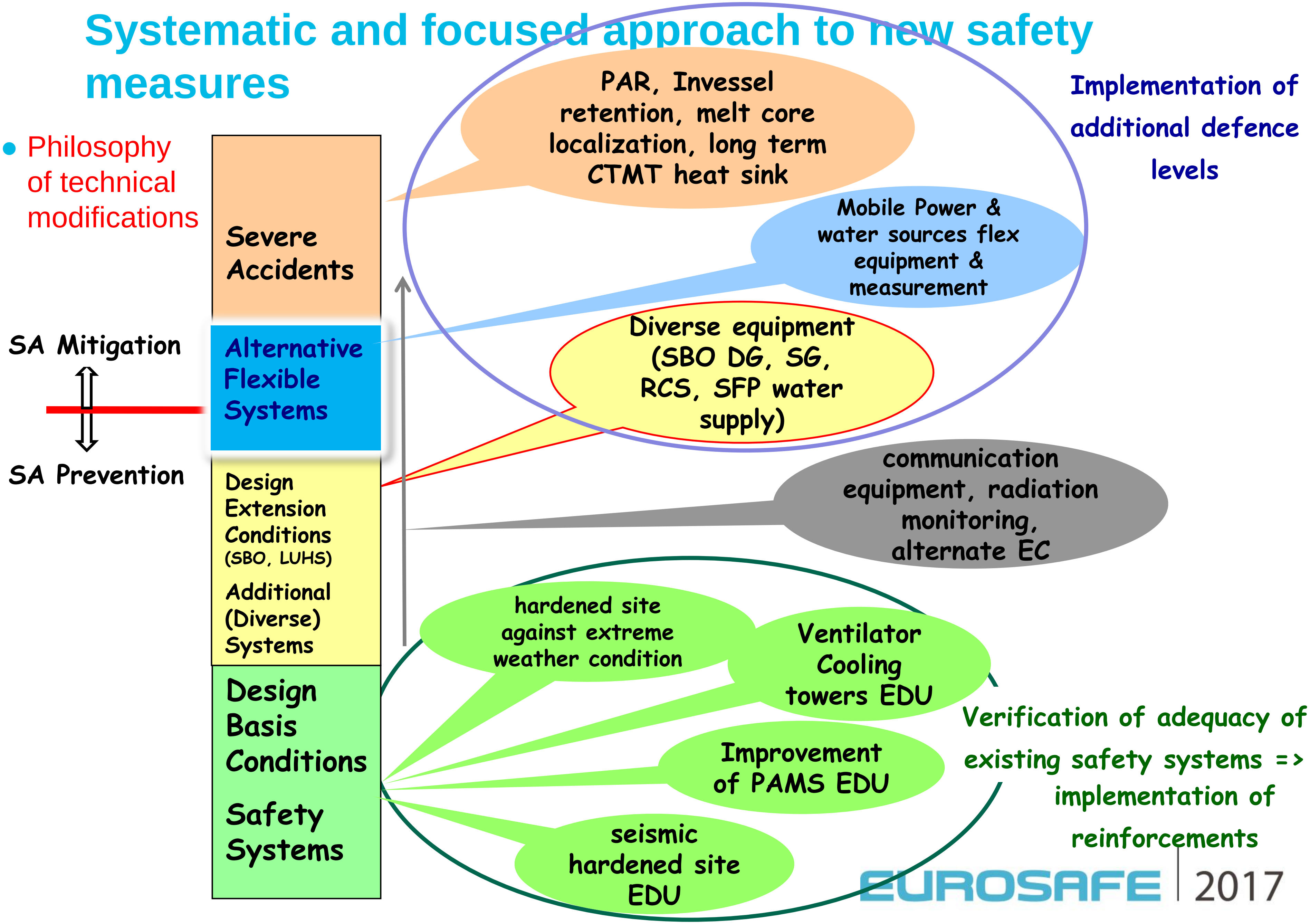
- A safety enhancement process - at both VVER sites in CR
  - a continuous effort since commissioning
- Significantly increased safety level
  - within systematic and focused process
- Despite the high level of safety
    - reached mainly by preventive means
  - a new period of enhancement process has been initiated
    - following the Fukushima accident

Systematic and focused approach to new safety measures

- A special attention to mitigative part of potential accidents
  - and relevant strategies and safety measures
- Important attributes for new preventive safety measures
  - diverse and alternative (mobile) means
    - diverse power sources, RCS/SFP/CNTM make up, alternative heat sink, alternative key parameters monitoring, etc.
- Analytical support
  - Use of probabilistic and deterministic methods, and their combination

Systematic and focused approach to new safety measures

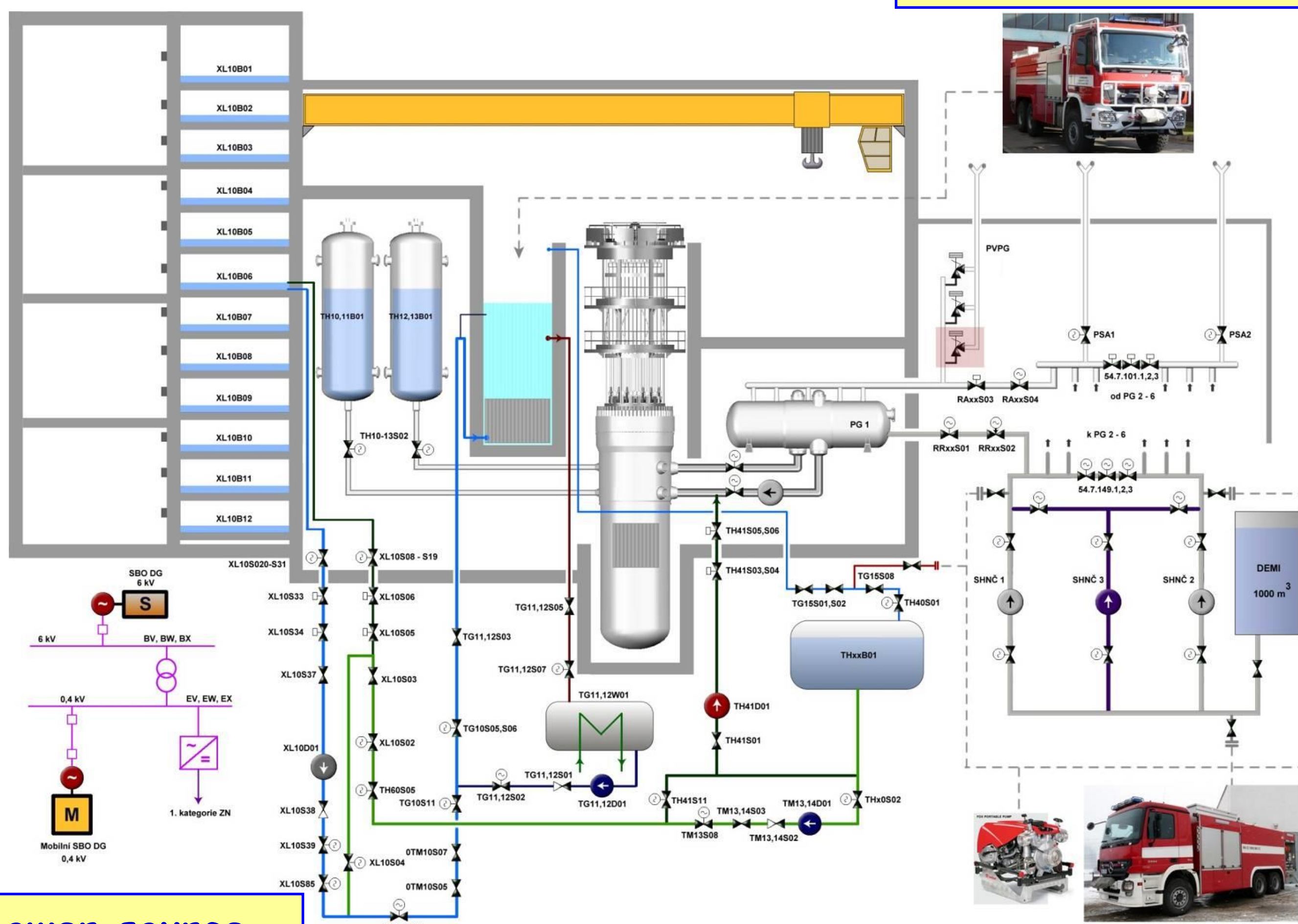
- Philosophy of technical modifications



Systematic and focused approach to new safety measures

- Stress test outcomes resulted in several plant modifications in prevention of severe accident – similar approach at both NPPs
  <u>Dukovany NPP as example</u>

➢ RCS / SFP / CNTM make-up



➢ Secondary heat sink

➢ Diverse power source

2017

Systematic and focused approach to new safety measures

- PSA has been recognized as a very useful tool
  - within the process of safety enhancement
    - used mainly for identification of weak points and prioritization
      - of safety measures
  - additional cooling towers at Dukovany site
    - example of the measure proposed by external hazard PSA
      - ultimate heat sink problem
        - as a consequence of external events of high density (high wind with return period 10 000 years)

Examples and Case Studies of Safety Assessment

- Implementation of Design Extension Conditions
- Analytical support of Severe Accident Strategies
  - and particular safety measures implementation

Implementation of DEC-A Concept

- When speaking about safety assessment of design extension conditions, i.e. analyses of events beyond design basis accident (DBA), one should distinguish between analyses of DEC without core melt (named DEC-A in the paper) and analyses of DEC with core melt (marked DEC-B in the paper).
- Whereas the later (DEC-B, severe accidents) have been widely assessed and analysed for at least 2 decades with the accelerator moment of Chernobyl accident, the former (DEC-A, BDBA) were analysed in the past only partially – typically only the anticipated transient without scram (ATWS) and station blackout (SBO) were analysed and documented in Safety Analysis Report.
- The more systematic work on safety assessment of DEC-A (BDBA) has been started only in the last decade with different starting point and speed in various countries. This effort has been initiated by initiatives and suggestions of European Utility Requirements (EUR), WENRA safety reference levels and IAEA introducing DEC term and concept into the safety standards series SSR-2/1 and GSR-Part4.
- The work on BDBA and DEC-A safety analyses for Czech NPPs was initiated in 2009 as a consequence of the Periodical Safety Review (PSR) after 20 year of the operation of the Dukovany NPP. The safety assessment of DEC-A and implementation of DEC concept in whole is based on recommendation from the IAEA, WENRA and EUR documents mentioned above.
- For the DEC-A safety analyses themselves the requirements of SUJB "Safety Guide BN-JB-1.7 Selection and Evaluation of Design and Beyond Design Events and Risks for NPP, 2010" has been applied.

Implementation of DEC-A Concept

Approach to DEC-A analyses:

- Selection of DEC-A (BDBA) events to be analyzed based on requirements of BN-JB-1.7 plus supplements according to PSA
- In selection based on PSA, transfer from "frequency of occurrence of initiating event" to "frequency of occurrence of scenarios"
- Realistic computer codes, models and analysis assumptions
- Acceptance criteria same as for DBA (with exceptions like higher system pressure AC)
- Majority of DEC-A analyses for the Czech NPP's Dukovany and Temelin have been done with help of RELAP5 computer code
- In UJV Rez the RELAP5 has been validated against experimental data from more than 20 tests carried out at various integral and separate test facilities.
- Approximately half of these tests were events of DEC-A type
- All computer codes to be used for safety analyses in the Czech Republic must be reviewed and licensed according to regulatory body (SUJB) directive VDS-030

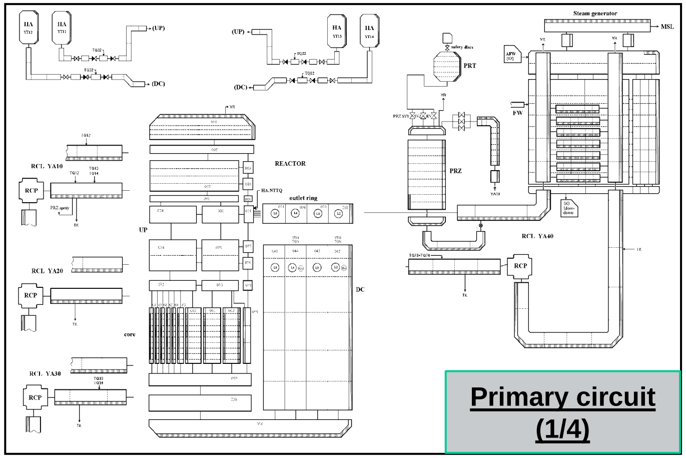
Implementation of DEC-A Concept

SUJB directive BN-JB-1.7 requires - besides the standard set of ATWS analyses - the following set of DEC-A (BDBA) events to be analysed

- Total long-term loss of inner and outer AC power sources
- Total long-term loss of feed water („feed-and-bleed„ procedure)
- LOCA combined with the loss of ECCS
- Uncontrolled reactor level drop or loss of circulation in regime with open reactor or during refuelling
- Total loss of the component cooling water system
- Loss of residual heat removal system
- Loss of cooling of spent fuel pool
- Loss of ultimate heat sink (from secondary circuit)
- Uncontrolled boron dilution
- Multiple steam generator tube rupture
- Steam generator tube ruptures induced by main steam line break (MSLB)
- Loss of required safety systems in the long term after a design basis accident

Implementation of DEC-A Concept

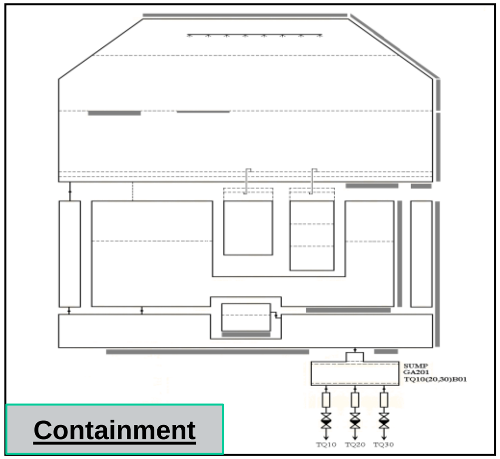
Nodalization of VVER-1000 for RELAP5



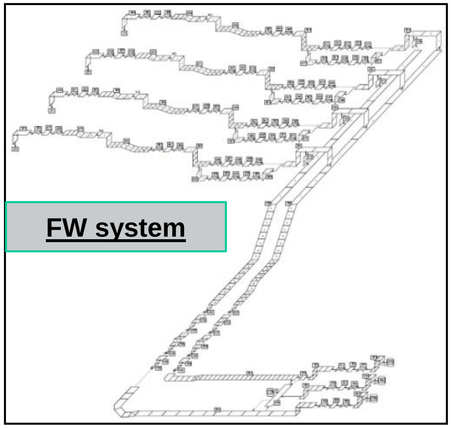
Primary circuit (1/4)

Input model statistics:

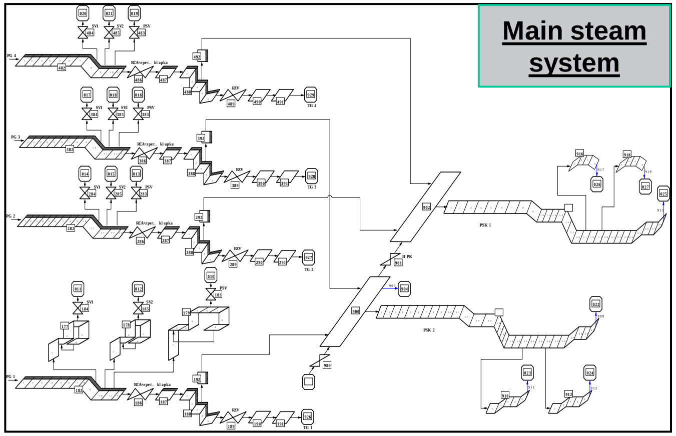
- 1800 control volumes
- 2400 hydraulic junctions
- 1600 heat structures with 8700 mesh points
- 2680 control variables
- 1110 trips



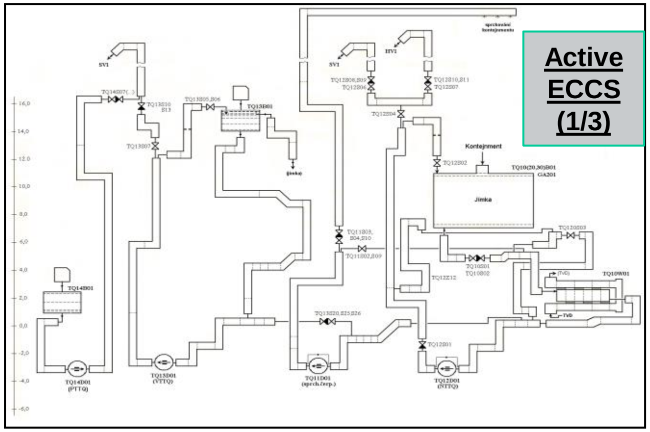
Containment



FW system



Main steam system

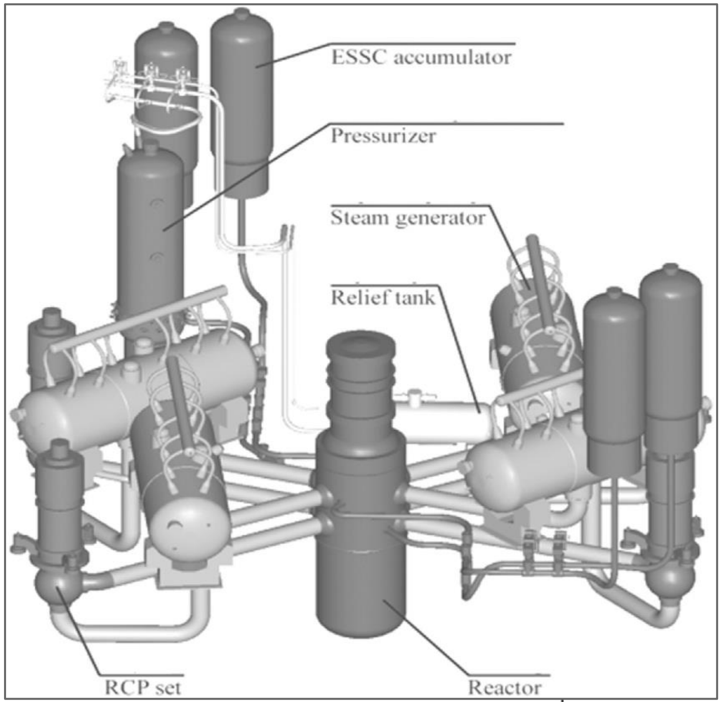


Active ECCS (1/3)

Implementation of DEC-A Concept

Example of DEC-A analysis for VVER-1000

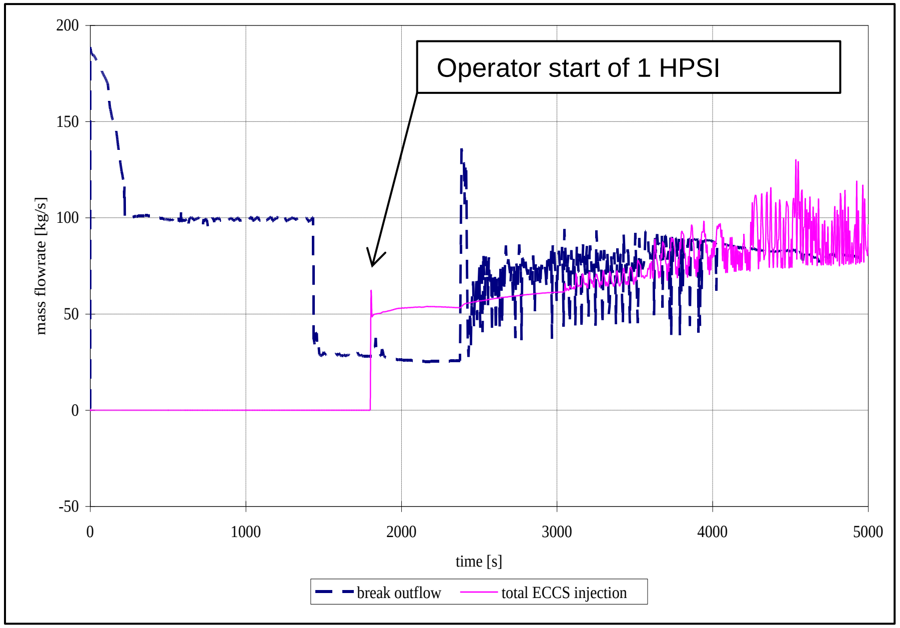
- Analysis of small break loss of coolant accident (SBLOCA) with break D50 mm in cold leg and without Primary Reactor Protection System (PRPS) which lead among other to failure of start of emergency core cooling systems (ECCS)
- Reactor is scrammed by DPS
- Operator manual start of high pressure safety injection (HPSI) at 30 min
- Calculation performed with RELAP5 computer code and detailed input model of VVER-1000

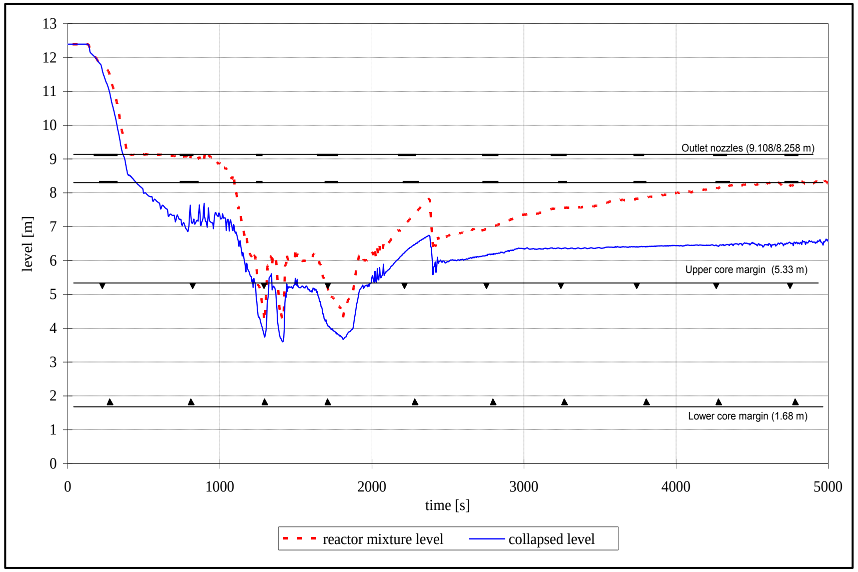


Implementation of DEC-A Concept

Results and concluding remarks to the analysis SBLOCA without PRPS

- Operator manual start of HPSI (based on EOP: E-0, E-1, FR-C) proved to be effective action and led to fast restoration of core cooling
- Number of other variant of SBLOCA and LBLOCA with PRPS failure was analysed





Implementation of DEC-A Concept

- The whole set of prescribed DEC-A analyses was already performed both for Dukovany NPP (VVER-440) and for Temelin NPP (VVER-1000). From 15 to 20 DEC-A analyses for each plant
- As for the documentation of DEC-A analyses in Safety Analysis Report, the temporary solution was the creation of a new **SAR subchapter 15.9.1** which contains basic results of all DEC-A (BDBA) analyses required by BN-JB-1.7
- Beside that the ATWS analyses are documented in subchapter 15.8 of the SAR as usually
- The final solution is introduction of new SAR chapter 19 that would contain both DEC-A (BDBA without core melt) and DEC-B (severe accident) analyses presented in systematic and integrated way
  - Then the Chapter 15 will contain only analyses of events ranging from normal operation (NO) to design basis accident (DBA)
  - New chapter „19.2 DEC“ for Dukovany NPP is partly implemented to SAR, at Temelin NPP is in progress

Implementation of SA Strategies and Measures

- ÚJV Řež provides complex services in SAM to Czech NPPs owned and operated by ČEZ a.s.
  - Accident progression
  - Evaluation of source terms
  - Identification of severe accident management strategies
  - Supporting analyses for optimization of SAM strategies
  - Validation of existing SAMGs
  - Supporting analyses for control room habitability
  - Development of layout of hydrogen mitigation system for Temelin NPP

- Stress test observations ⇨ National Action Plan - SA main actions
  - ⇨ Increase of the capacity of the system for emergency hydrogen removal (A#46 – Dukovany NPP, A#47 – Temelin NPP)
  - Cooling of the melt from the outside of RPV (A#48 – Dukovany NPP)
  - Recriticality (A#61 – both NPPs)
  - Control room habitability (A# 58, 31, and 51 – both NPPs)
  - The means for maintaining containment integrity due to overpressure (A# 46 – 50 – both NPPs)
  - ⇨ Corium in/ex vessel cooling (A# 48, 49, 50 – Temelin NPP)
  - Extension of SAMGs for shutdown / severe accident in SFP (A#56 – for both NPPs)
  - ⇨ System setup of training (drills), exercises and training for severe accident management according to SAMG, including possible solution of multi-unit severe accident (A#55 – both NPPs)

Implementation of SA Strategies and Measures

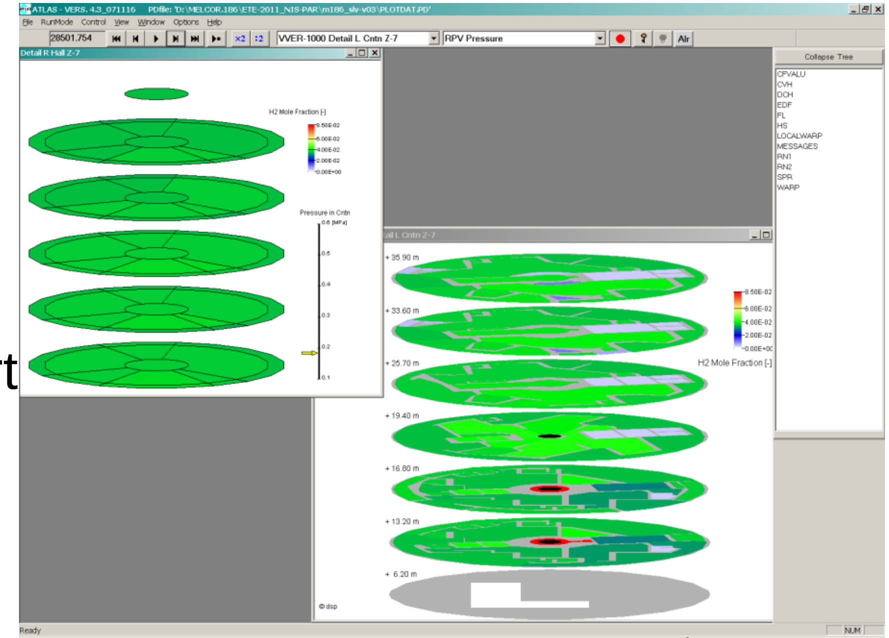
Analytical support of hydrogen removal system design

- Project duration 2013-2015
- Three main steps of methodology
  - Integral analyses of selected scenarios – determination of sources to Cntn
    - Integral model of Temelin NPP in MELCOR code
  - Analyses of H2 risk based on Sigma and Lambda criteria in detailed Cntn model
    - Detailed model of Cntn in MELCOR code
      - 138 CVs, 348 FLs, 432 concrete and 147 steel HSs
      - External sources of masses, energy and fission products
  - Optimization analyses of PAR layout – numbers, sizes and locations of PARs – NIS supplier
    - Optimization criteria
      - Lambda criterion elimination
      - Sigma criterion elimination in most of nodes (temporary occurence in limited space allowed)
      - Global and local hydrogen concentration (in dry air; local H_2 < 10%dry, global H_2 < 8%dry, and PAICC < P_{design} + 1 bar)

Implementation of SA Strategies and Measures

<u>Analytical support of hydrogen removal system design</u>

- Three main SA scenarios – 2 branches on MCCI
  - Additional case on variant location of LOCA break
- Hydrogen spatial distribution evaluated with ATLAS postprocessor two windows – variant parameters visualized including fulfillment of Sigma and Lambda criteria
- Temelin NPP already equipped with AREVA PARs on DBA
  - 22 AREVA units FR90/1-150
- Newly proposed system with 109 equiv. NIS22 units
  - NIS22, 44, and 88 used in final design
- System based on analytical support already installed and in operation since 2015



Implementation of SA Strategies and Measures

Corium localization at Temelin NPP

- Objective of corium localization
  - To restart heat removal from failed fuel and to stabilize containment conditions with the aim to prevent (or minimize) FP releases
- Time evolution of activities
  - From IE ⇨ Prevention of SA
  - From Entry to SA ⇨ Mitigation of SA in RPV
  - From LHF ⇨ Mitigation of SA out of RPV
- Temelin NPP already implemented several additional measures to original project design for SA prevention (applicable also in mitigation phase)
  - Diverse equipment (TB50 – water supply to RCS, SFP, and Cntn sprays)
  - Alternative (mobile) equipment (mobile DG, T-joint, and mobile pump)

Implementation of SA Strategies and Measures

<u>Corium localization at Temelin NPP</u>

- LHF is assumed as failure of alternative and diverse equipment (cliff-edge effect)
  - Timing range of hours (depends on scenario)
  - ? quantification of contribution of new equipment ⇨ PSA
    - PSA update is ongoing
  - Requirements to new equipment for SA mitigation
    - More simple than existing systems
    - Reduced requirements to operating staff and energy supply, etc.
  - All of assumed retrofits for corium localization, up to now, are focused on coolant injection into RPV/Cntn
    - They open other issues of SAM
      - Long term heat removal from Cntn, if design systems are un-available (sprays, UJ system etc.)
      - Removal of large mass of contaminated water from Cntn – processing and storing

Implementation of SA Strategies and Measures

Corium localization at Temelin NPP – Requirements to SA Solutions

- Additional measures for SA are reasonable, if fulfil following conditions
  - Effectivity = quantified benefit to safety (prevention of early FP releases and minimize FP releases) + confirmed physical fruitfulness with sufficient margin
  - Reasonable technical feasibility
  - No negative impact to reactor during normal operation (including all procedures/activities during outages)
  - Simplicity – applicability under SA condition (limited personal capacity, limited accessibility …)
  - At least partial independency of functionality assurance in comparison with existing emergency systems
  - Consistency of approaches with other utilities operating VVER-1000 (or reactors of similar power) and VVER-1000 designers

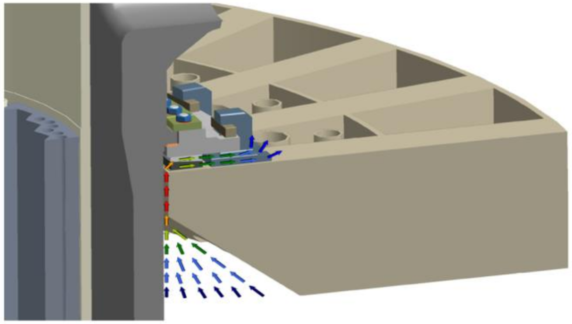
Implementation of SA Strategies and Measures

<u>Corium localization at Temelin NPP</u>

Three steps of possible solutions of corium localization

- Early degraded core re-flooding (TMI-2 like scenario) (**IVR-IN**)
  - In case of limited duration of applicability – influence of conditions for IVR-EX or ExVC solution to reduced decay power conditions
- IVR with external RPV cooling (**IVR-EX**) (IVR-ERVC)
  - Recently – Deflector for increase of CHF seems to be
    - Necessary for physical feasibility
    - Unacceptable due to too much complicated conditions of installation and removal during each of outage – too many risks
  - Success, at least temporary, of previous IVR-IN can provide IVR-EX physically feasible without deflector
- Corium cooling outside of RPV (**ExVC**) (ExVR)
  - Various approaches investigated due to mainly very high dose rates in reactor cavity, which would significantly complicate any work there

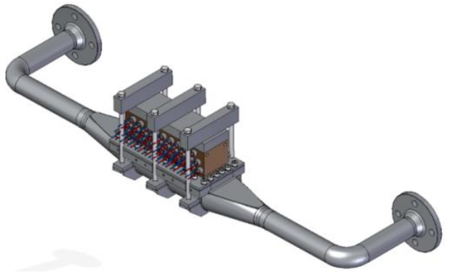
Implementation of SA Strategies and Measures



Corium localization at Temelin NPP - **IVR-EX**

- Steam escaping from reactor cavity
  - Measurement performed
    - Flow area around RPV is sufficient
  - Modifications of biological shielding seem to be necessary
    - Required minimum flow area is ~ 600 cm^2 is not confirmed by measurement
- Experimental program to assure physical efficiency
  - UJV performed extensive analytical support
  - UJV performed set of small scale test at BESTH2 facility
  - UJV is constructing THS-15 facility
    - ČEZ support this activity and co-finance performing of tests

Implementation of SA Strategies and Measures

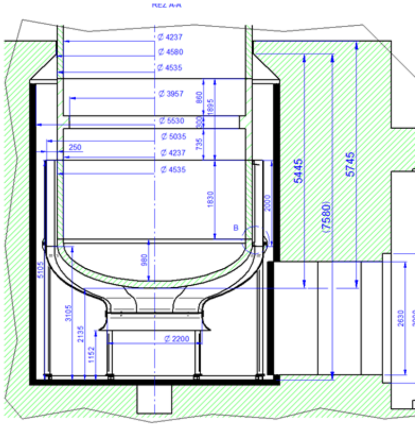


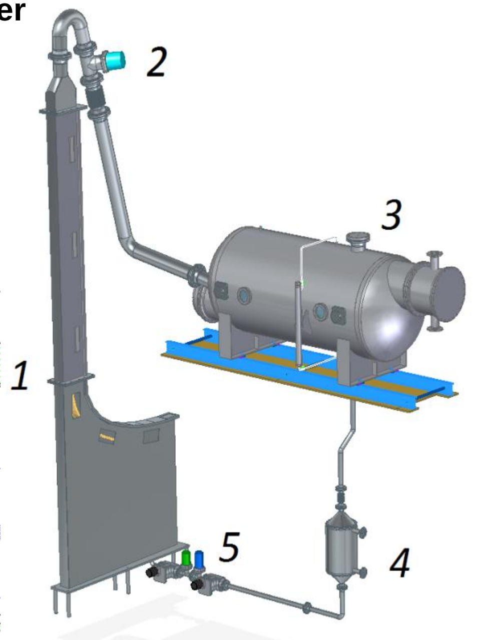
<u>Corium localization at Temelin NPP</u> - **IVR-EX**

Verification of ERVC Efficiency for VVER-1000/320

- Combination of analytical and experimental activities
- Experimental activities
    - Small scale test facility BESTH2
        - Chemical processes on surface of specimen
            - Corrosion
            - Formation of boric acid crystals on surface
        - Natural convection formation
        - Impact of surface conditions on heat transfer
            - Polished, corroded, coating (High Velocity Particle Coating „cold spray" technology – collaboration with PSU)
        - Impact of surface declination
    - Large scale facility THS-15
        - Scale 1:1(height and radius) for confirmation of VVER-1000 vessel cooling during applied IVR strategy
        - Segment 3.8° - angle of sector (power capacity)
        - Facility under construction

1. Cavity segment
2. Reduction valve
3. Condenser
4. Cooler
5. Pump

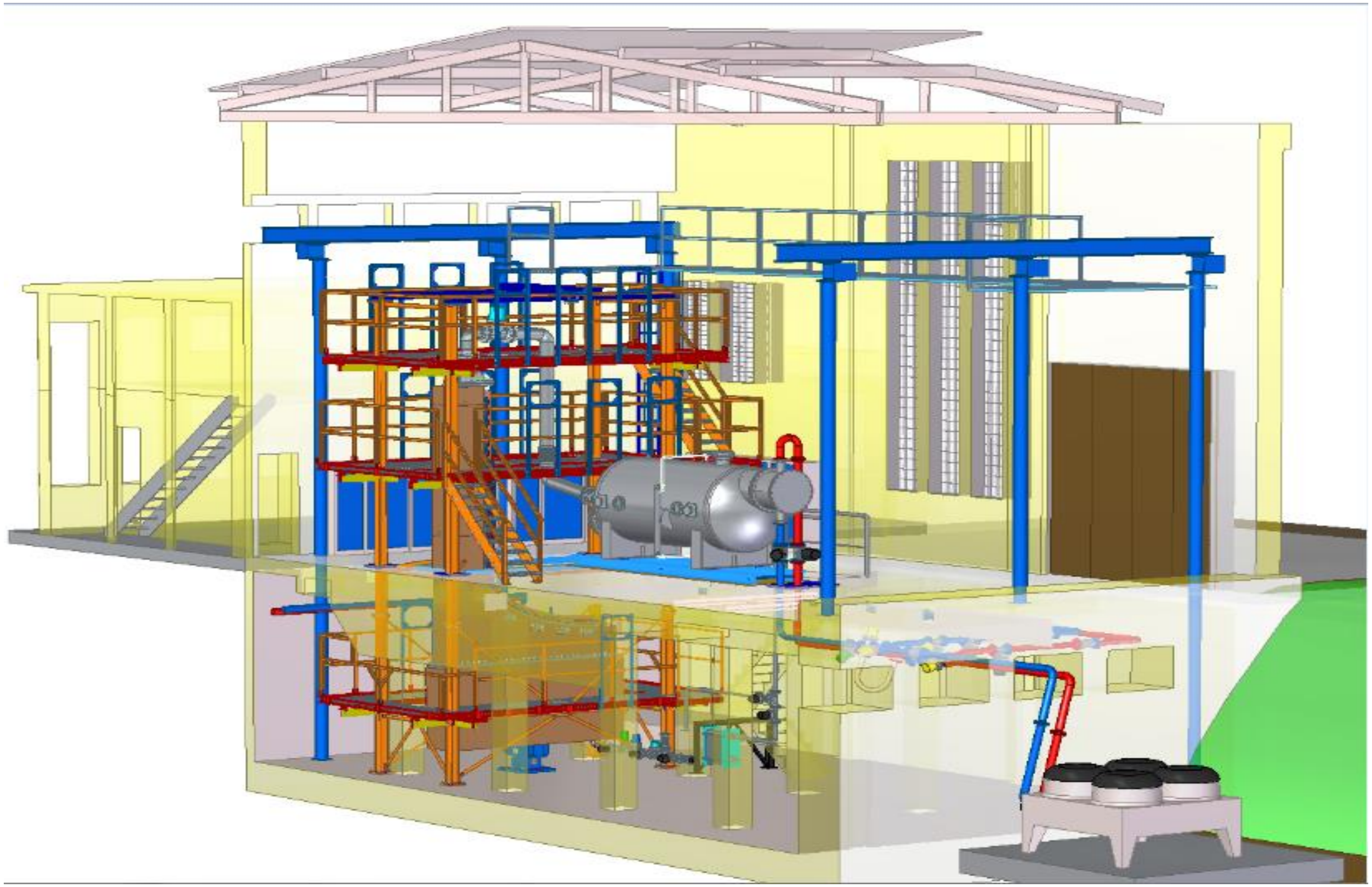




Implementation of SA Strategies and Measures

Corium localization at Temelin NPP - **IVR-EX**

- THS-15 … Thermal-Hydraulics Stand – initiated 2015



Implementation of SA Strategies and Measures

Corium localization at Temelin NPP - **IVR-EX**

- Comparison of VVER-1000 and THS15 facility

Parameter	VVER-1000	THS-15
Scale (volumetric)	1:1	1:95
Size of cooling channel by deflector [mm]	120 (100 – 250)	120 (100 – 250)
Angular sector	360°	3.8°
Flow area of channel in cylindrical part of RPV [m^2]	1.755	0.0184
Hydraulic diameter of channel [m]	0.24 (annulus)	0.135 (trapezium)
Height of cylindrical part of deflector up to [m]	2.9	2.9
Heat flux to wall	25 MW	263 kW

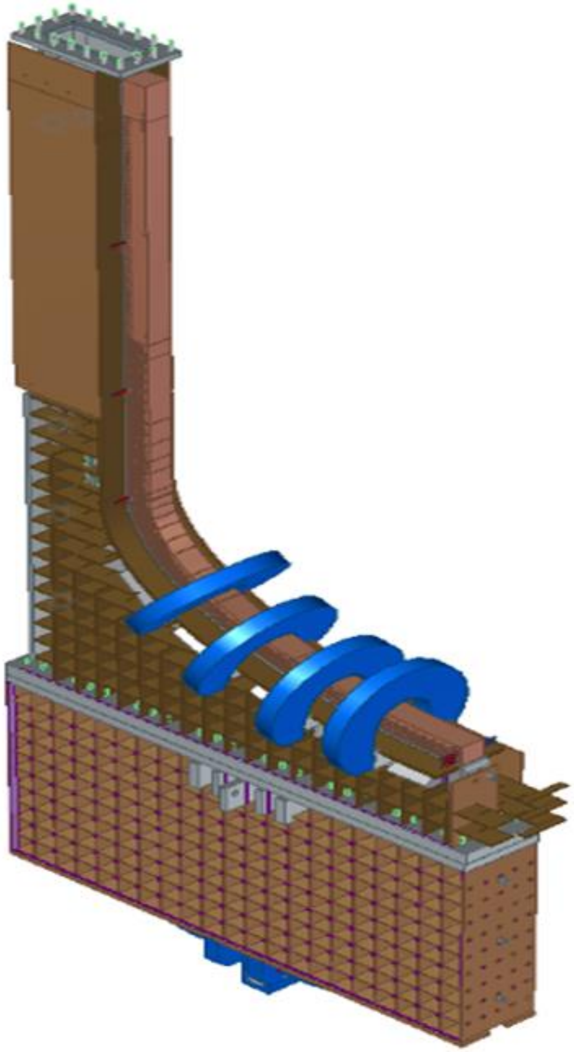
Implementation of SA Strategies and Measures

<u>Corium localization at Temelin NPP</u> - **IVR-EX**

- 17 heating segments along the whole height of the channel defined
  - Based on assumed heat flux profiles
    - 2 and 3 layer profiles assumed – supporting analyses from Kurchatov Institute using SOCRAT/HEFEST code, but also UJV simulations with FLUENT code – overall 5 profiles is expected to be tested

- Each segment has defined length with installed electrical power in KW
  - Segment length is based on expected heat flux profiles
  - Segment power is based on expected CHF value

- That determines number of heating patrons in each segment



Implementation of SA Strategies and Measures

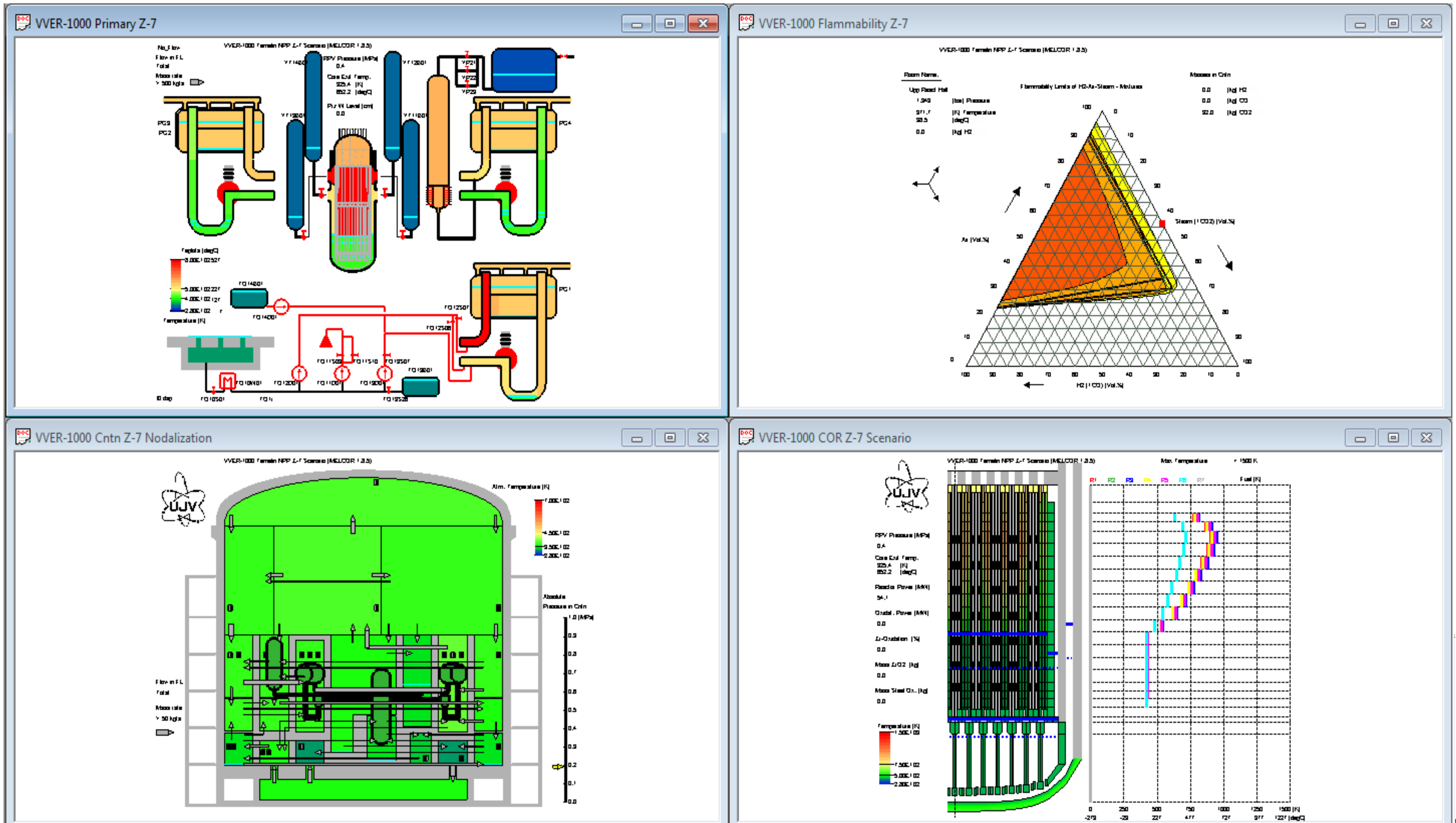
Staff training on SA and SAM

- Recent approach to NPP staff training for SAM – application of ATLAS tool (GRS, Germany)
    - Set of training courses prepared
        - Phenomenology of SA
        - Structure and application of SAMG
        - Demonstration of SA progression – visualization using ATLAS tool
    - Trainee
        - Members of technical support center
        - Operators or other staff which are potential members of TSC
    - Independent lessons for each NPP (Dukovany NPP and Temelin NPP) due to differences in plant designs
        - Plant specific screens, but mainly
        - Different unit behavior during SA and SAMGs

Implementation of SA Strategies and Measures

Staff training on SA and SAM

- Example of ATLAS screens for Temelin NPP



Implementation of SA Strategies and Measures

<u>Staff training on SA and SAM</u>

- Several limitations identified in application of ATLAS
  - Conditions of approval done by GRS on using for NPP staff training
  - Only results of one calculation can be visualized
    - Solved with multiple operation of ATLAS tool, but it does not allow some useful visualization approaches
      - Synchronized (scrolling) visualization with common time control to see differences in progressions due to SAM measure application
  - Very complicated development of screens
    - Nodalization dependent screen without any possibility for automatization or simplification of development process
      - Development in Excel can slightly simplify procedure

- UJV initiated project for development of new tool with solving of ATLAS problematic topics ⇨ VINSAP
  - Project is ongoing (2015-2017), paid by Technological Agency of CR

Implementation of SA Strategies and Measures

<u>VINSAP Tool</u> (**<u>Vi</u>**sualization of **<u>N</u>**PP **<u>S</u>**evere **<u>A</u>**ccident **<u>P</u>**rogress for Training on SAM)

- Development is done for visualization of MELCOR code results (M186 and M2.2)
  - Due to transformation (conversion) of output file to specific database format, the transformation tool can be modified to use VINSAP also for other codes
- Principal version is developed in Czech language, but all description are called during compilation from one list, which can be translated and alternative language version released
  - Recently also English mutation is prepared, some terms need to be corrected as translation done by programmers, not SA specialist
- Tool consists of 4 main utilities
  - Transformation
  - Re-calculation
  - Screen-editor
  - Visualization

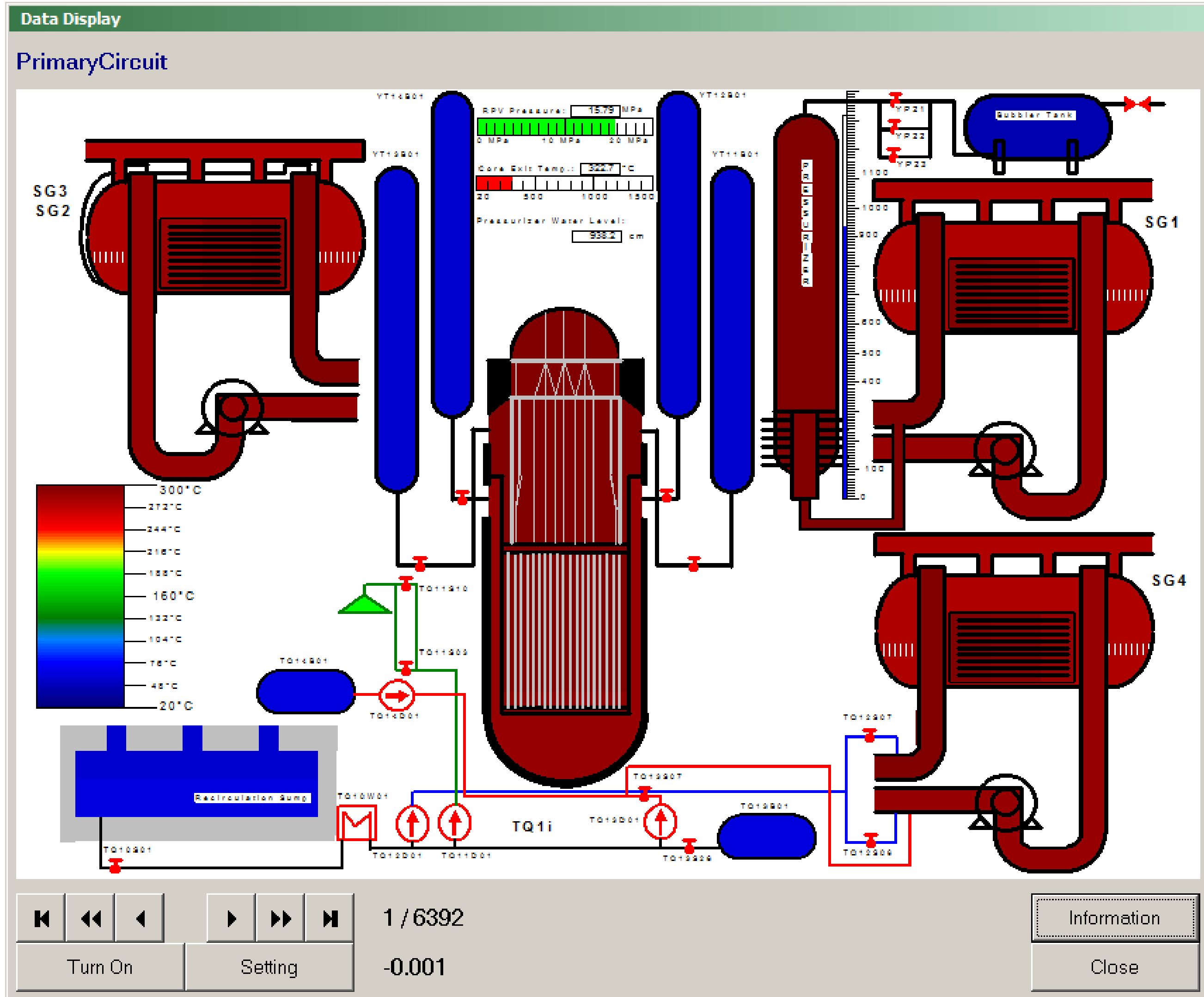
Transformation, Re-calculation, Screen-editor: Utilities for results processing and screen preparation

Visualization ⇨ Final utility for training

Implementation of SA Strategies and Measures

VINSAP – Primary Circuit Screen Example

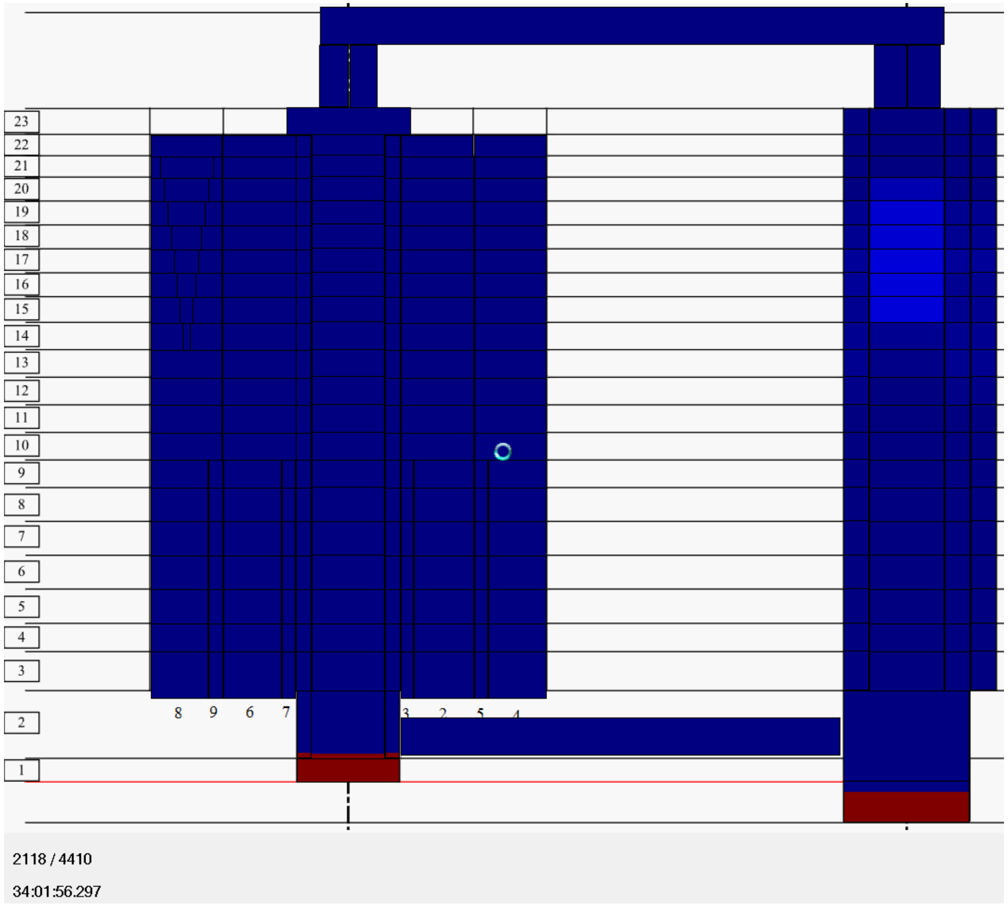
- Further development ongoing
  - User defined color scales



Implementation of SA Strategies and Measures

VINSAP – OECD THAI-III TH-27 Exercise

- He concentration evolution
  - Screen was prepared for result processing purpose within 1 hour
  - Purpose - explanation and demonstration of predicted blockage by He cloud



Conclusions

- A systematic continuous effort of safety enhancement
  - ongoing at both VVER sites in the Czech Republic
    - since commissioning
- A Fukushima accident has initiated a new period
  - of safety enhancement process
    - Implementation of diverse and alternative (mobile) means to prevent SA
      - became even more important attributes
    - Implementation of special means to eliminate progress and mitigate SA phenomena
- Advanced approaches in analytical support
  - are being used within this systematic process

Thank you for your attention

Any Questions?

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