ÚJV Řež, a. s.

Measurement of Core Shroud at NPP Temelin

Nuclear Regulatory Commission

International Workshop on Age-Related Degradation of Reactor Vessels and Internals

May 2019

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May 2019

Structure

- Basic facts about VVER 1000 RPV Internals
- Degradation mechanisms influencing performance of RVI
- Computational simulation of swelling and radiation creep development
- Critical location identification
- Approach to measurement
- Design of the device
- Time schedule of the whole project and plan for implementation

NPP Temelin Basic Information

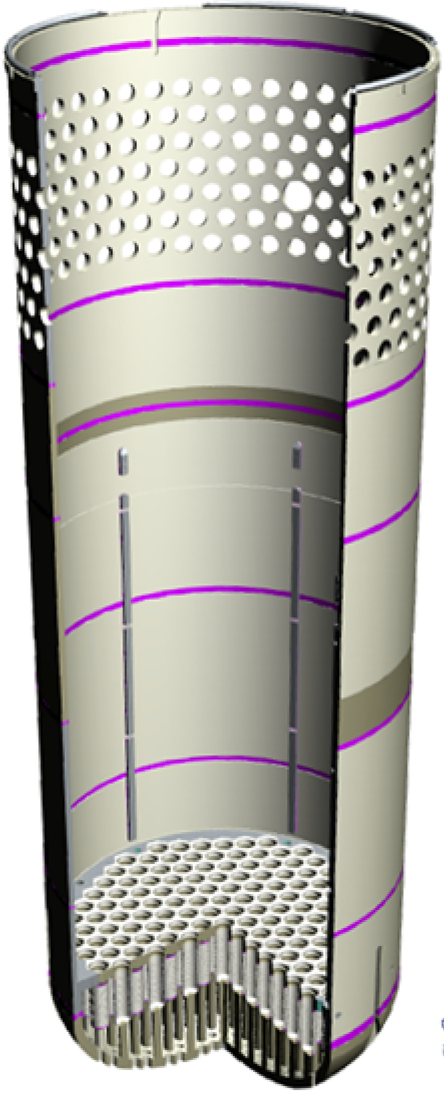
VVER 1000 type, (PWR) 2 units

Russian design, manufactured in Czech republic by Czech companies

- Operation since 2001
- Power up-rate to 105.7 % - 1056 MW of electric power output
- Original design life time 30 years (excluding RPV which has 40 years)

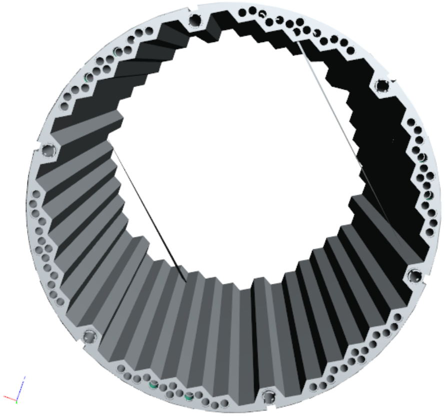
RPI VVER 1000 – Components and Material

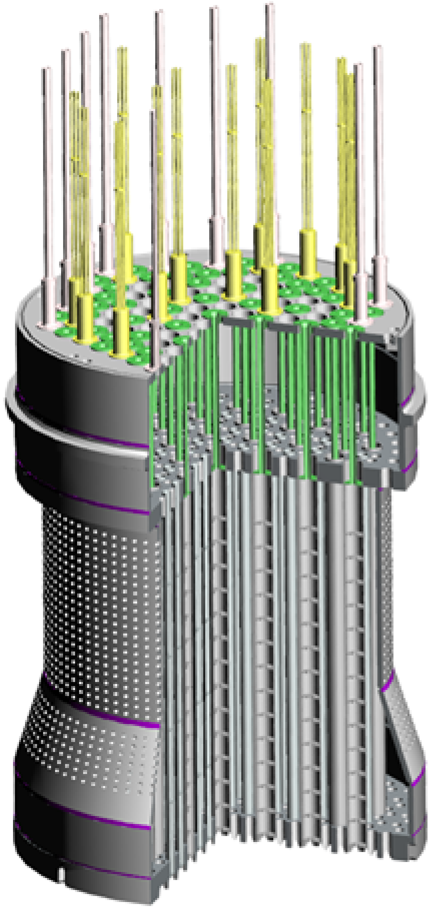
- Basic material is Ti stabilised austenitic stainless steel 08Ch18N10T (similar to A321]
- Small parts are from hi strength Fe-Ni-Cr alloy (ChN35VT-VD)



Core barrel

Core shroud

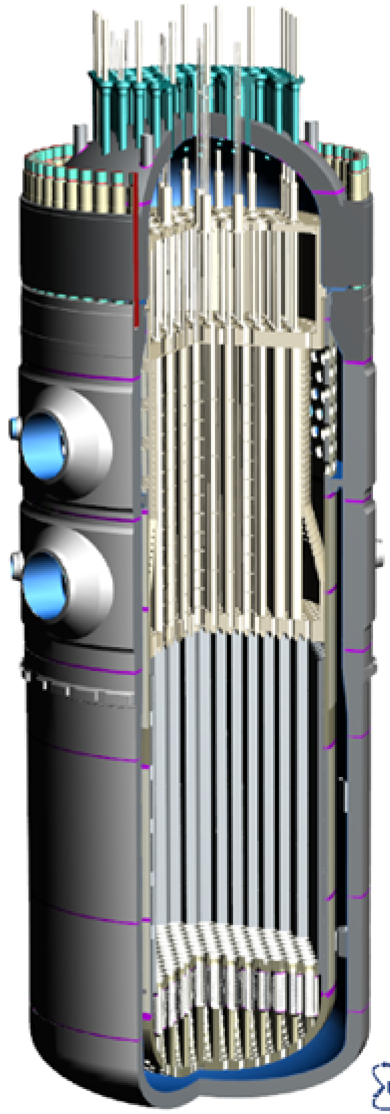




Protective tube unit

Functions of RPV Internals

- Support and geometry maintenance of the core
- Medium flow control in RPV
- Control elements functions support
- Instrumentation equipment support
- Shielding of the RPV material from neutron and gamma radiation



Chemical composition of RVI main construction materials

Ocel	C	Mn	Si	P	S	Cr	Ni	Ti	W	Co
08Ch18N10T	0.07	1.42	0.44	0.020	0.010	18.65	10.50	0.50		
ChN35VT-VD	0.08	1.48	0.43	0.015	0.012	14.88	34.88	1.39	3,38	0.02
14Ch17N2	0.16	0.40	0.40	0.022	0.007	16.32	1.95			0.02

Design and Operational Parameters

- Design pressure up to 17.65 MPa
- Design Temperature up to 350°C, working temperature 320°C
- VVER chemistry (low oxygen, low hydrogen water with injection of boric acid)
- Radiation load up to 1.5 dpa/ year for most critical part of core shroud (computational prediction), it corresponds about 90 – 100 dpa after 60 years of operation

Expected and Controlled Degradation Mechanisms

- Fatigue (low and high cycle)
- IASCC
- Wear
- Radiation swelling and radiation creep
- Loss of fracture toughness due to thermal and neutron aging - Limit Embrittlement Area development
- Mechanical damage

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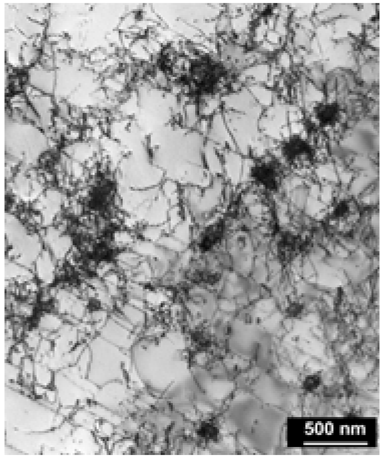
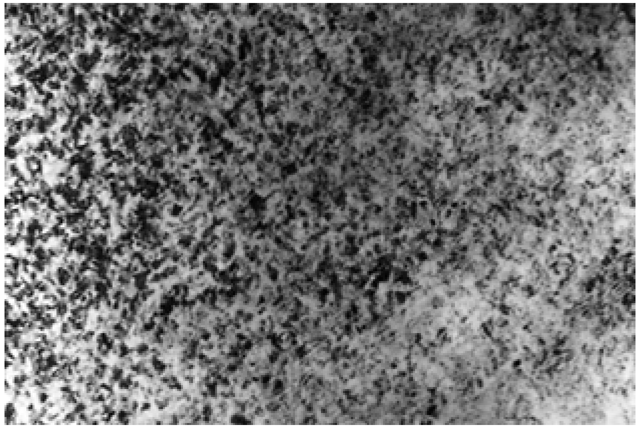
Swelling and radiation creep damage manifestation

- **Change in microstructure (Frankel loops, dislocation density increase, nanocavities, microcavities)**
- **Degradation of mechanical properties**
  - Elongation, Fracture toughness, Yield strength, Tensile strength
- **Increase in volume of heavily loaded area of material (neutron flux & temperature)**
  - As consequence – macroscopic (measurable by NDT method) change in geometry of RVI components: Core shroud



Dislocation structure of 08Ch18N10T steel prior irradiation

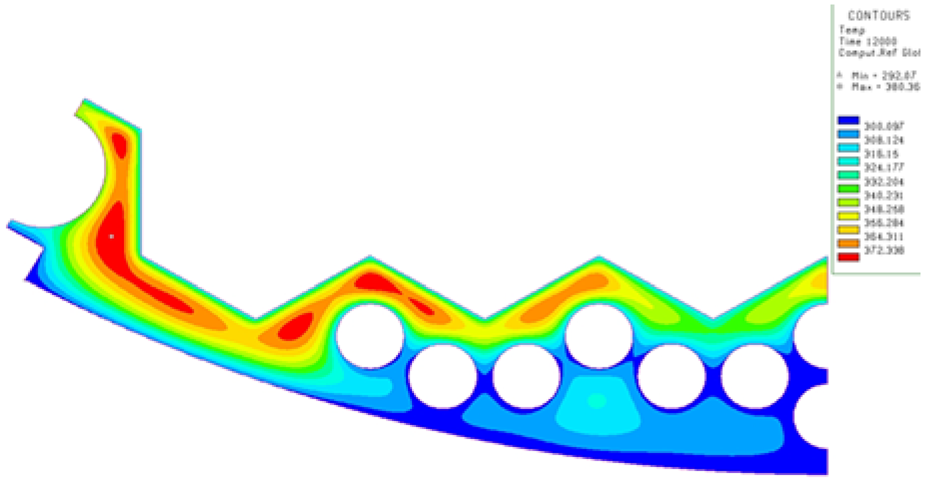


Irradiation defects in 08Ch18N10T steel after irradiation, Frank loops, perfect dislocation loops,”black dots”.

Radiation Swelling and Radiation Creep of Core Shroud

- **Degradation mechanism "radiation swelling„ was detected in core baffle of type of VVER 1000**
  - Ukraine
  - Russia

Calculated temperature distribution for the 12th campaign of the 1st block of NPP Temelin.



- Degradation mechanism caused by a combination of fluence (dpa) and temperature (elevated temperature during operation plus heat from gamma radiation) distributed in the bulk of the core shroud.
- Degradation of the crystal lattice , misplaced atoms, micro-void, voids, change of fracture mechanical properties

- **In CR today's assessment of swelling and radiation creep - only computational**

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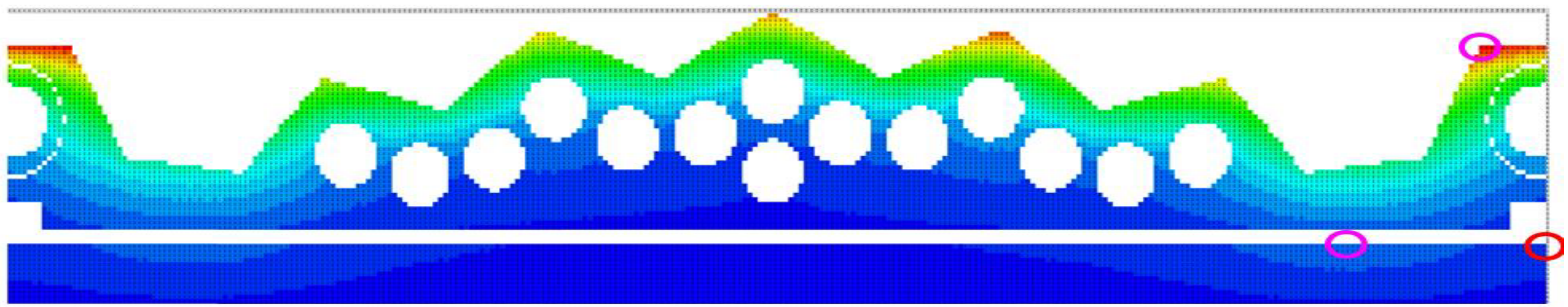
Identification of Critical Point of Swelling Development

- **First calculation of RS and RC development were performed in 2012 – 2013 by NRI Rez and Gidropress (Russia) independently with good agreement**
- **Actually the absorbed dose and temperature distribution is calculated for each campaign to cover complex history of temperature & neutron load as key factor of swelling development**

❑



2D calculation model (core shroud & barrel) with identification of location with maximal dpa and gamma heating values in selected campaign, 2018 calculation

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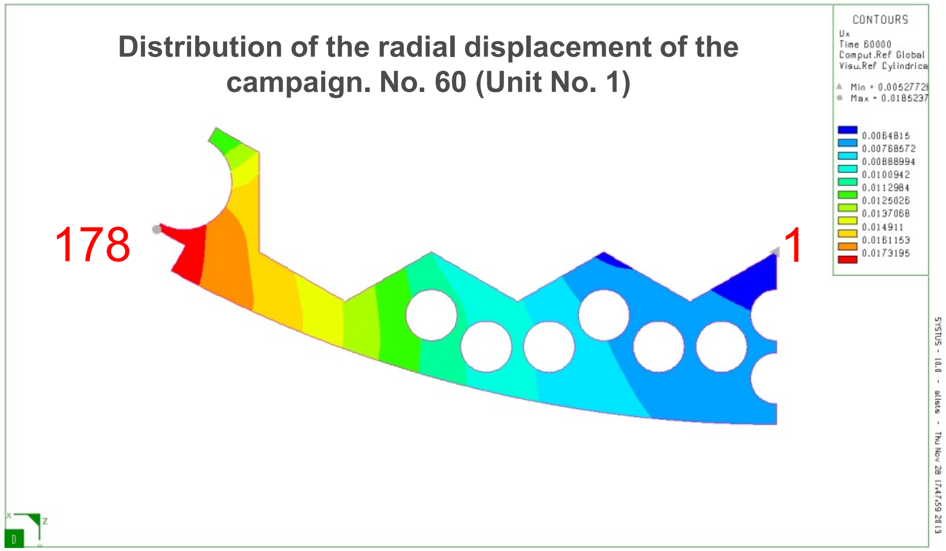
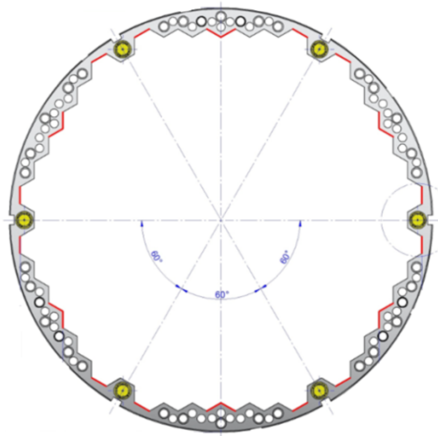
Identification of Critical Point of Swelling Development

Based on the calculation the most critical locations of core shroud swelling (and consequently geometry changes) are:

- The center of the segment (point no. 1) moves according to the simulation towards the core
  - The gap between inner surface of core shroud and fuel element is 4 mm.
- The outer surface of the core shroud where threaded rod is located point no. 178, it moves according to simulation in direction to the barrel
  - The smallest gap between core shroud and barrel is 2.5 mm (up to 10 mm).





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Measurement of Core Baffle

Benefits of the core baffle assessment using NDT - dimensional inspection

- Provides the information about the actual state of component and demonstrate the functionality of the device for the next operation
- Repeated measurement give information about dimension changes, and makes possible experimental trending and prediction of the DM „radiation swelling“ development
- Verify calculations of DM „radiation swelling“ development, calibration of the physical model used
- Make possible to plan corrective measures well in advance of their actual implementation,
- Verification of corrective actions.

Experience with measurement of Core Shroud in the world

Russia

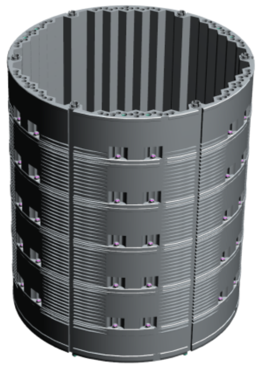
- Computational evaluation of swelling is compulsory, experimental verification recommended for decrease of conservatism
- Macroscopic changes of core shroud geometry measured
- Laser scanning approach, the scanning probe positioned in the *center reactor point* at the different levels of Z- axis
- Declared level of accuracy 0,5 mm

Ukraine

- Experimental verification of the core shroud geometry changes are required for LTO phase for VVER 1000
- Macroscopic changes of core shroud geometry measured
- UT scanning approach used, the UT probe on the beam centered with respect to the centre reactor point at the different levels of Z- axis

UJV approach to measurement of Core Shroud dimension changes

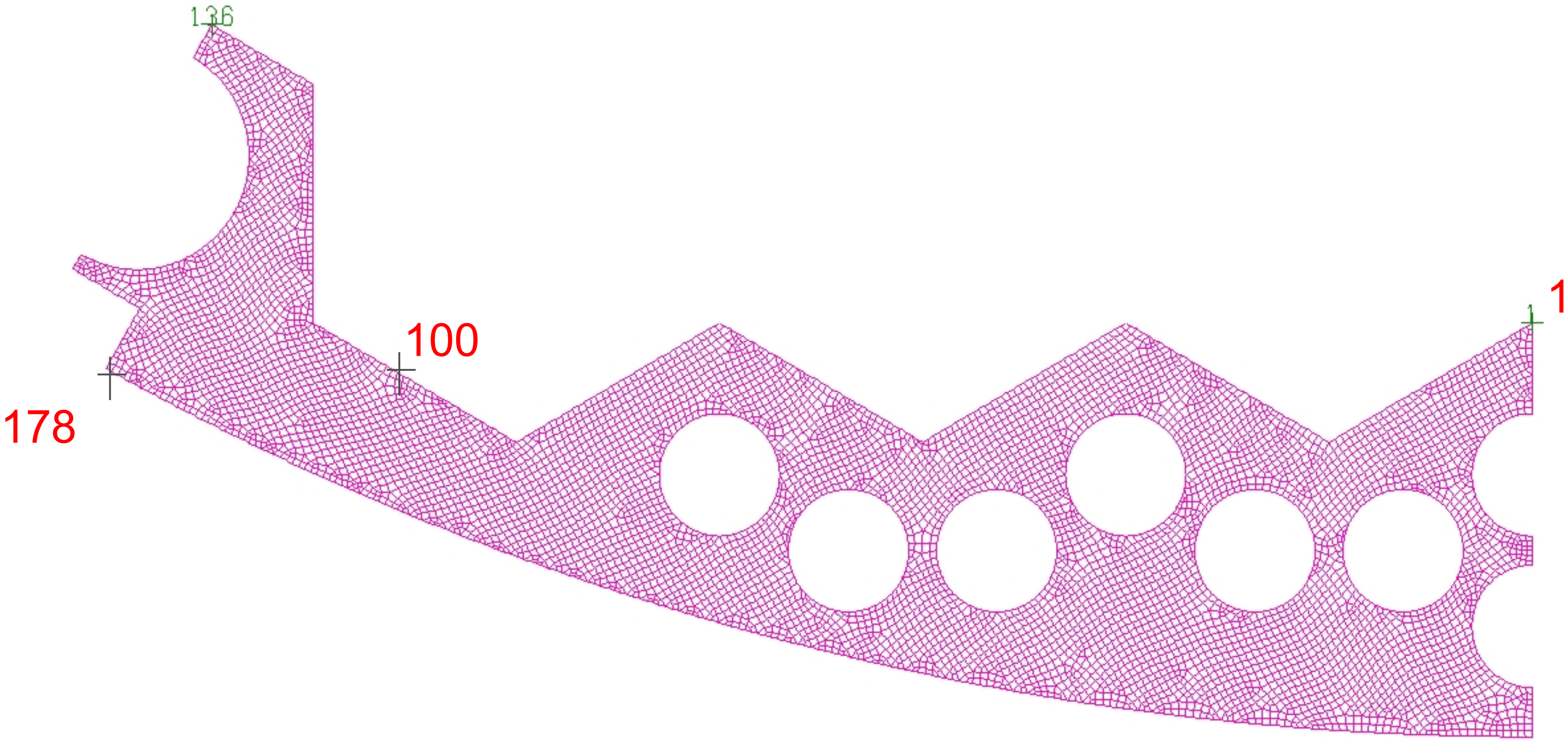
The basic requirements:

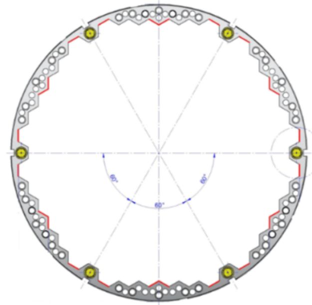


- The measurement must not be dependent upon *center point of the reactor* as it was identified as the most problematic part of measurement realized
- It should be possible to realize measurement with the same equipment during time horizon 15 years
- The device must be independently calibrated prior each measurement

Selection of locations for measurement

The positions of selected nodes on the "inner surface" of core baffle with large displacement during operation due to swelling development



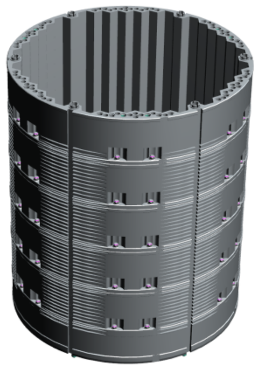


Node no. 1 - near of two small canals.

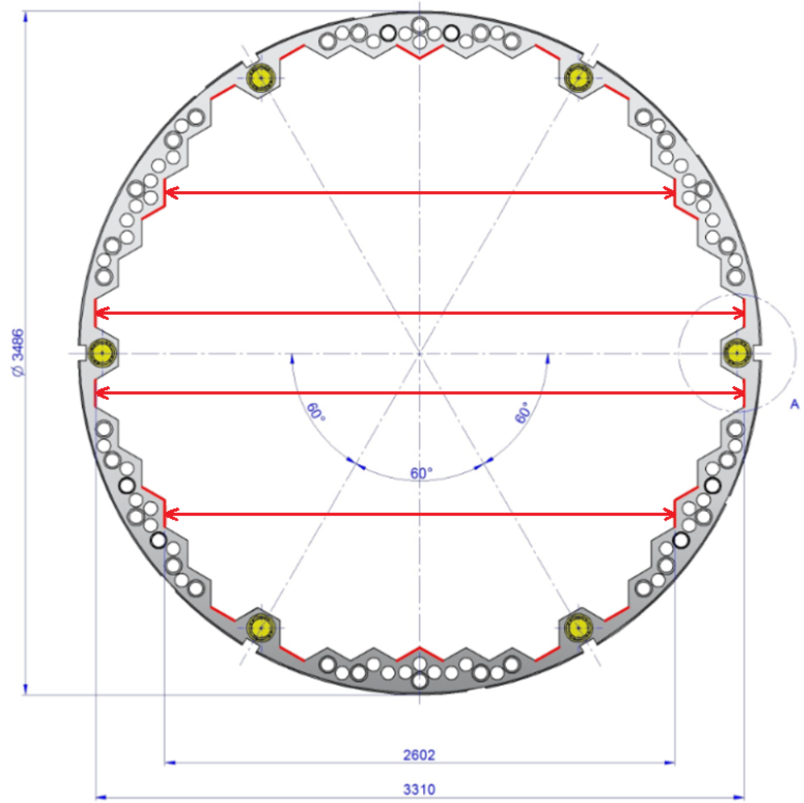
Node no. 100 - in the middle of the facet near the grand canal.

UJV approach to measurement of Core Shroud dimension changes, cont.

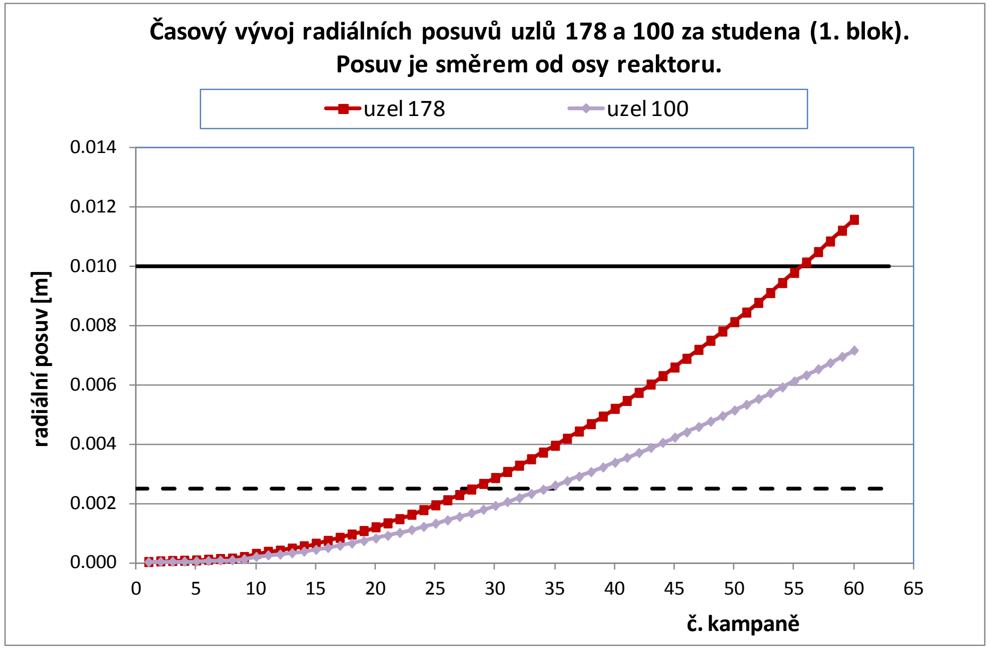
The measurement principle

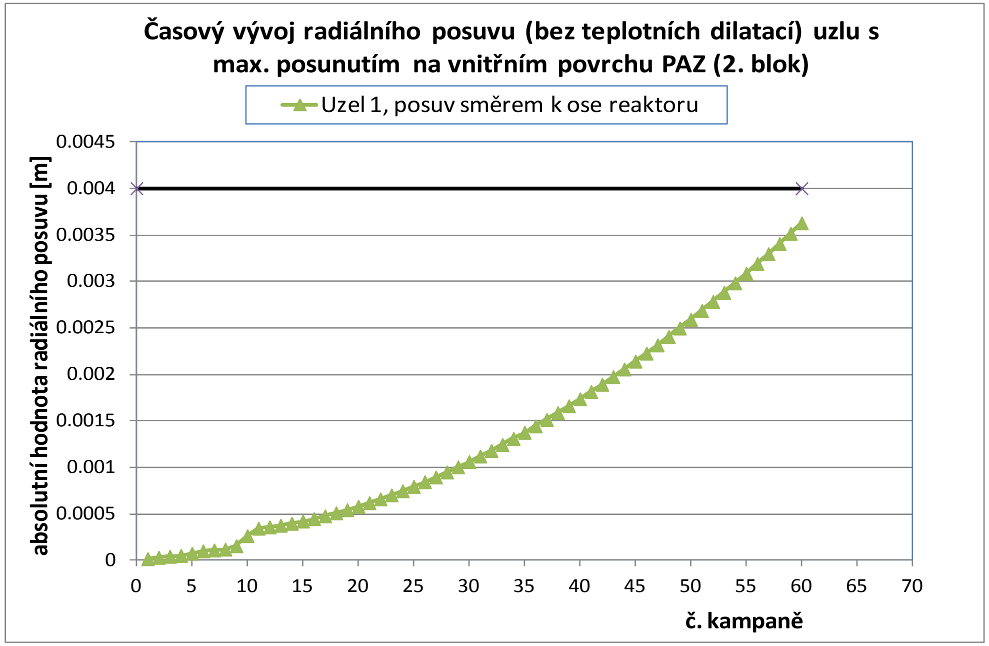


- Distance measurement of specific locations at the inner surface of the core shroud as it is specified in the picture (areas near threaded rod and the middle segment).
- Device rotation 2x 60 ° should provide a information about geometry changes of the whole perimeter of the core shroud ring.
- The measurement is performed at the different Z axis level (at least 3 per core shroud ring, or as required).
- Advantage – the specified distance were measured during assembly process of the reactor internals so zero values are accessible for comparison



The predicted shifts of selected nodes





Prediction of displacement for nodes No. 100 and 178. It is necessary to highlight that prediction is based upon the worst campaign from neutron flux point of view. Displacement prediction based upon real history shall be more modest.

Displacement of Node. 1 is about 3,6 mm after 60 years, about 0,6 mm after 20 years.

The measured change of diameter after 20 years should be 1,2 mm (in the direction to the axis of the reactor).

Hardware requirements

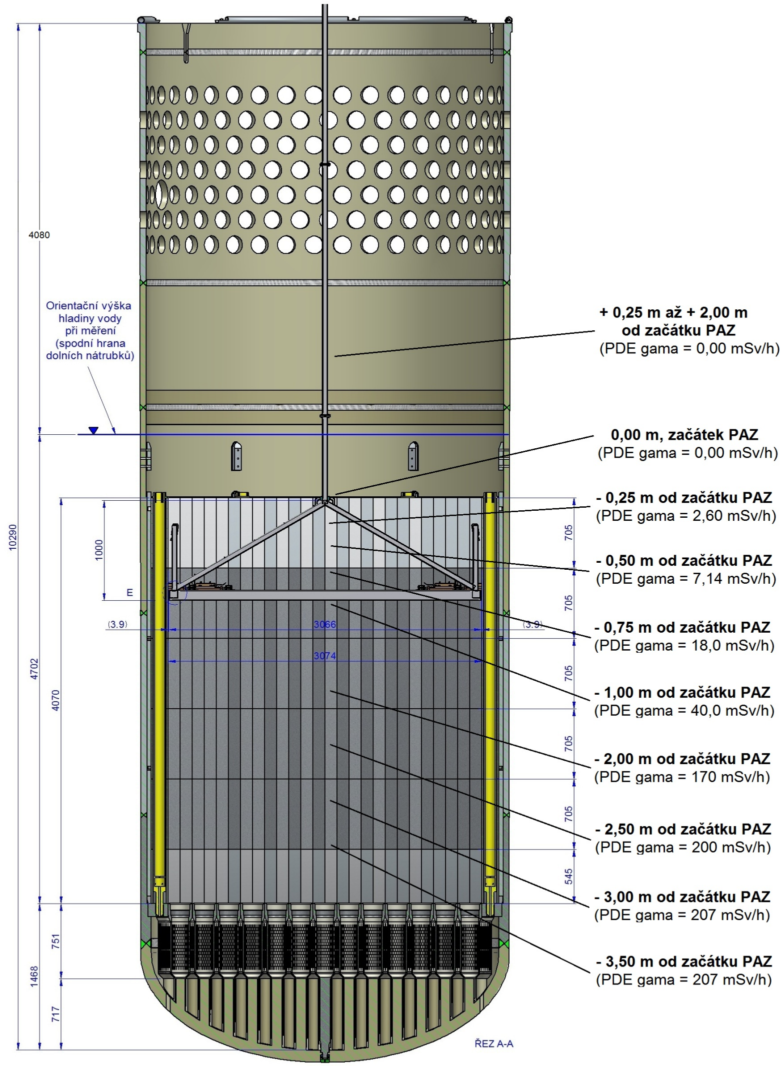
Requirements for inspection implementation

- Measurements in the water with boride acid
- Under hydrostatic pressure corresponding to the depth of reactor shaft.
- High level of radiation.
- Coolant temperature - maximum 50 ° C.
- It is necessary to minimize influence on length of NPP outage.
- Requirements for a high measurement accuracy – order of tenths of mm.

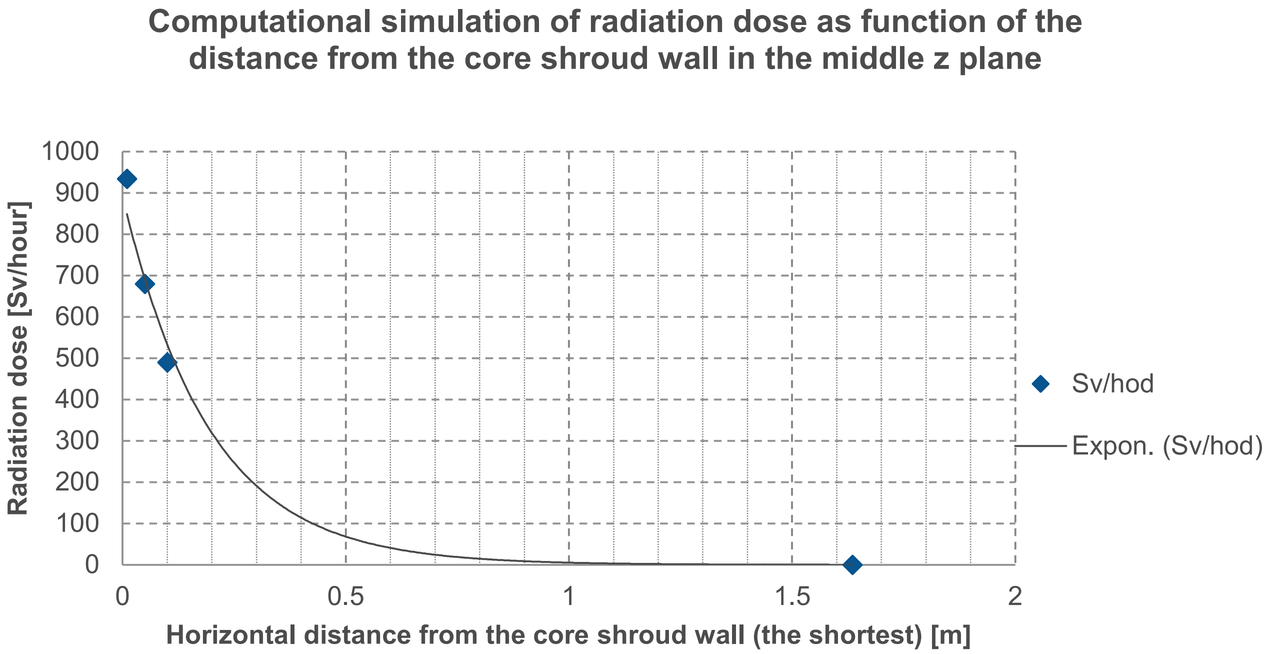
Gamma radiation dose measurement

To guarantee life time of the device it was necessary to determine the radiation dose and qualify resistance of the material and component used

Measured gamma values (mSv/h) In the centre of CS	Z axis level with respect to the CS “beginning” [m]
0	-2
0	-1
0	-0,5
0	-0,25
0	0
2,6	0,25
7,14	0,5
18	0,75
40	1
170	2
200	2,5
207	3
207	3,5



Gamma radiation dose measurement, cont.



As water provide very good shielding it was decided that where possible, the components sensitive do radiation shall be positioned in the centre of the CS

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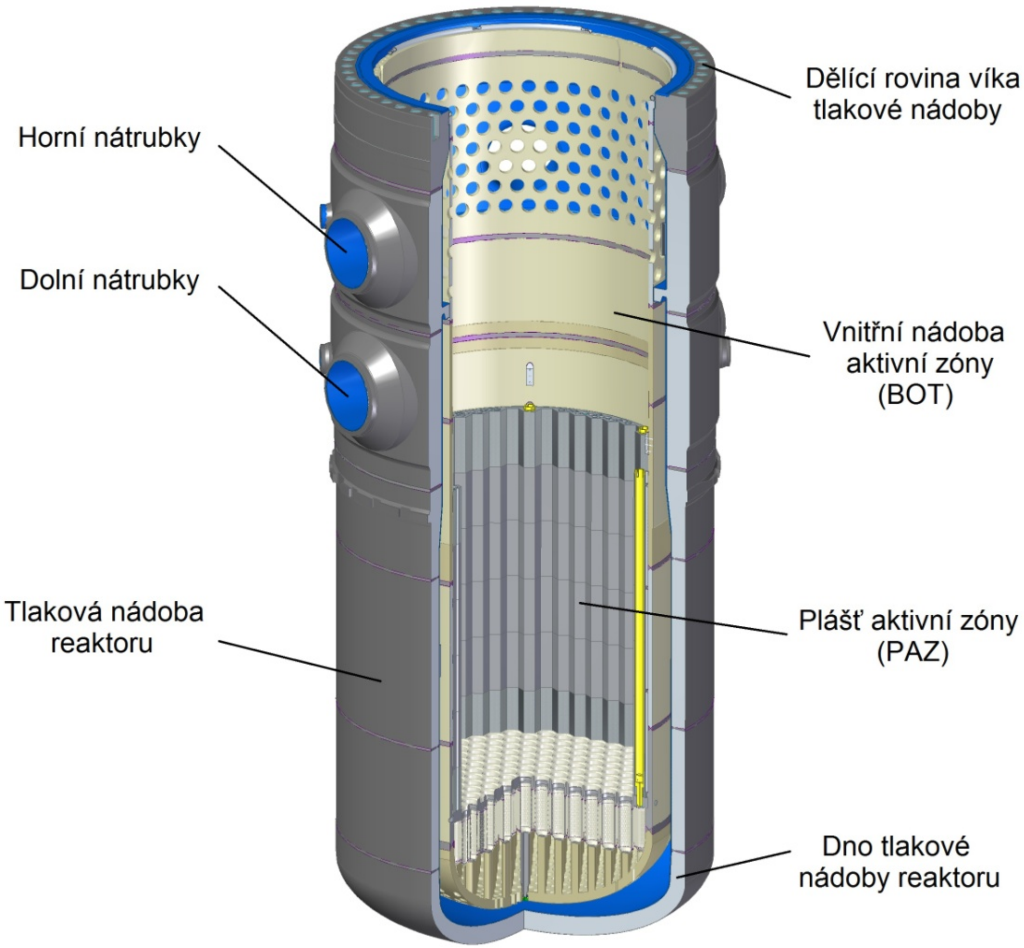
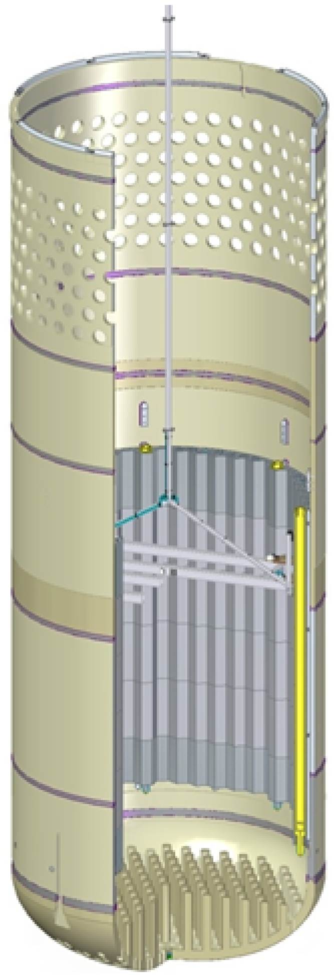
Measurement of Core Shroud – Design Model

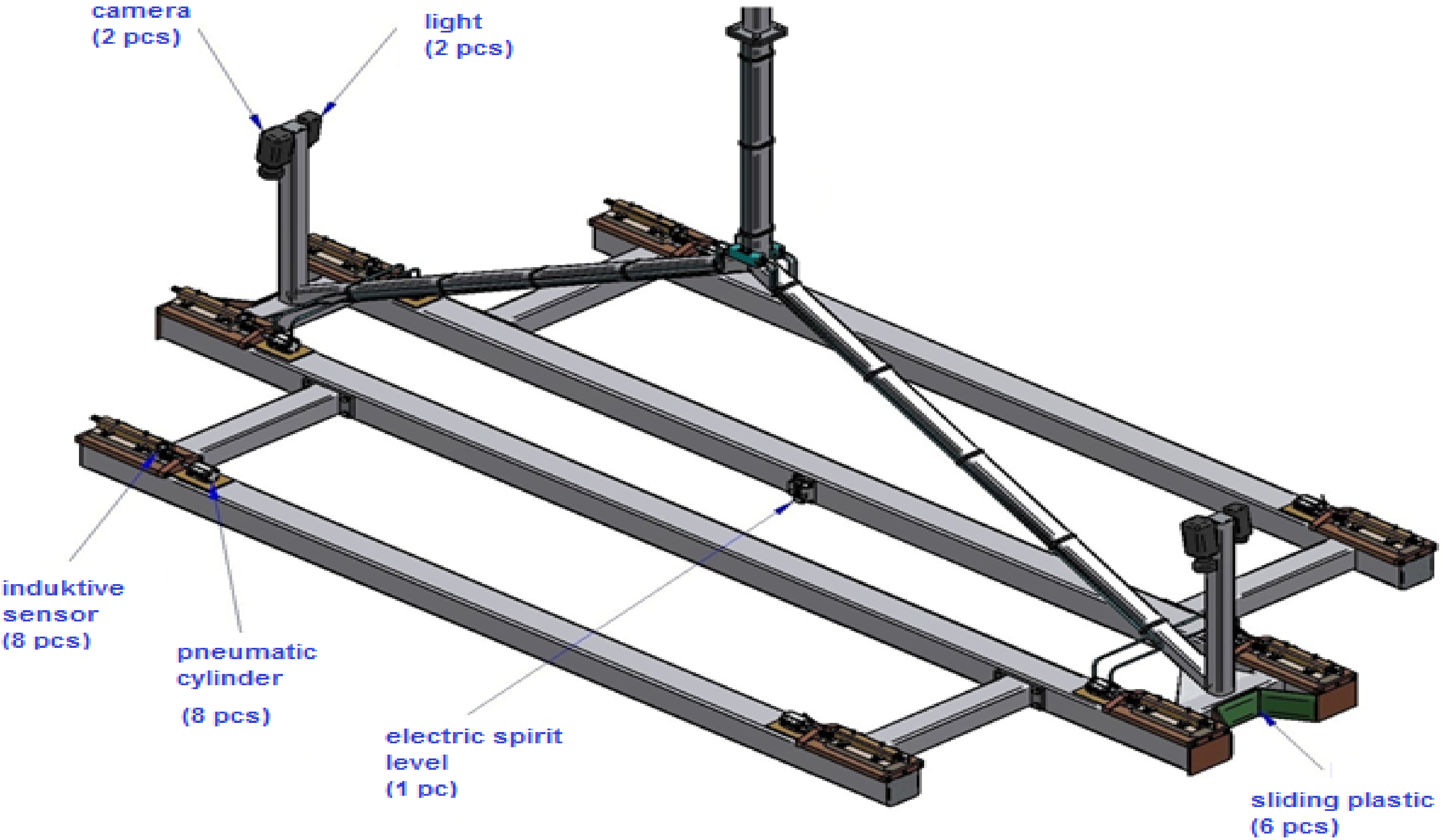
Reactor vessel, model design of the device in core shroud





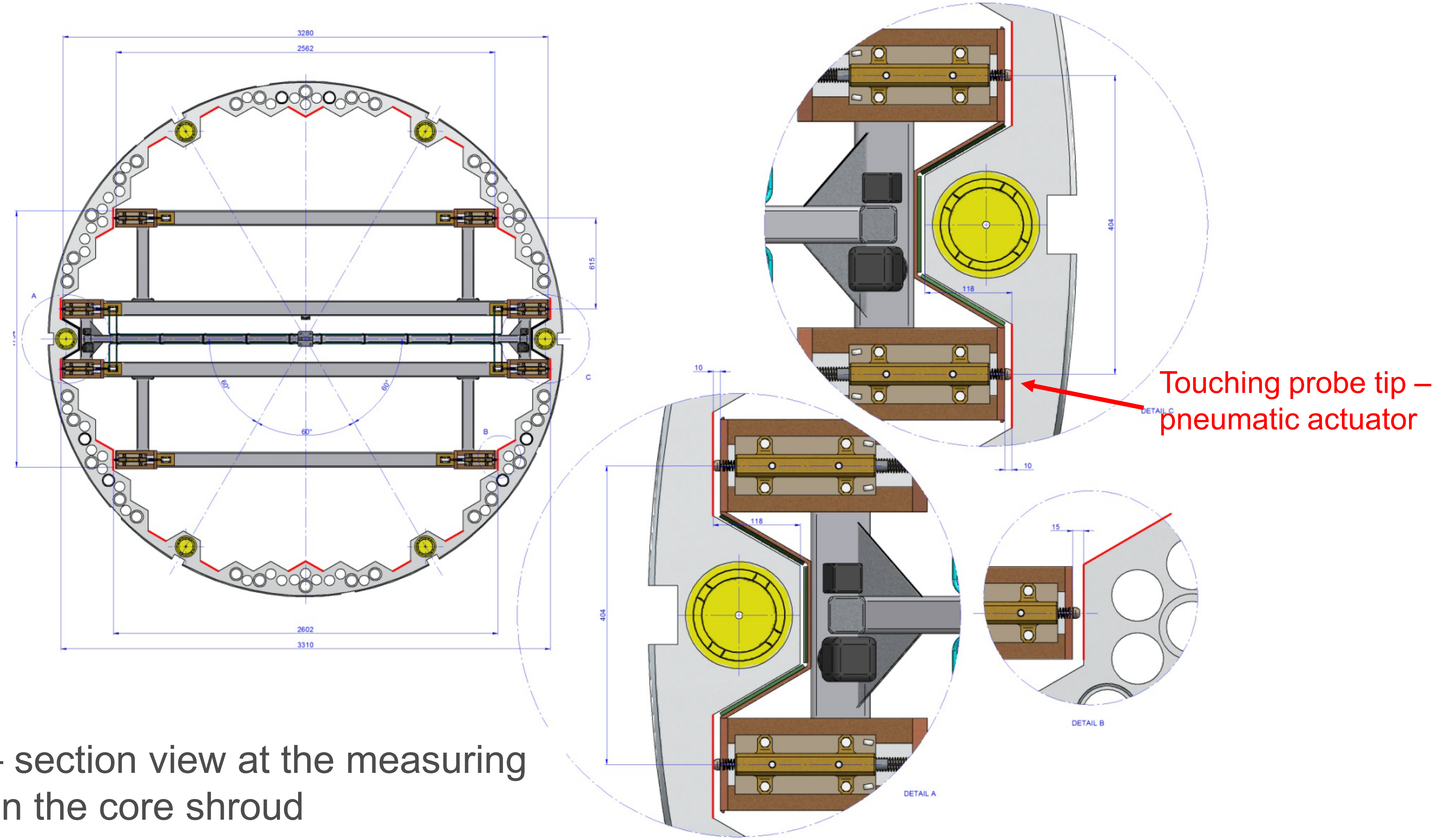
Measurement of Core Baffle – Design Model

Components of the device:



Measurement of Core Baffle – Design Model

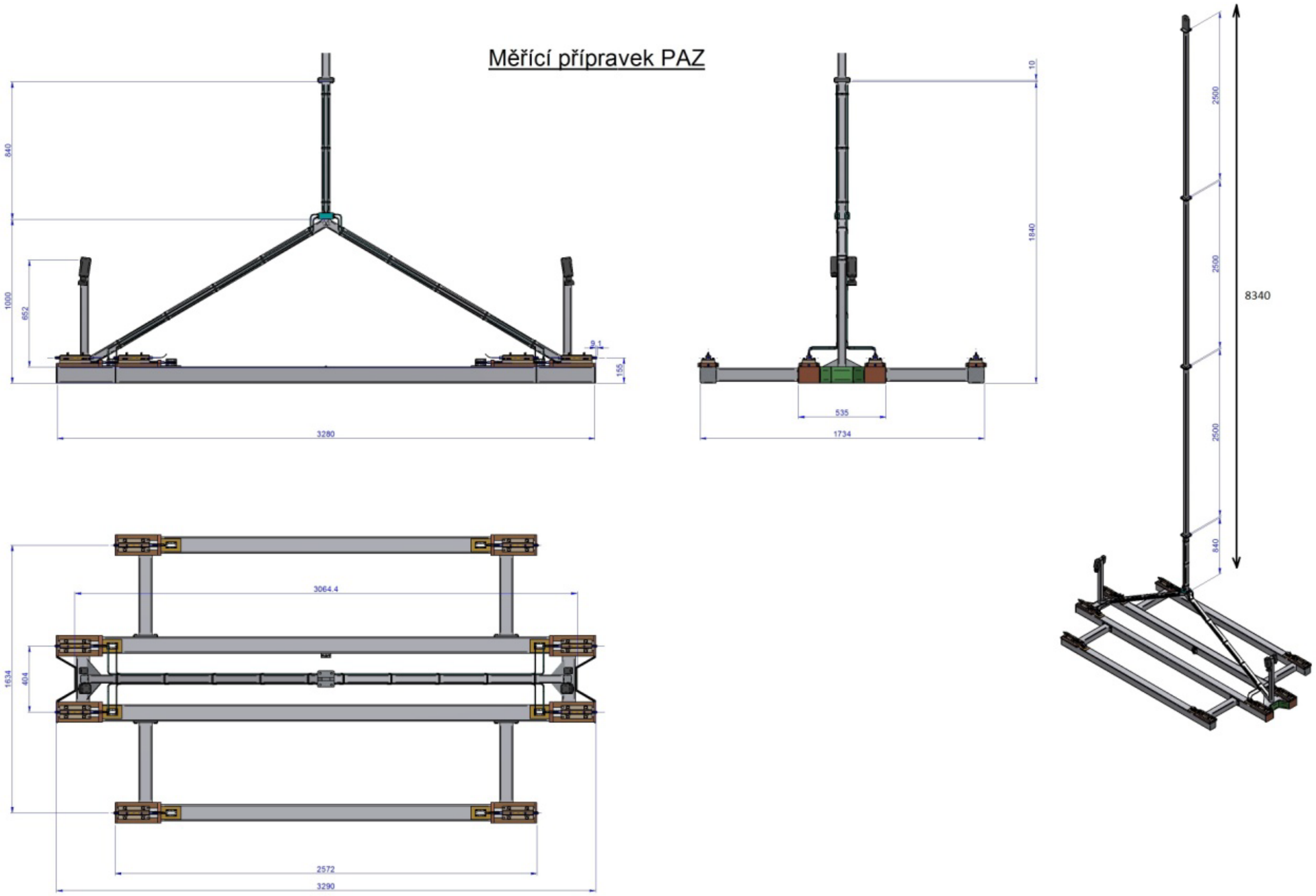
Drawing of the device for the core shroud baffle dimensions measurement.



Cross – section view at the measuring device in the core shroud

Measurement of Core Baffle – Model of Design

Drawing of equipment for measuring



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Design - accuracy

Description of the sensors used (including parameters)

- Incremental induction sensors (touching the surface of the core shroud):
  Displacement in the range of 0-15 mm

- Optical length sensor – optical fibre:
  Measured dimension: 2 x 2602 mm and 3310 mm x 2

- Electronic water level (spirit level) (ACS-360-1-SC00-VK2-PM)
  Measuring range: 360 °
  Tilt measurement accuracy: ± 0.1 °

- Thermometer for compensation of temperature changes :
  Measurement range: 20 to 40 ° C (max. 50 ° C)

- The entire system:
  Officially declared accuracy during the entire lifetime: ± 0.25 mm (supposed ± 0.1 mm)

Design Model - Requirements

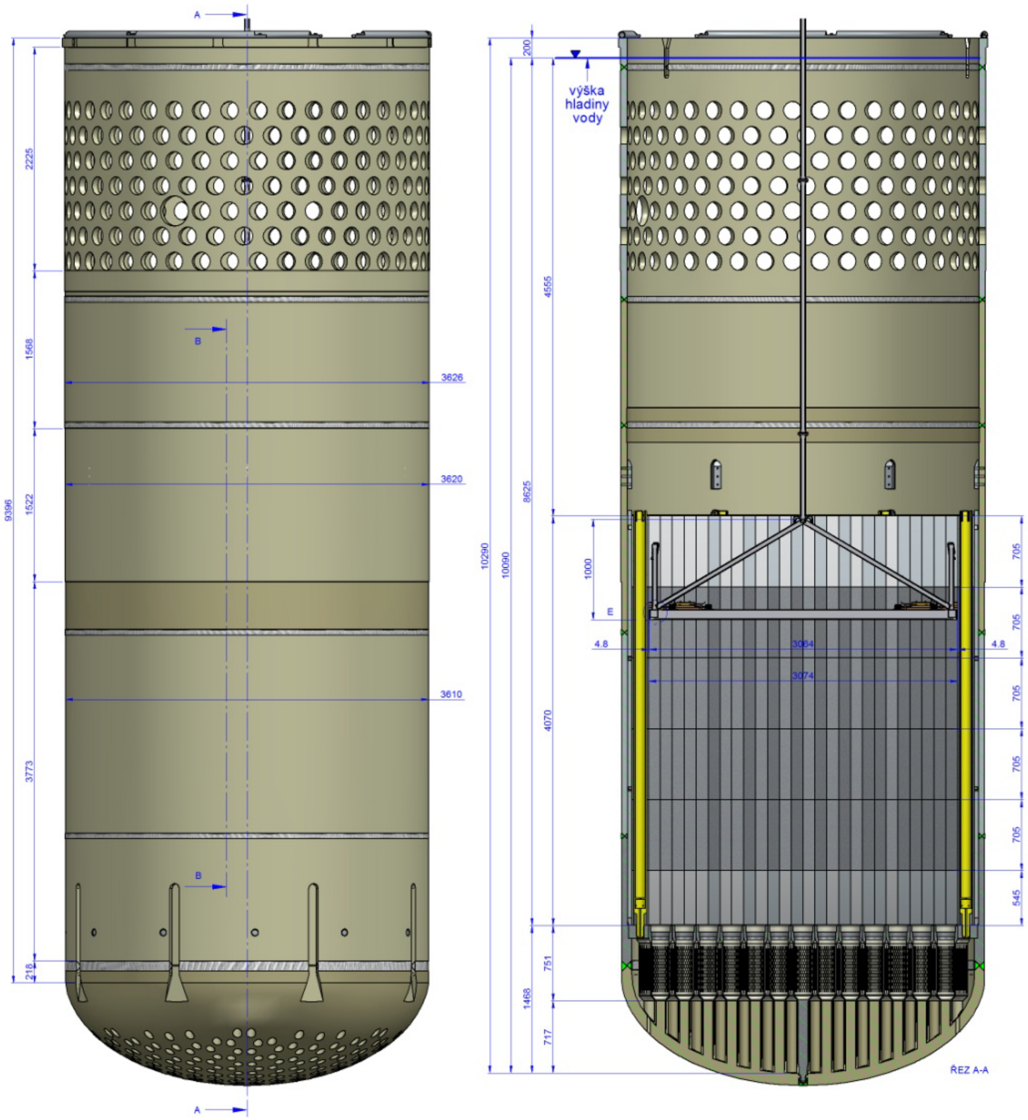
Specific hardware requirements

- Measurement frequency every 3 years
- Lifetime of the equipment at least 20 years.
- Environment about 10 m below the water surface with the admixture of boric acid (H3BO3) in a concentration of 15 g / l.
- Equipment must withstand ionizing radiation.
- Incremental optical sensors must allow pneumatic ejection test probes (to ensure an adequate pressure during measurement) and subsequent retraction of the probe spikes.
- In case of accidental failure of the system must ensure the automatic retraction of probe tips using (springs) to avoid jam of the inside the core shroud.

The storage and transport dimensions are limited by requirement of NPP to (L x W x H): 3300 x 600 x 1100 mm

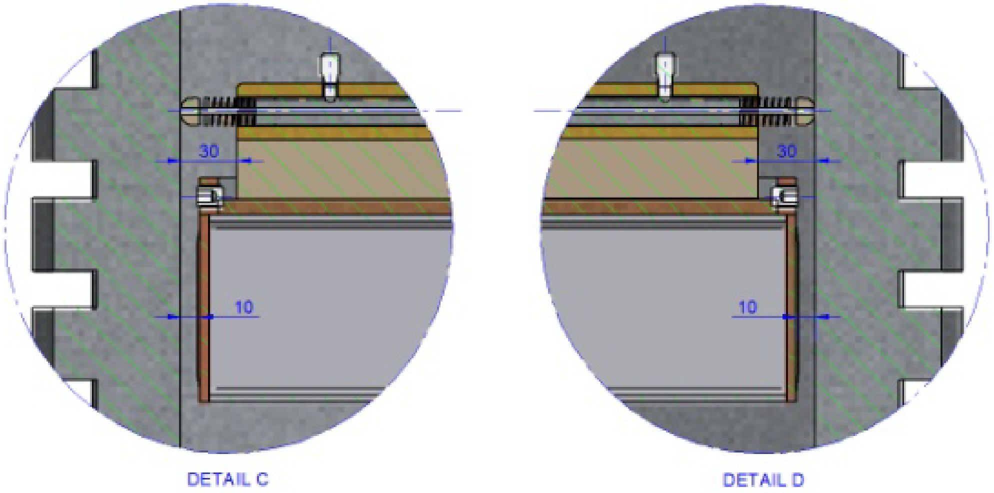
Measurement of Core Shroud – Design Model

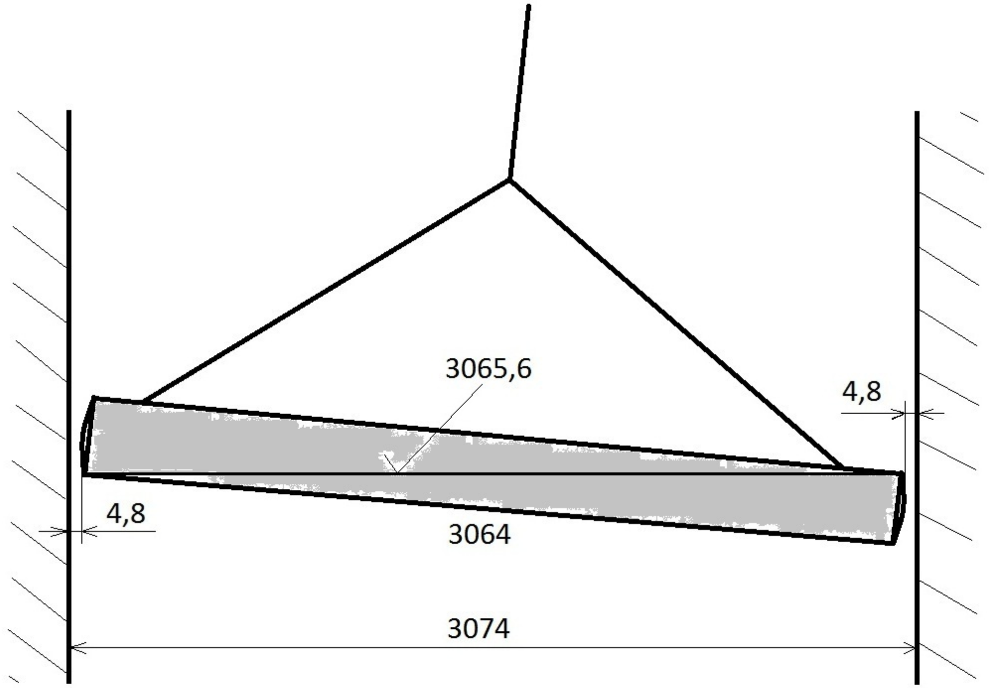
- **Position of device in core barrel during measurement**

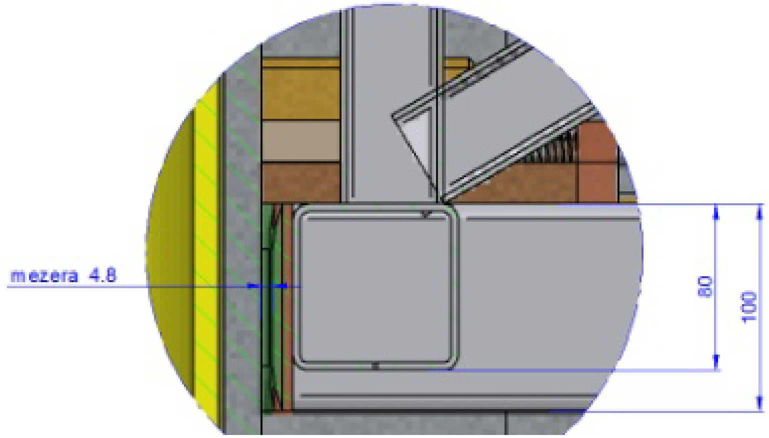


Measurement of Core Shroud

- **Analysis of the possibility of a jam of the measuring equipment core baffle**







Due to rounding of the guiding sides of the measurement platform the smallest possible clearance during tilting accident is 9.6 mm.

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Measurement of Core Baffle

Conditions for the implementation of controls at ETE

- **The best possibility - during overhaul with repair of MCP**
  - Minimal influence on the critical path - about 3-4 days during ISI of RPV flange, so called period of "axis of cold nozzles„.
  - The water level in the reactor low "on the axis of cold nozzles„.
  - Water temperature about 35-40 °C.
  - High radiation.

Polar crane in reactor hall as tool for measurement of core shroud dimension

Measurement of Core Shroud

Time shedule of measurement

- **The equipment is going to be transported in advance to the reactor hall for preparatory work before the test.**
- **A rough estimate of the time required for the proposed measurement procedure is:**
- mounting on the crane, transport of equipment to core baffle = 1.5 hours
- the measurement = 6 - 10 hours
- removing the equipment, releasing the crane = 1 hour
- a total of up to about 12 hours
- **After detachment from the crane the device must undergo complete decontamination and packaging for storage.**
- **According capabilities and available capacity crane equipment is going to be loaded onto a carriage and transported out of the reactor hall.**

Measurement of Core Shroud

The project schedule

2016 - Engineering design of measuring equipment

- structural design measuring instrument
- development of measurement technology and data processing

2017 - Design and manufacture of various parts of the equipment, qualification of measuring equipment

2018 - Manufacturing of the prototype, production test specimen for qualification, initiation tests to verify the measurement technology

2019 - Qualification and calibration of measuring equipment, completion of documentation

2020 - Submission of final documentation of equipment and documentation for measurement in NPP

2021 (2022 – 2023 according to NPP operation) - the realization of measurement

Measurement of Core Shroud – Summary

Measuring is going to enable:

- To obtain information about the true state of the core shroud - detect deformation due DM „radiation swelling“.
- Repeated measurement to determine a trend of effect of DM radiation swelling on the geometry of core shroud.
- To verify calculations describing DM „radiation swelling“.
- To demonstrate the functionality of the device for further operation and to implement aging management program with respect to swelling.

Thank you!

Backup Slides

Measurement of Core Baffle- Handling Parameters

Manipulation

- **Fixation of measuring equipment is ready for mounting to lift 160 tons.**
- **Rigid fixation of the measuring instrument with the possibility of tilt compensation.**
- **Parameters handling:**
  - Z axis: step micro 0,02 to 0,2 m / min., normal 0,25 to 2,53 m / min., turn + - 270 degrees, 0,033 rev / min.
  - X – Y plane: (bridge) + - 370 m / min., micro 0,191 to 1,9 m / min., normal 2 - 20 m / min.,
  - Height measurement is available with two decimal places from a meter (35.22 m)
  - Measuring of bridge rotation in degrees.
- **Hinge enough stiff - prevent the entrapment of the load and can prevent tilting.**
- **Estimated time of preparatory handling before measurement about 1 hour.**