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NUGENIA+ WP6.9 DEFI-PROSAFE

DEFInition of reference case studies for harmonized PRObabilistic evaluation of SAFEty margins in integrity assessment for LTO of RPV/DEFI-PROSAFE

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Sustainable Nuclear Energy Technology Platform

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Introduction

- **RPV integrity is based on deterministic assessment within EU following national code and specific safety factors to cover potential uncertainties in**
  - Thermal-hydraulic RPV loading, flaws, material embrittlement
- **No commonly accepted European methodology to assessment margin in RPV integrity accounting for uncertainties propagation**
  - Approach is proposed in DEFI-PROSAFE for assessing the key parameter that could represent the total safety status (safety margin) of a reactor pressure vessel
  - Based on deterministic and probabilistic assessment
- **New feature is the consideration of the propagation of thermal-hydraulic uncertainties in the assessment**
  - Method to decrease the conservatism of TH loading for a given scenario

Objectives

- **To support utilities in the regulatory justification of margin evaluation including propagation of uncertainties in their structural-integrity assessment of the RPV for LTO**
- **Approach is proposed for assessing the key parameter that could represent the total safety status (safety margin) of a reactor pressure vessel**
- **Added values:**
  - uncertainties , variation in thermal-hydraulic loading are addressed
  - identification of major contributors and understand level of conservatism, quantification of impact: improve margin
  - DEFI-PROSAFE: benchmark definition of case study

Partners / main tasks

- **AREVA- GmbH**
  - Coordination
  - Review Methodology
  - Create decks for RELAP5, CATHARE, local mixing model
  - Perform PIRT
- **UJV**
  - Review Methodology
  - Review RELAP deck, create ATHLET
  - Flaw distribution and POD
  - Benchmark definition
- **PSI**
  - Review Methodology
  - Review RELAP deck
  - flaw distribution and POD, fracture toughness model

Tasks (5 WPs)

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- **WP1 Definition of an approach to evaluate margin (AREVA+PSI+UJV)**
  - Why: Because no guideline exists for RPV probabilistic integrity assessment; no methodology exists for propagation of TH uncertainties
  - How: make use of experience (PROSIR, ICAS) and state-of-the-art material testing (Master Curve) to define a methodology for performing the future benchmark. For TH uncertainties, by applying the Wilks method instead of deterministic bounding values
- **WP2 Thermal hydraulics (all)**
  - What: Creation of models (RELAP5, ATHLET, CATHARE) for simulating the UPTF testing facility
  - Why: to quantify uncertainties by comparison with experimental results, and identify possibilities for reducing uncertainties; to investigate propagation of uncertainties
  - How: by application of a local mixing code, by application of the Wilks methods (instead of using a deterministic bounding value)
- **WP3 PIRT (AREVA-G+UJV)**
  - TH parameters important for RPV integrity assessment must be identified and ranked in order to select the type of treatment of uncertainties

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Tasks (5 WPs)

- **WP4 Uncertainties description flaw/material (all)**
  - Why: Reduced basis in PROSIR
  - How: setup statistical distribution of input data for the probabilistic fracture mechanics assessment based on consideration of literature search and available data
  - Who: UJV (flaws/POD) AREVA (materials)
- **WP5 Definition of case study (all)**
  - Why: to evaluate the adopted methodology and allow verification/validation
  - How: description based on available benchmark PROSIR and following methodology WP1

Results – Task Margin approach (D6.9.1)

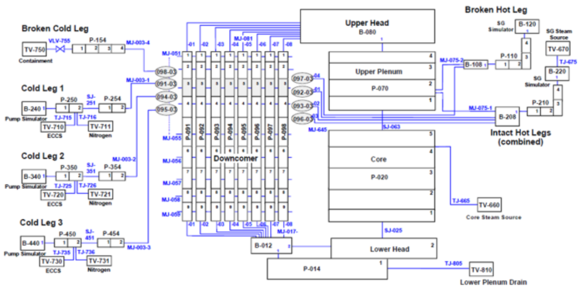
- **The method of quantifying the remaining margin is based on the comparison of maximum allowable adjusted reference temperature resulting from deterministic and probabilistic integrity assessments:**
  - for deterministic assessment, the margin is given as the difference between the maximum adjusted reference temperature ART from the deterministic assessment and the ART of the RPV for a given term of operation
  - for probabilistic assessment, the margin is given as the difference between the maximum ART for a limiting conditional probability of RPV crack initiation or failure (uncertainties assessment and probabilistic fracture mechanics assessment) and the ART of the RPV for a given term of operation
- **In the methodology, the Master curve and the WPS effect are applied**
  - The remaining margin can be expressed by the difference between the probabilistic and deterministic margin
- ***Methodology for including TH uncertainties will be presented by Dr. Trewin***

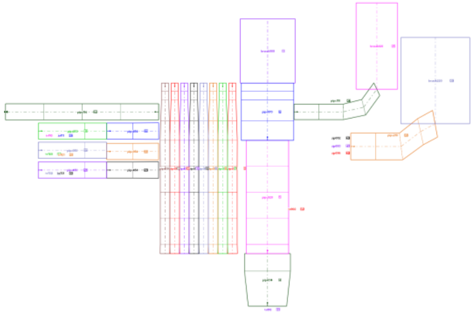
Results – Task Margin approach (D6.9.1)

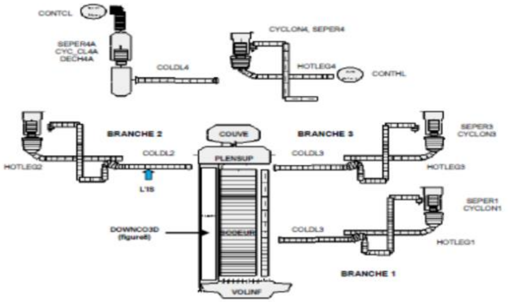
- **For including the uncertainties in TH, the proposed methodology is as follows.**
  - Apply a local mixing model (see also next task)
  - Apply the Wilks method to replace a bounding TH loading for fracture mechanics analysis (as for the deterministic approach) to more realistic TH loading
  - Parameter values for highly ranked phenomena from the PIRT are treated statistically, if possible, and otherwise conservatively. Parameters for low-ranked phenomena from the PIRT can be assigned best-estimate values.
  - Randomly selected values from the distributions of the statistical parameters are used in multiple simulations of the transient.
  - The number of simulations is given by the Wilks criteria.
  - Values for determining the TH loading during the transient that are not exceeded with a 95% probability at the 95% confidence level are determined statistically.

Results – Task TH (D6.9.2)

- **The model reactor, a 1300-MWe PWR (as simulated in the 1:1 scaled UPTF experiments) serves as the reference model in the final benchmark definition.**
  - Experimental data were provided to the DEFI-PROSAFE consortium for temperatures in the downcomer and the boundary conditions: partially filled cold leg, injection flow rate of 40 kg/s, injection temperature of 30 °C
  - Input decks were created for RELAP5/MOD3.3, ATHLET, and CATHARE V2.5_3 that were validated by comparisons with the experimental data.





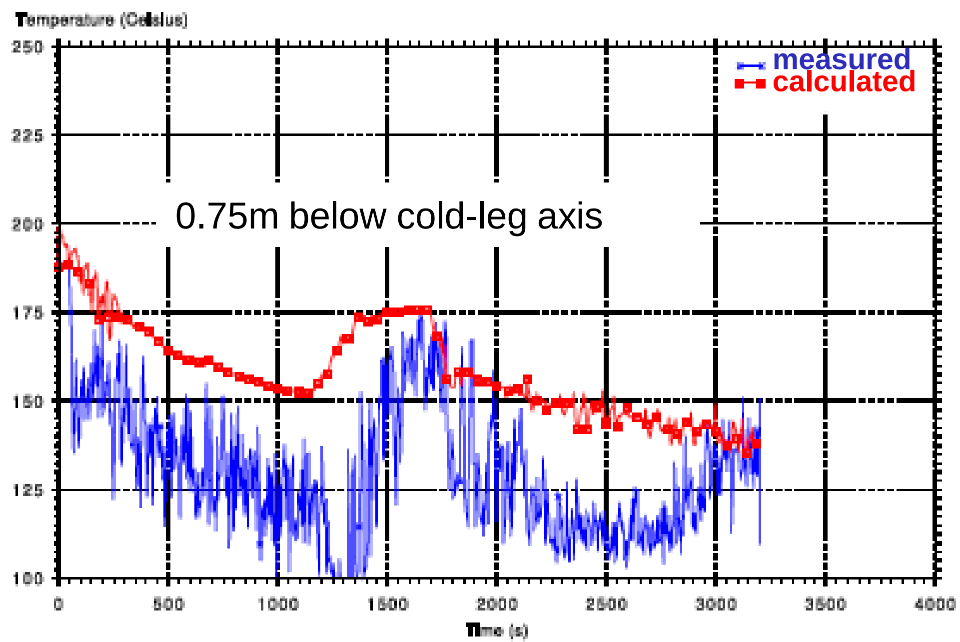


  - Comparisons revealed that calculations were usually conservative except in the downcomer under the cold-leg nozzle of the loop with cold injected water.
- **Agreement between calculated and experimental values can be improved with the use of mixing analyses.**

Results – Task TH RELAP(D6.9.2)

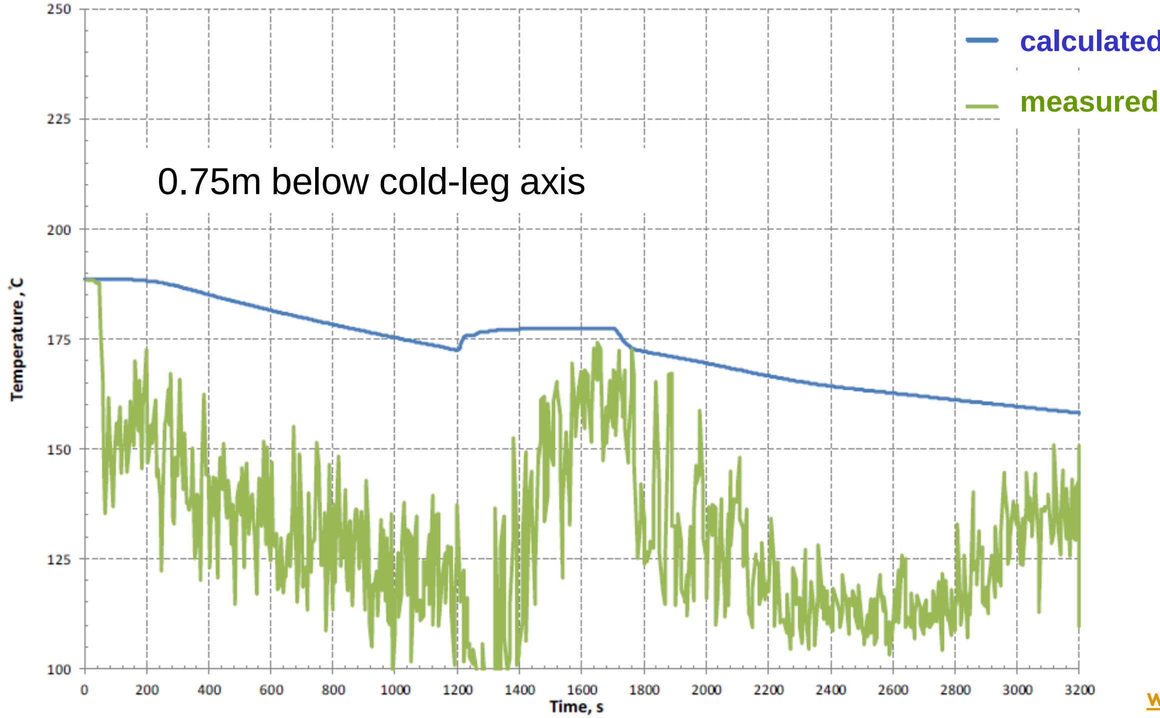
- **RELAP5 results: Average values for temperature and heat-transfer coefficient are compared with measured local values**
  - Values for temperature and heat-transfer coefficient in downcomer volumes below the cold-leg of the injected loop depend on the size of the volume.
  - Temperatures in larger volumes approach the warmer, average value, which is not conservative.

injection flow rate
= 40 kg/s
injection temperature
= 30 °C



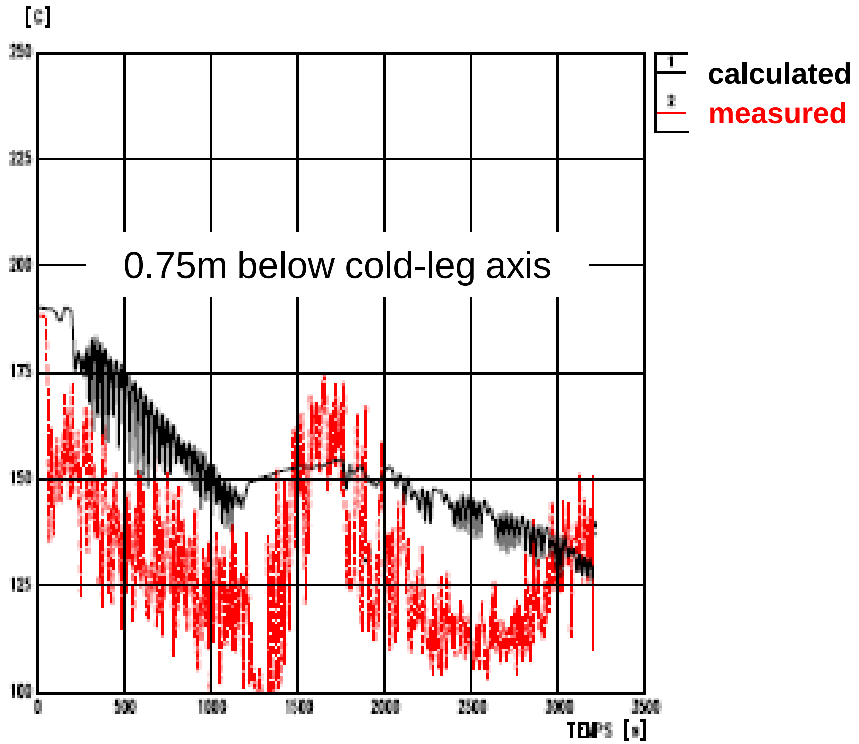
Results– Task TH ATHLET (D6.9.3)

- **ATHLET results: Water temperatures adjacent to test vessel wall at an elevation 0.75 m below cold-leg axis of injected loop. (Injected water flow = 40 kg/s, temperature = 30 °C)**
  - Calculated temperatures are comparable to measured values, but some non-conservatism exists in the downcomer below the cold leg of the injected loop.



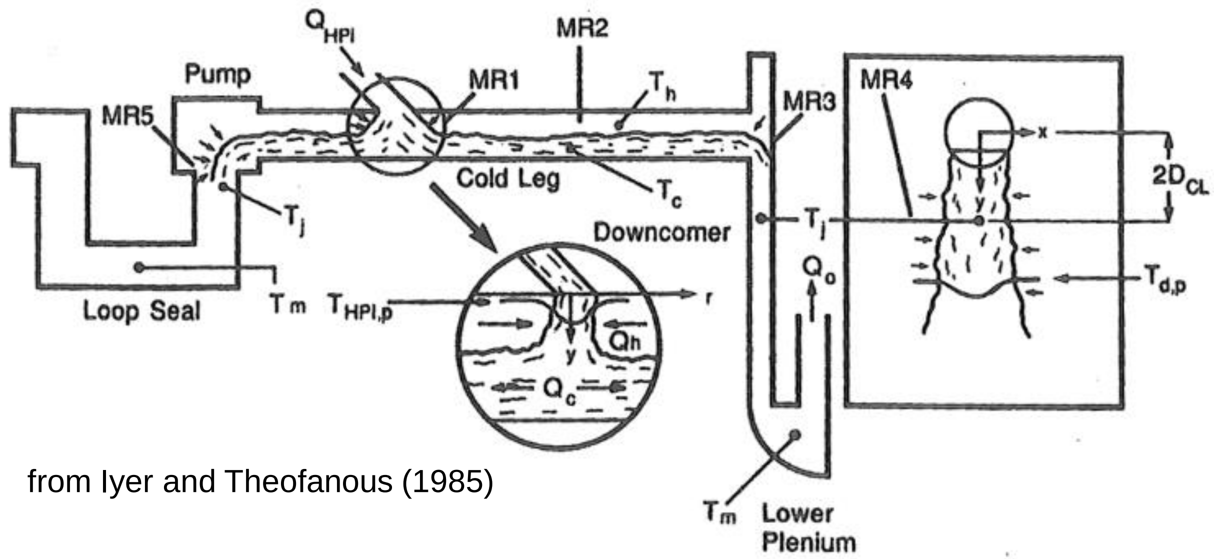
Results– Task TH CATHARE (D6.9.3)

- **CATHARE results: Water temperatures adjacent to test vessel wall at an elevation 0.75 m below cold-leg axis of injected loop. (Injected water flow = 40 kg/s, temperature = 30 °C)**
  - Width of each node is wider than the plume width.



Results – additional Task TH local mixing (D6.9.3+)

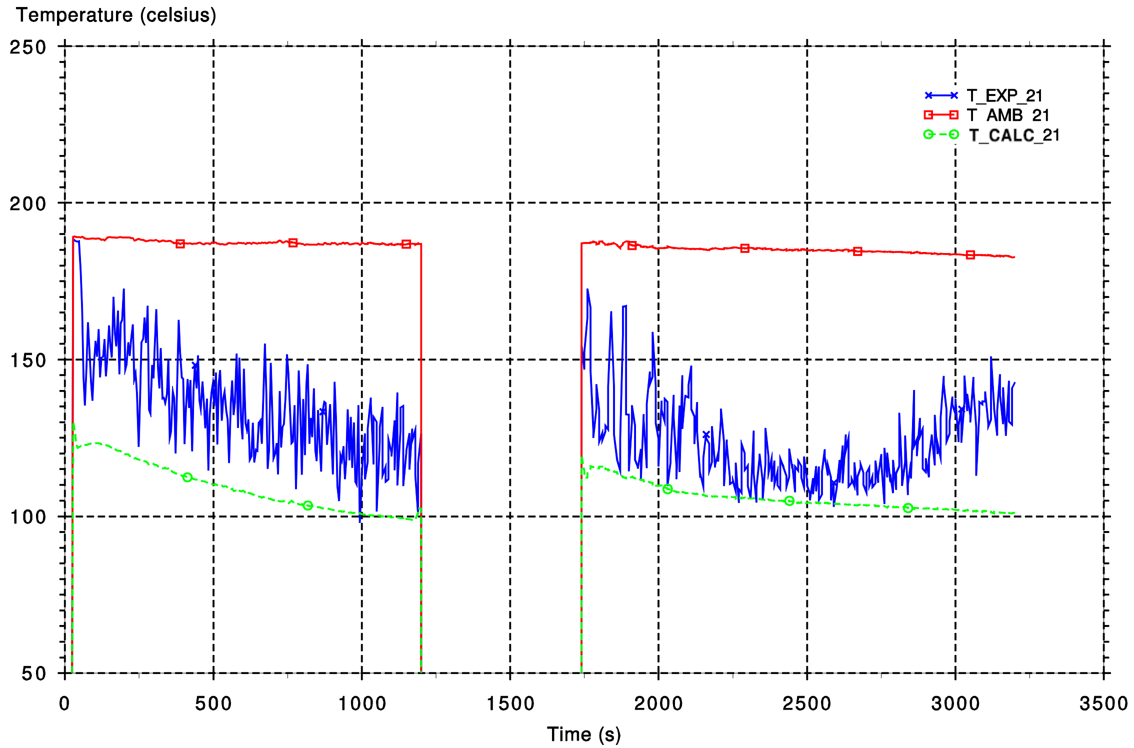
- **Better agreement can be achieved by simulating the three-dimensional distributions in temperature and heat-transfer coefficient that arrise due to mixing between stream of hot and cold water (one phase).**
- **Calculation of distributions can be accomplished with various methods, e.g. CFD and phenomenological models**
  - KWU-MIX uses various phenomenological models depending on the mixing region (MR)



from Iyer and Theofanous (1985)

Results– Task TH MIX (D6.9.3+)

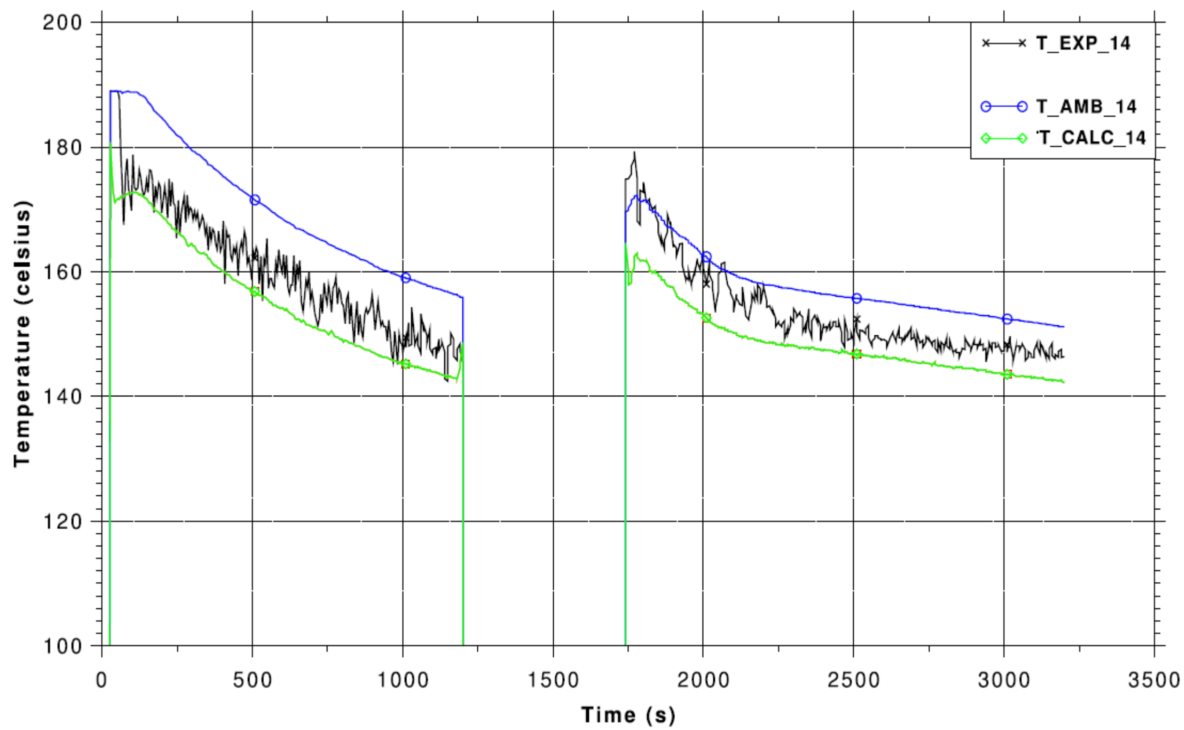
- **Water temperatures adjacent to test vessel wall at an elevation 0.75 m below cold-leg axis of injected loop. (Injected water flow = 40 kg/s, temperature = 30 °C)**



Measured (T_EXP_21) and calculated (T_CALC_21). Measured water temperature T_AMB_21 outside plume region.

Results – Task TH MIX (D6.9.3+)

- **Water temperatures adjacent to test vessel wall at an elevation 3.0 m below Cold Leg 2 axis. (Injected water flow = 40 kg/s, temperature = 30 °C)**



Measured (T_EXP_14) and calculated (T_CALC_14). Measured water temperature T_AMB_14 outside plume region.

Results Task Phenomena Identification and Ranking Table , PIRT (D6.9.4)

- **The most important phenomena and processes are**
  - *break flow*
  - *reclosure of the pressurizer valve if it is stuck-open*
  - *safety-injection flow rate*
  - *accumulator injection rate*
  - *jet behavior, flow distribution and mixing*
  - *interphase condensation & non-condensables*
  - *time of flow stagnation*
  - *liquid/vapor interface in upper downcomer*
- **The most important boundary conditions are**
  - *accumulator injection temperature and initial pressure*
  - *high-pressure injection temperature*
  - *safety-injection asymmetry*
  - *break size*
  - *time of reclosure if the pressurizer valve is stuck-open*
  - *break location*
  - *low-pressure injection temperature*
- The values of these parameters will be assigned statistically (preferably) or conservatively (if necessary) in the benchmark definition in order to include the effect of uncertainties.

Results Task Uncertainties description (D6.9.5)

- **Flaw distribution, POD, the deliverable includes**
  - *discussion on flaw distribution based on the literature search*
  - *Flaw detection and sizing from EPRI performance demonstration*
  - *Discussion of validity for service induced flaws and manufacturing type flaws*
  - *Discussion of validity for cladding to base metal interface*
  - *Discussion of validity for small flaws of about 3 mm through wall extension*
  - *VVER type RPV NDE qualification experience*
  - *VVER type RPVs qualified site inspection results*
  - *Discussion on relevant flaw types: in weld, underclad, in base metal*
- **Materials, it includes**
  - *Physical and technological properties for the benchmark*
  - *Chemical composition (PROSIR for benchmark)*
  - *Fracture toughness based on T0 for ferritic RPV for transition + upper shelf*
  - *Embrittlement models (PROSIR for benchmark, and other)*
  - *Fracture toughness irradiated RPV cladding*

    Derived from latest J-R investigation (Japanese work + Radiation response of the overlay cladding from the decommissionedWWER-440 Greifswald Unit 4 reactor pressure vessel)

Results Task Benchmark definition (D6.9.6)

- **Case study definition (ongoing)**
  - Pre-requisite with repetition of main PROSIR task to validate tools
  - Evaluation of TH uncertainties propagation resulting from the important parameters from PIRT and following the Wilks method
    - *Reference case from ICAS / PWR 1300*
  - Margin assessment based on adopted methodologie and including TH uncertainties

Conclusions and Outlook

- **Dissemination**
  - NUGENIA
- **Impact**
  - decrease in epistemic uncertainties (TH, Fracture toughness)will have a positive impact on margin for LTO
- **Conclusions**
  - Methodology for margin assessment for RPV integrity based on deterministic and probabilistic
  - Proposed methodologie for consideration of TH uncertainties
- **Next steps**
  - Request NUGENIA TA4 to review methodology (TRS ?)
  - Incorporate benchmark in other project proposal (new co-operation), or later proposal