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BRITTLE FRACTURE ASSESSMENT FOR LTO OF WWER RPV

IPP CENTRE

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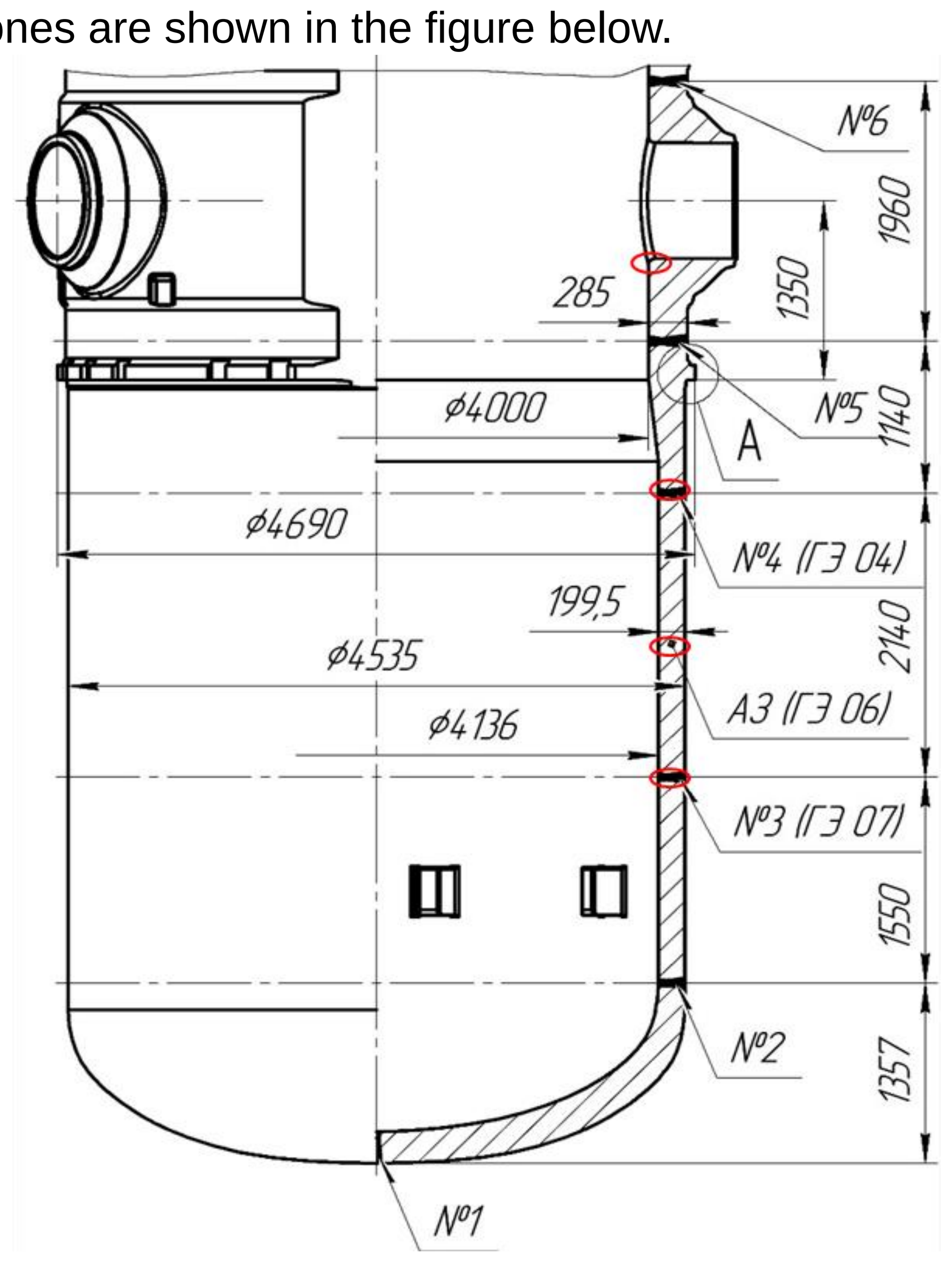
Introduction

The majority of Ukraine Nuclear Power Plants were built in the 80's, and have VVER type of Reactor. The design lifetime is about 30 years of operation. The current work concerns the long-term operation (LTO) of Reactor Pressure Vessel (RPV) beyond the initial designed life-term, which is generally accepted world practice. Brittle strength is the major criterion for RPV safe operation in LTO.

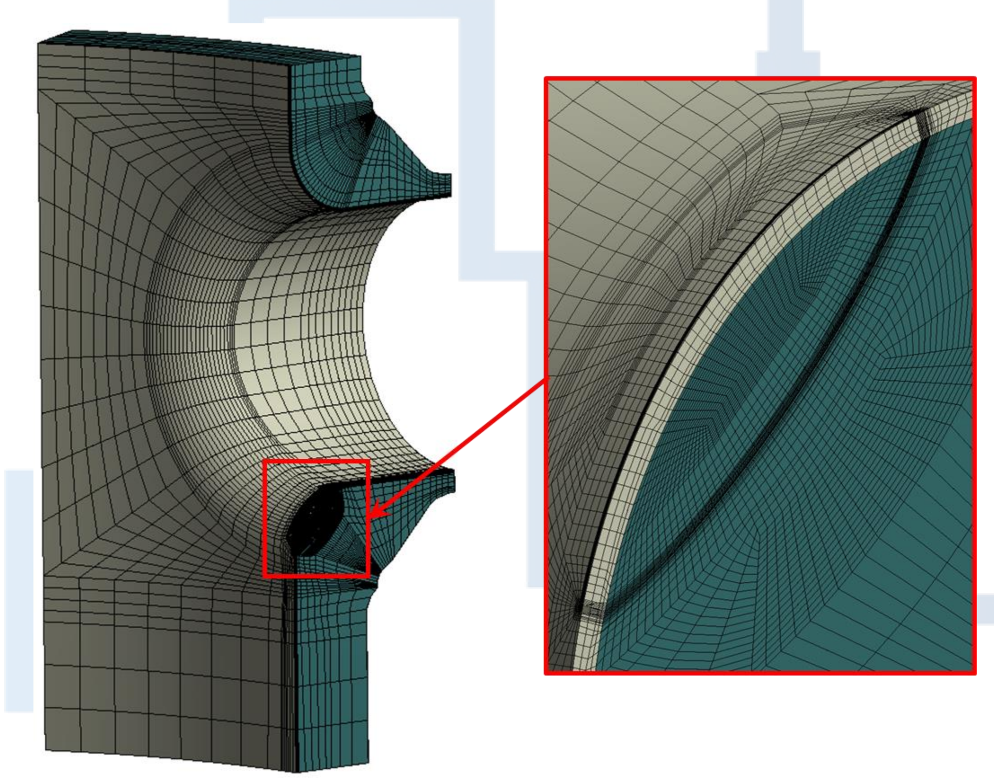
To assess the resistance to brittle fracture of the reactor pressure vessel, four potentially dangerous areas were considered. The main hazardous points affecting long-term operation are welded joints No. 3 and No. 4. The base metal of the cylindrical forging, which carries the maximum radiation load, was also estimated. The RPV nozzle zone also requires significant attention because the maximum value of the SIF occurs in this zone, which may approach the maximum allowable value for 15Cr18Ni10Ti steel (200 MPa√m). The abovementioned zones are shown in the figure below.



The state of the base metal and cladding is monitored for each potentially dangerous section. The absence of detected defects allows us to postulate semi-elliptical axial and circumferential cracks with a depth of 1/10 of the total wall thickness and a ratio between the ellipse semi-axes of 0,3 and 0,7.

Linear fracture mechanics

During LTO projects approximately 60-70 scenarios are analyzed for each unit. Therefore, an original efficient procedure has been developed for quick estimation and selection the most dangerous scenarios. This procedure includes a module for solving the temperature component of the problem, which calculates the change in temperature distribution over the wall thickness, and a module for strength assessment, which evaluates the change in selected characteristic "strength parameters" over time. In the case of linear fracture mechanics analysis, the maximum value of SIF and the minimum value of Tka are the characteristic strength parameters.

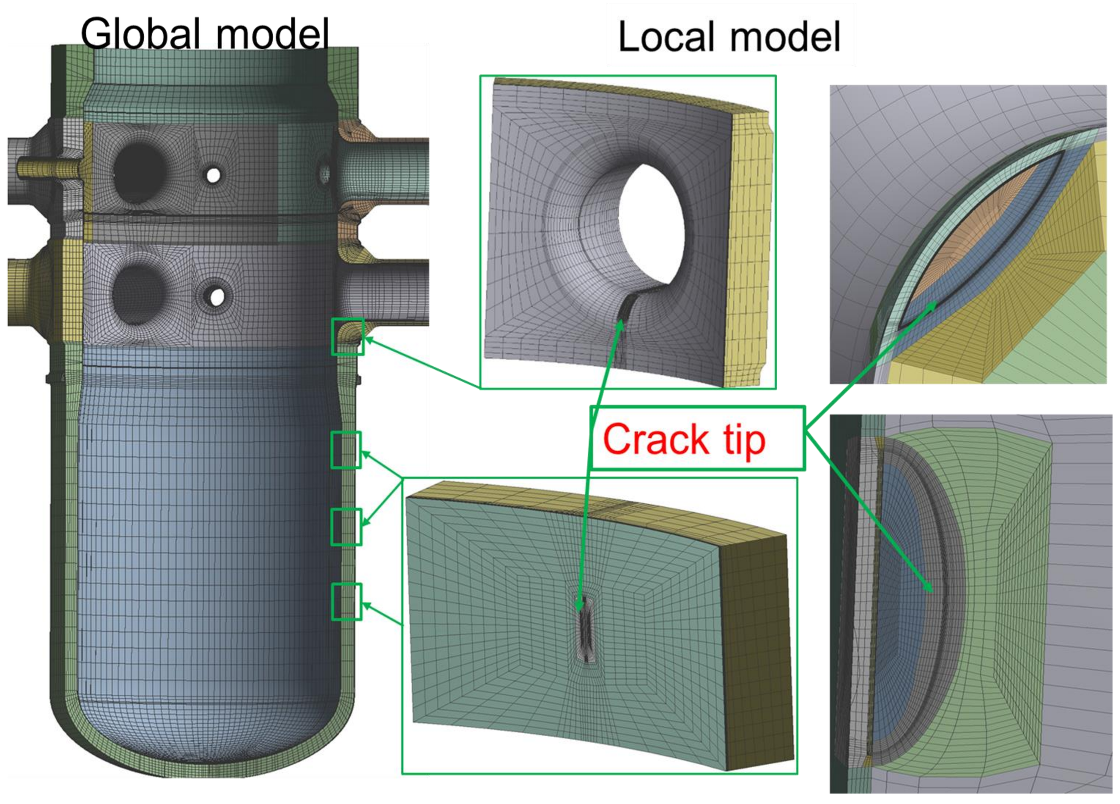


The analytical procedure was used only for the analysis of the cylindrical part of the RPV. A FE model with an embedded defect was created to cover the nozzle area. The finite element model of the nozzle zone of the RPV is presented below.

Based on the results of linear fracture mechanics, we identify 2-3 dangerous scenarios from each TH group (LOCA, MSLB, PRISE and OTHER). For these scenarios, a detailed calculation is performed using the methods of nonlinear fracture mechanics and mixing code results.

Non-linear fracture mechanics

To calculate the accident scenario in the elastoplastic state, we used the "submodeling" technology. The technology consists in using the results of the global model calculation to import boundary conditions for a submodel. The figure below shows the global finite element model and submodels, which have improved mesh quality and a pre-embedded defect. To evaluate the integrity of the corrosion-resistant cladding, the crack was extended 1 mm into the cladding.



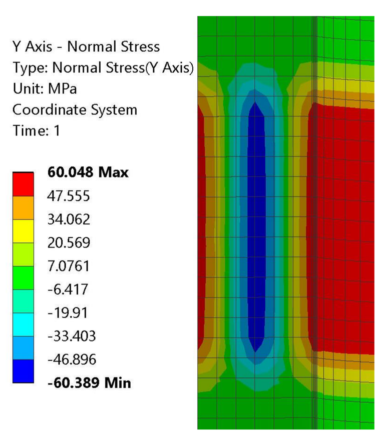
Note that "global" model doesn't contain crack, so the dimensions of the submodel should be chosen properly. The following were chosen in the work: the model size in the axial direction is 4 crack lengths and the model size in the circumferential direction is 8 crack lengths.

In the welded joint zones, residual stresses must be taken into account. The distribution of residual stresses in the welds of the VVER-1000 reactor was calculated using the VERLIFE formula:

$$\sigma_{y,z} = 60 \cdot \cos\left(\frac{2\pi \cdot x}{w_t}\right); \sigma_r = 0.$$

Residual stress fields can be defined in a variety of ways:

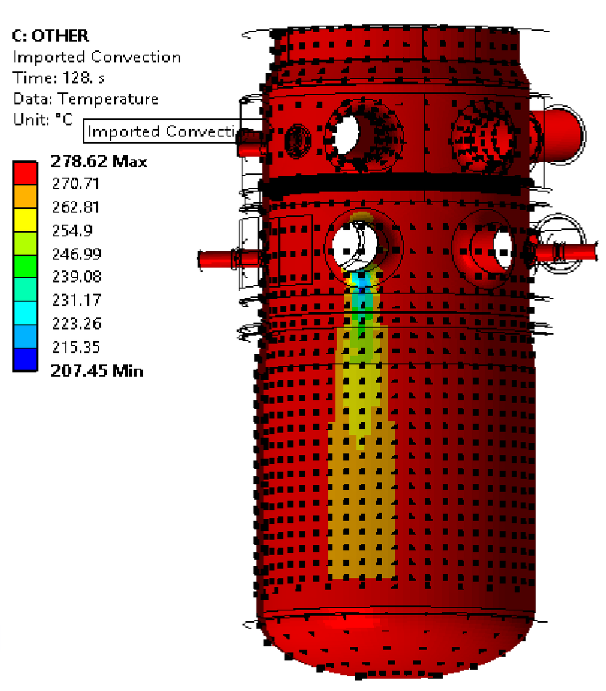
- Overpressure
- Strain state setting as initial stress
- Strain state setting as initial strain



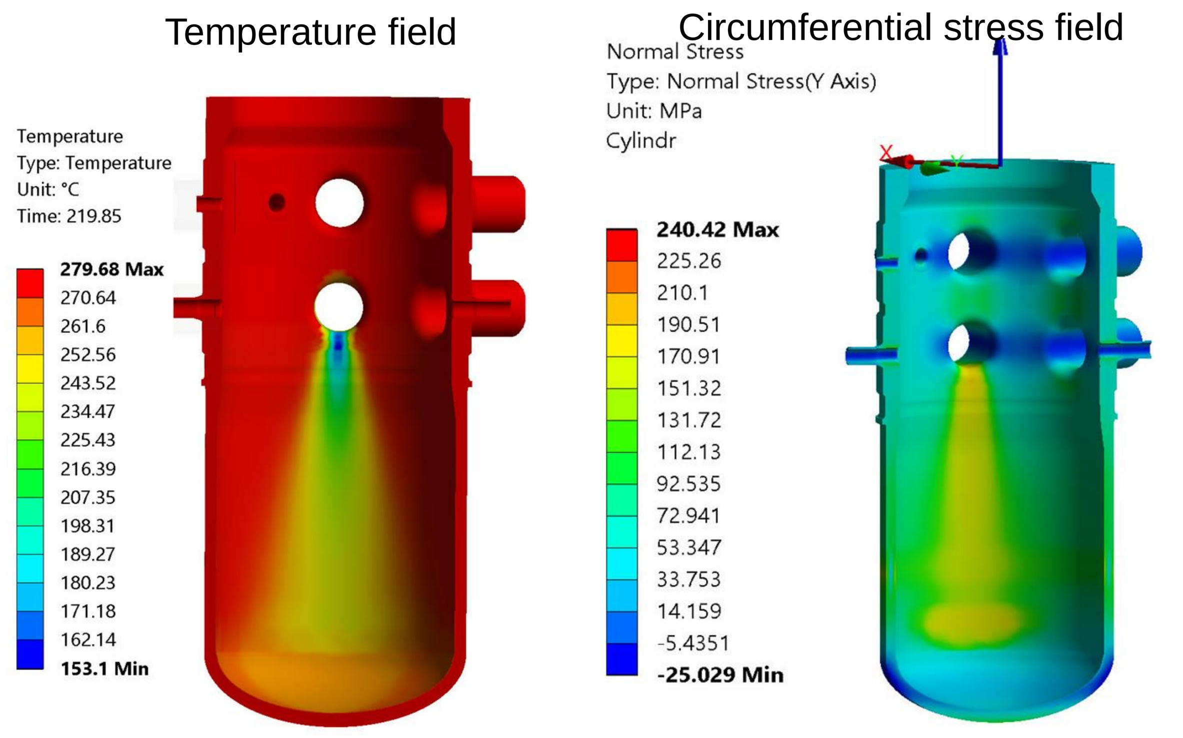
The residual stresses in the form of stress fields were calculated for both the global model and the submodel. The figure shows the distribution of the residual stress field for the submodel.

A more accurate thermal-hydraulic calculation was performed for the determined accident scenarios with an analysis of coolant mixing in the reactor downcomer section. The refined data with mixing covers a sector slightly less than 180 degrees. Therefore, the calculation requires a combination of conventional thermal-hydraulic data (RELAP) and refined data with mixing. In the prepared preprocessor, the thermal-hydraulic data is assigned the coordinates of the real geometry. The data in the form of a data array is loaded into ANSYS and interpolated onto the inner wall of the RPV.

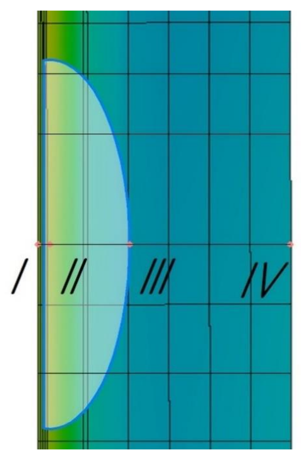
Import the combined RELAP and GRS-MIX data



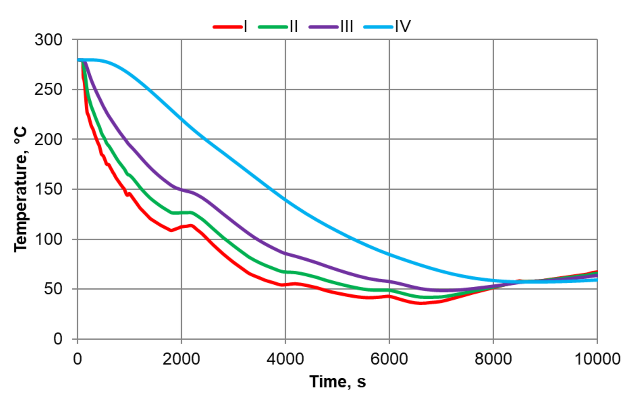
In the temperature fields presented, we can see the cold plum and its influence on the stress state.



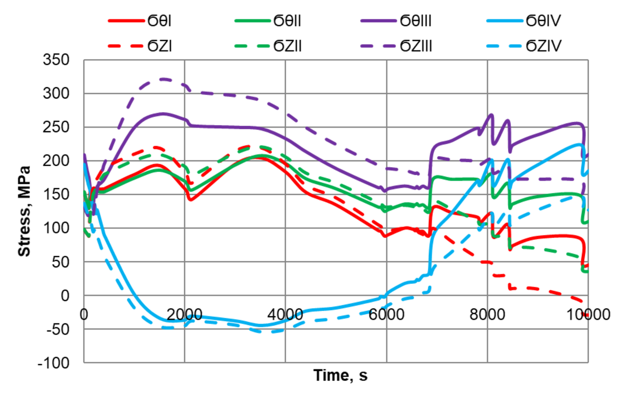
The results of the temperature and stress calculations are presented below, for points I, II, III and IV, which correspond to the inner surface of the RPV (on the cladding); the base metal (BM) point bordering the cladding/BM(WS) interface, the deepest point of the crack and a point on the outer surface of the RPV.



Temperature change at characteristic points on the wall in the crack zone

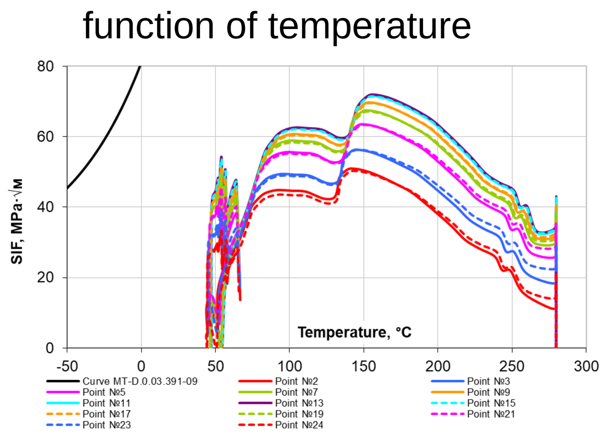


Stress change at characteristic points on the wall in the crack zone

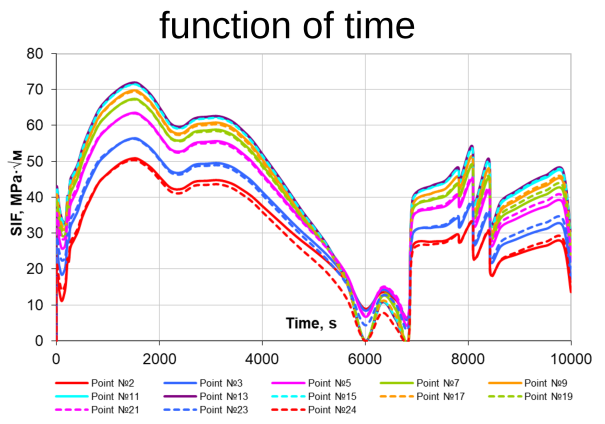


The target result of calculating the submodel with a crack is the J integral.

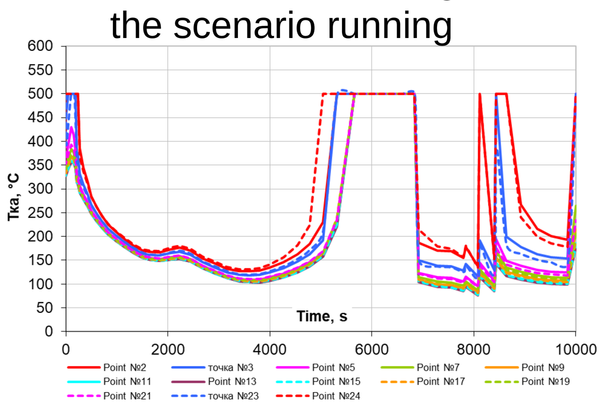
The SIF value as a function of temperature



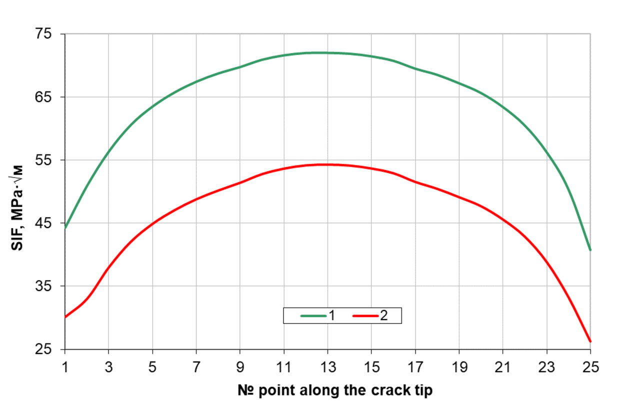
The SIF value as a function of time



The Tκa value during the scenario running



The SIF value along the crack fro



Conclusions

The research presents a general approach to assessing brittle fracture of RPV. The brittle fracture resistance assessment consists of linear (LFR) and nonlinear fracture mechanics (NLFM) calculations. Only RELAP data was used for analysis using LFR. The calculations in the elastic-plastic state are used for the final allowable reference temperature estimations. This calculation is performed on the combined GRS-MIX and RELAP data for underclad defect, inserted for 1 mm in the cladding.

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