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Experimental tests and validation of calculation criteria of acceptable Tk shift with respect to PTS at VVER.

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EXPERIENCE AND PERSPECTIVES

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Integrity Reactor Pressure Vessel

- The integrity of a Reactor Pressure Vessel (RPV) limits the life of the whole NPP over all its lifetime.
- The observance of operational limits and conditions (LaC) of a reactor guarantees the designed lifetime of RPV.
- Violation of these LaC of a reactor and/or violation of pressure test regime caused either by a human factor or due to technical reasons is part of the complex of many degradation factors that increase operation risk and hence cause shortening of safe operational lifetime of RPV and NPP.

Loss of Coolant Accident

- In particular, after a long term operation of NPP and material radiation ageing (Tk shift into „plus“ temperatures) these violations introduce negative impact on the remaining life time, safe operation life at the full power of NPP.
- The most severe type of an accident is the Loss of Coolant Accident – LOCA that introduces the conditions for pressurized thermal shock (PTS).

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PTS Conditions

- The PTS conditions appear due to cold-water injection onto hot surface of the RPV wall in the areas of cold legs.
- Rapid cooling of the RPV wall causes thermal stress, KI increase and decrease of fracture toughness KIC in the embrittled active zone at the same time.

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Experimental Tests of PTS (1)

- Experimental tests of PTS on model specimens of the active zone material (VVER) at real RPV wall thickness together with calculations modelling the tests conditions are carried out in Škoda Plzen JS plc in cooperation with AV CR CAD – Plzen. In the presented paper these works and their results are described, analysed and discussed in the following items:

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Experimental Tests of PTS (2)

- *Methodology of the fracture tests at temperature gradients and PTS cooling tests on large specimens (1500x1200x140mm) with a designed postulated crack and other smaller cracks in the cooled area (test are performed at a loading stand ZZ 8000 (80MN) in Škoda Plzen JS plc.).*
- *Simulation of radiation embrittlement of tested material near the end of the RPV designed life, the material is subjected to standard mechanical property tests and fracture tests of standard test specimens modelling the PTS regime of material loading (K_I-T)*

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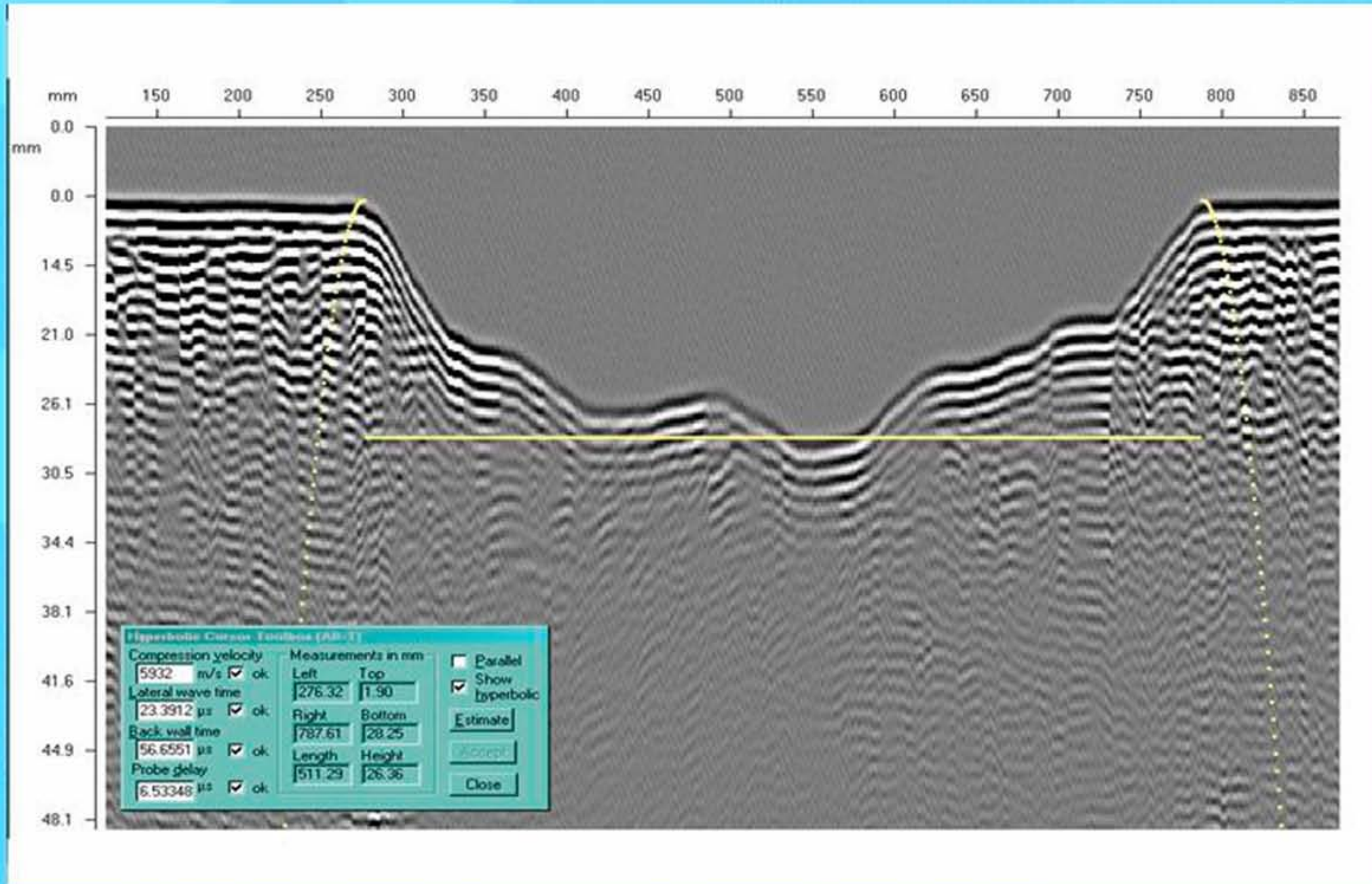
Experimental Tests of PTS (3) (on-line monitoring)

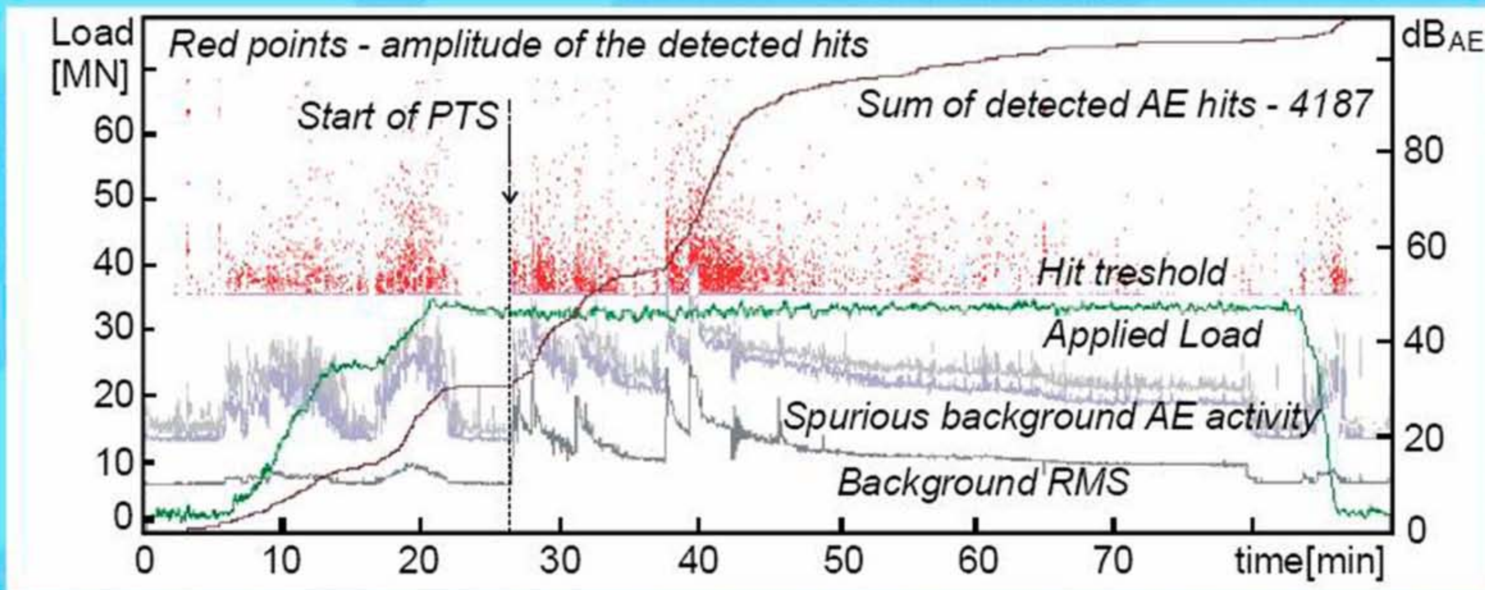
- *100% NDT tests of a specimen before the beginning of tests and μTOFD before and after each particular test of a specimen*
- *on-line monitoring of the test conditions based on instrumentation of a specimen with thermocouples, COD and strain gauges together with on-line monitoring of Acoustic Emission during the tests*
- *calculation of K_I at the critical points of the crack front during the test, based on monitored boundary conditions and fractographic analysis after the fracture of a specimen and evaluation of*

100% NDT tests of a specimen before the beginning of tests and μTOFD before and after each particular test of a specimen



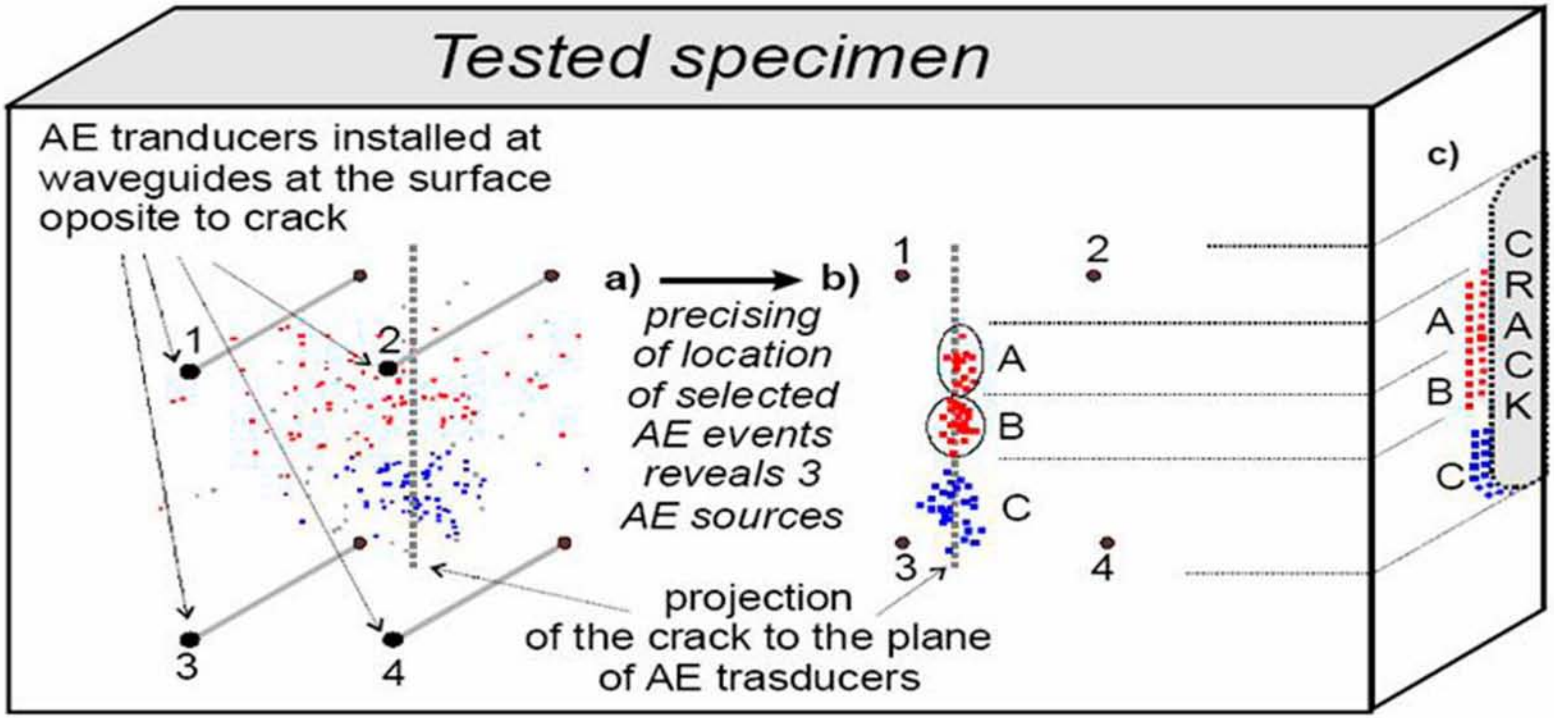
Crack of Specimen after PTS testing

Tolal AE activity detected at chanel 2 - most of the detected AE activity is spurious noise (1)

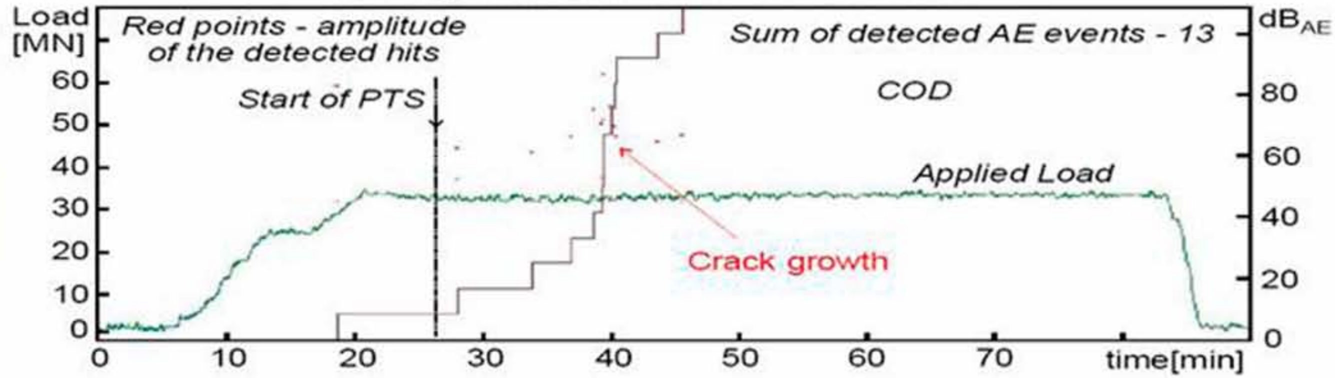


Result of filtration and selection of detected AE events.

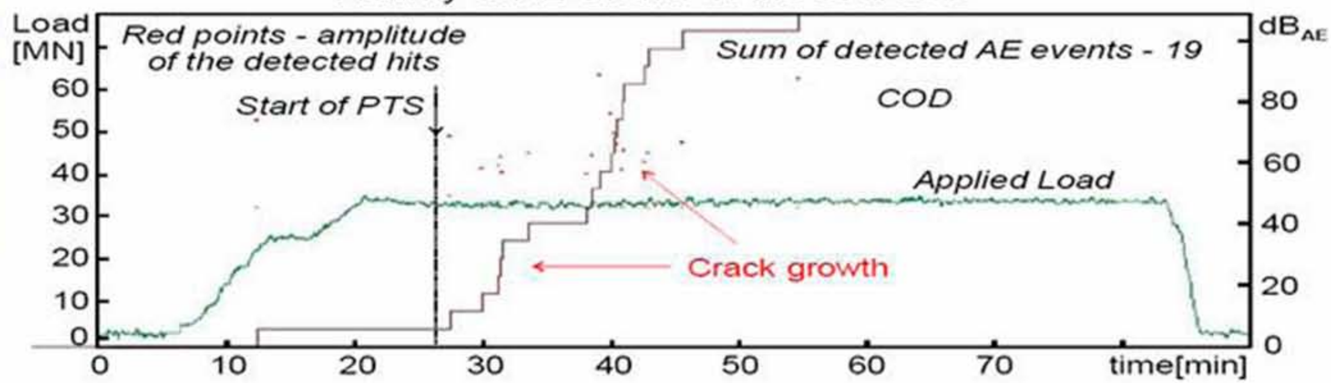
Result of filtration and selection of detected AE events.
a) standard plane location of detected and filtered AE events
b) precising of location of selected AE events by detail analysis of AE hits Δt
c) projection of AE events at the front of crack



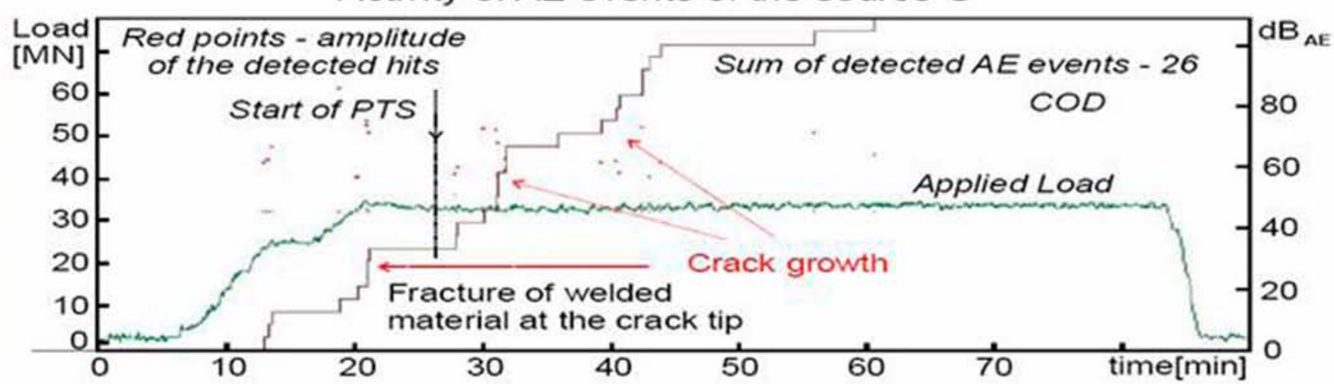
Activity of AE events of the source A



Activity of AE events of the source B



Activity of AE events of the source C



The tests were oriented to the task of arrest of crack growth initiated by PTS loading.

- A) In the case of
- crack growth initiation didn't cause in any cases break of body

- all crack growth initiations were arrested in the tough depth of body.

- deep crack (1/4 of wall thickness)
- - initial crack tip in brittle welded material
- - high level of prestressed crack before PTS
- - intensive cooling of body surface
- The reasons for result A) are :
- The energy of thermal stresses due to PTS is not sufficient
- to break the body in the high toughness material (in depth of body)
- The maximumPTS overstressing of crack tip in tough material
- stabilizes the crack tip (WarmPrestressing - WPS)
- During the fall period of SIF no crack initiation were found.

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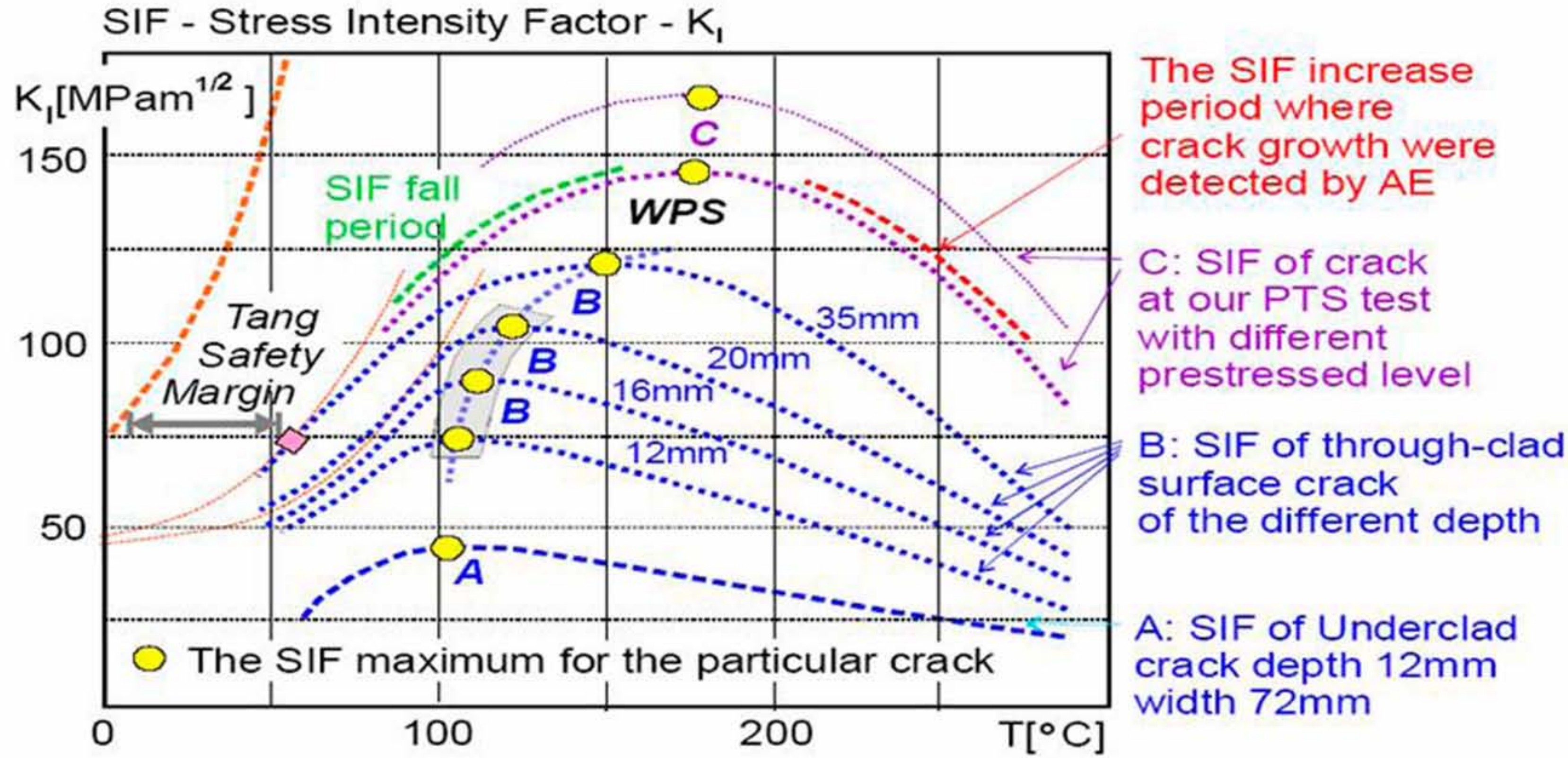


High intensity cooling of body with depth crack is not the most serious case because SIF reaches its maximum at hot tough tip of crack where WPS stabilizes crack tip against crack growth initiation during SIF fall period.

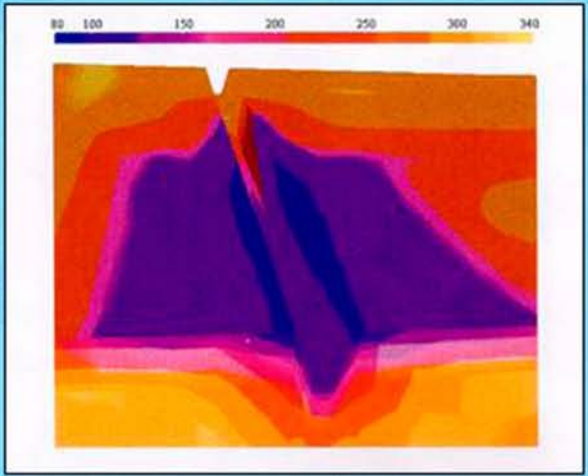
The most serious are surface throughclad cracks of the depth 12 to 20mm, that reach the maximum of SIF at low temperature.

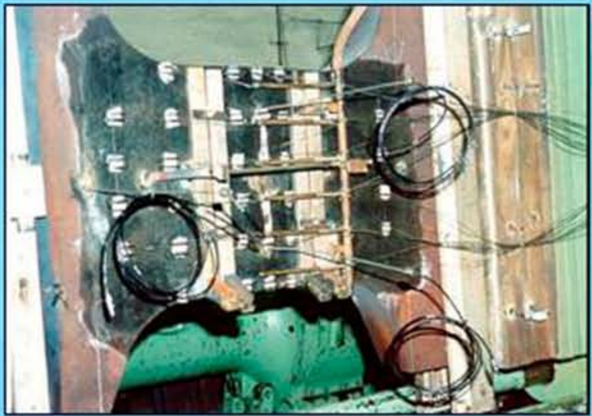
Experimental Modelling

- The presented works are oriented to the experimental modelling of the real response of materiel subjected to loading conditions near to the real conditions of material loading with the emphasize on the PTS regime conditions. There are two basic objectives of the presented works.

Large Scale Experiments for RPV Materials

- **Pressurized Thermal Shock (PTS)**
  - **Verification of type VVER RPV material against PTS**
  - **Special loading equipment ZZ 8000 (maximum tensile power of 8000 t)**
  - **Representative material sample actual RPV wall thickness with an artificial defect of critical size**
  - **On-line temperature and stress fields monitoring**
  - **Weld representing the pressure vessel circumferential weld in the core region (weld No. 5/6) for type VVER 440 RPV**





Basic Objectives of the Presented Works

- There are two basic objectives of the presented works. Firstly, it is to identify the real response of material to real conditions with respect to standard material properties. Secondly, it is to validate the calculation assessment of PTS criteria for accepted embrittlement – Tk shift.

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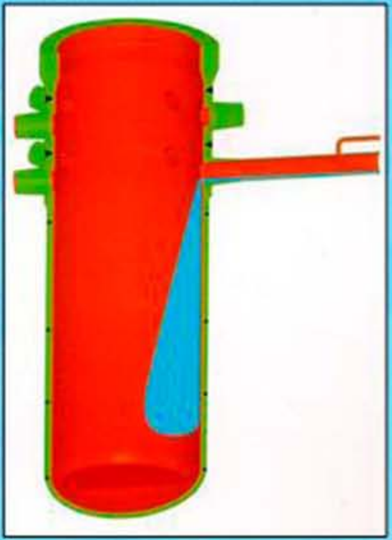
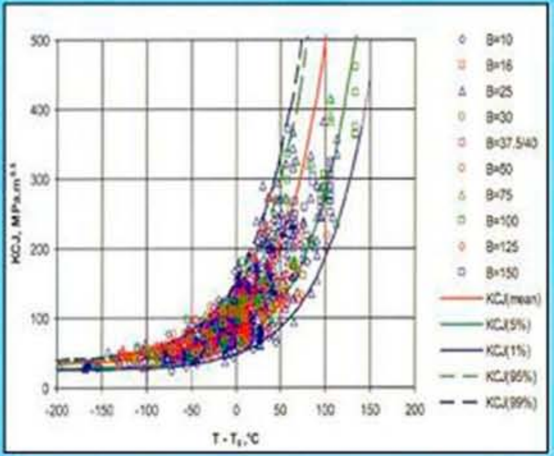
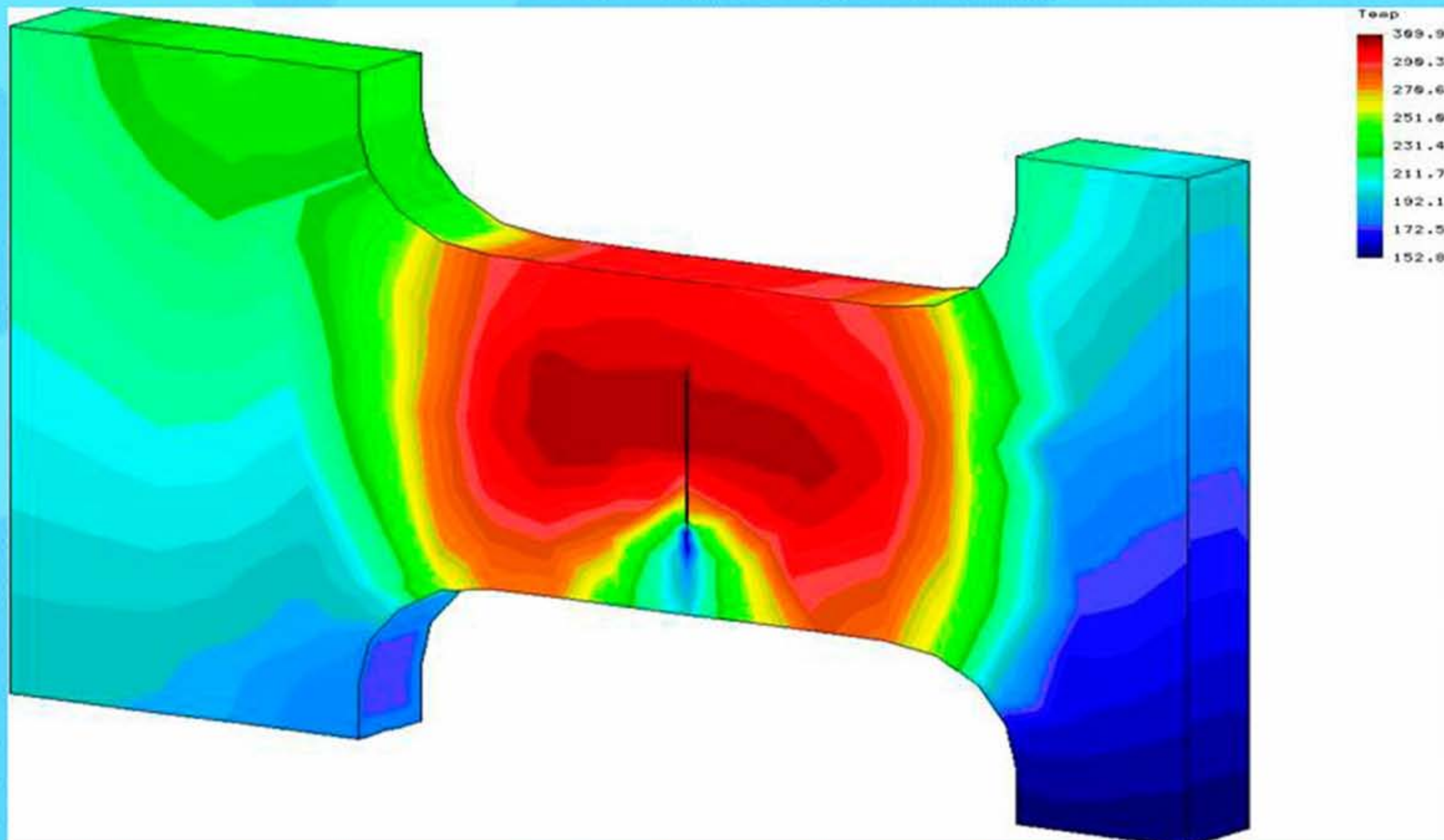
Reactor Pressure Vessel Integrity

- Reactor pressure vessel integrity and lifetime assessment - references
  - *Extensive data base of VVER RPV material properties*
  - complementary RPV VVER 440 material testing and qualification test programme of RPV VVER 1000
  - *Special large scale tests* - PTS condition simulation
  - verification of type VVER RPV material against deterioration by pressure temperature shock
  - *Surveillance programmes*
  - modified systems for RPV embrittlement monitoring
  - neutron fluence monitoring on reactor ex-vessel using a set of activation detectors
  - *Repair welding development*
  - preparing of the RPV robotic repair welding using remote control system and verification/qualification of the welding process

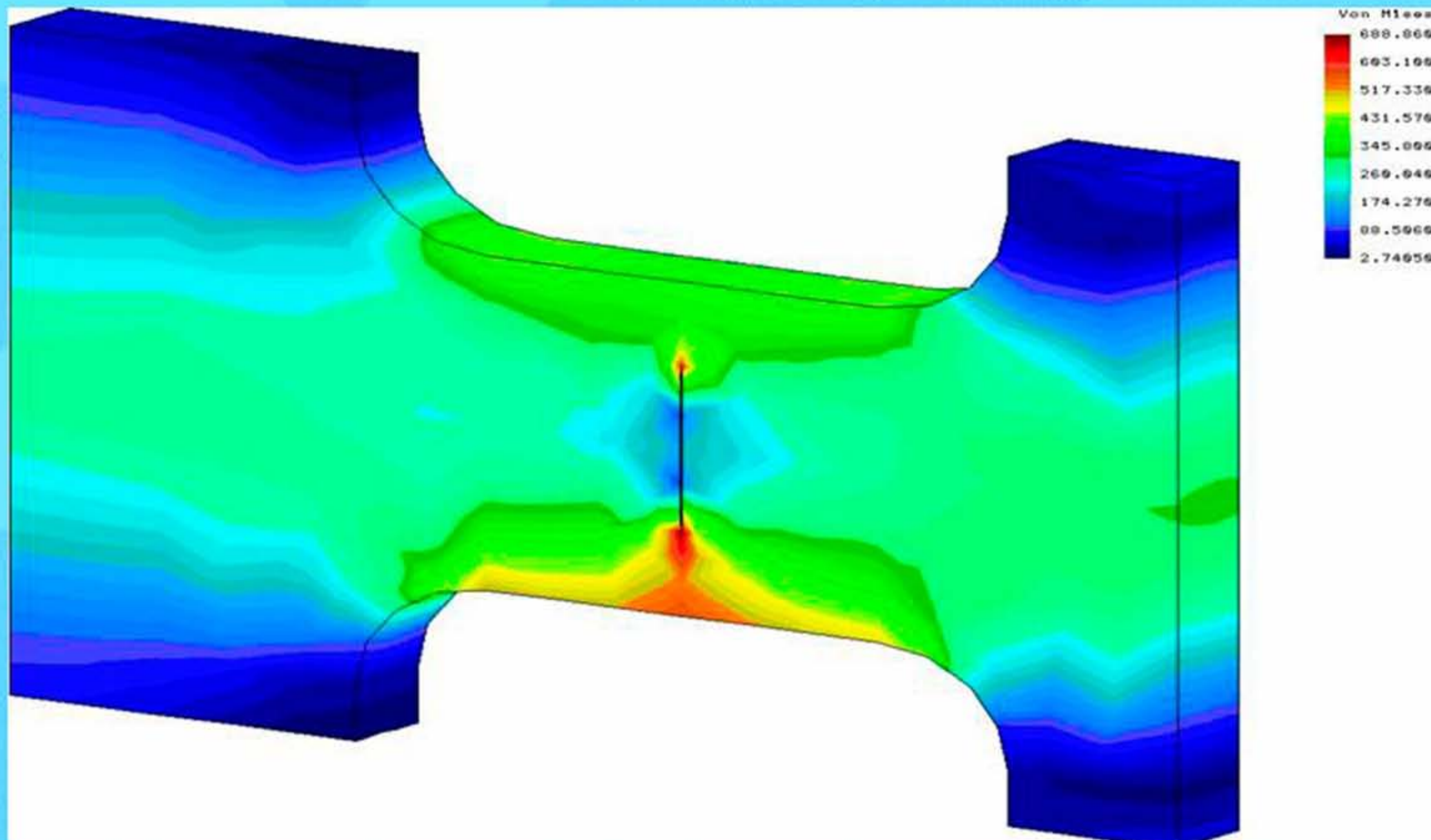




On-line Temperature Field Monitoring

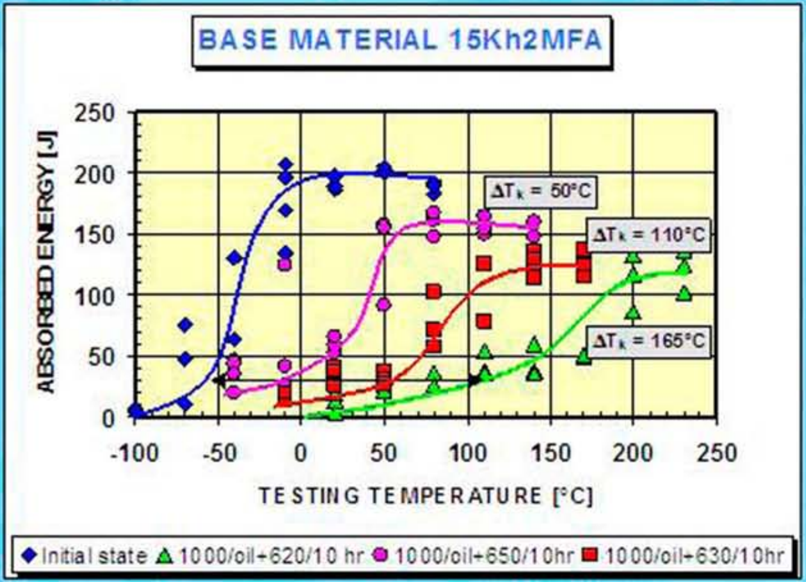


Stress monitoring



Irradiation Embrittlement Simulation

- Expected properties corresponding to the EOL
- Max. obtained shifts of Charpy-V transition temperature (Tk)
  - Base material 80 – 100°C
  - Weld metal 140 – 186°C
- Increase in yield strength is about 200 – 300 MPa
- Methods for simulation:
  - Step cooling – effective only for higher P, Sn, Sb and Ni
  - Quenching and lower temperature tempering

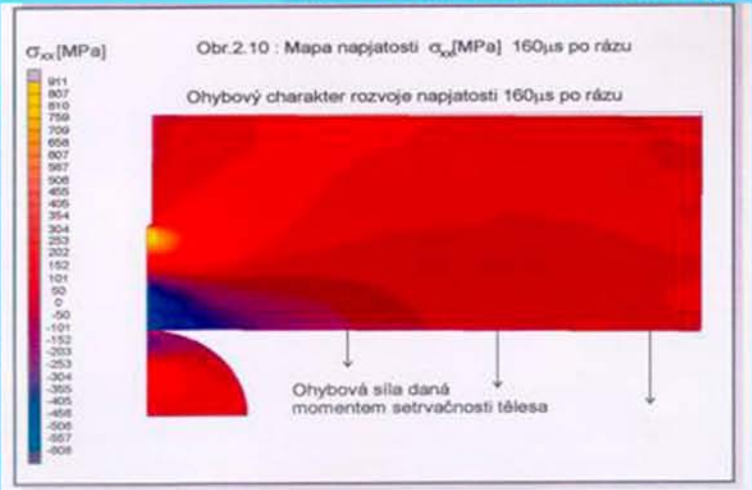


REFERENCES:

- Special tests VVER 440 RPV with underclad cracks at the frame Phare 2.01/95 programme
- PTS large scale tests
- Repair welding

Life Time Monitoring

- **Cask Body and RPV Life Time Monitoring**
  - NATO science for peace programme
  - Spent fuel transport and storage casks of type B
  - Monitoring program and evaluation of cask material
  - Testing of non-aged and aged (simulation) samples with the aim to select the method to be used for residual lifetime evaluation
  - Semi-destructive and non-destructive solution
  - Verification of methods for monitoring degradation of cask body material
  - Residual life time determination
  - One Point Bend Test – computer modelling



References:

Possibility and experiences from RPV lifetime assessment

Surveillance programme innovations

Hardness measurements before RPV recovery annealing

Indentation testing on RPV in Paks, Bohunice and Dukovany NPP