Czech Approach to Ageing Management of Reactor Pressure Vessel and Reactor Vessel Internals - State of Knowledge

Forthcoming U.S. Nuclear Regulatory Commission International Workshop on Age-Related Degradation of Reactor Vessels and Internals Technical Information Exchange Public Meeting

May, 2019, Rockville

Jakub Ertl
ČEZ Company
Czech Republic

Content

- BASIC INFORMATION ABOUT CZECH NPPs
- LTO DEPARTMENT
- AGEING MANAGEMENT PROGRAMS FOR CZECH REACTORS
- SURVEILLANCE PROGRAM IN DUKOVANY NPP
- SURVEILLANCE PROGRAM IN TEMELIN NPP
- METHODOLOGY OF RADIATION DAMAGE EVALUATION
- FAST NEUTRON FLUENCE EVALUATION
- AGEING MANAGEMNT PROGRAM FOR RPV INTERNALS

DESCRIPTION OF DUKOVANY NPP

4 units - WWER 440/213 type, six-*loop primary circuit* (second generation)

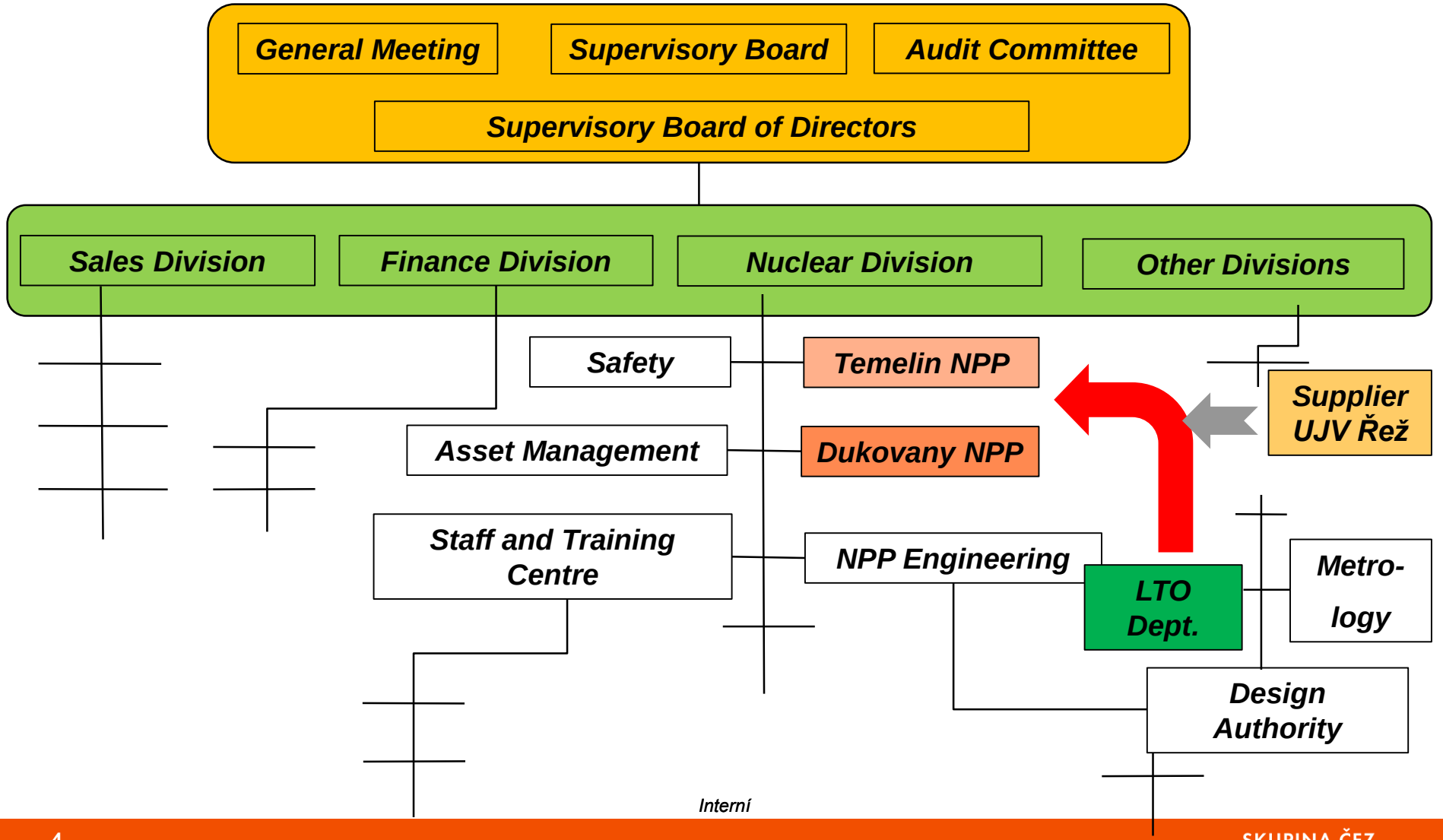
- **Water cooled, Water moderated, (Energy) Reactor – WWER,** (Pressurized Water Reactor – PWR)
- Each reactor loop has a horizontal steam generator, main circulation pump and main gate valve
- Unit 1 was put to operation in 1985 (Unit 2 and 3 – 1986, Unit 4 – 1987)
- Power up-rate 105 % to 510 MWe /unit within 2009-2012
- Design lifetime 30 years (only RPVs have 40 years), LTO prospect up to 60 years

DESCRIPTION OF TEMELIN NPP

- **Two Units WWER 1000/V320 type, four-loop primary circuit**
- Each reactor loop has a horizontal steam generator and main circulation pump
- Containment made of sealed reinforced concrete with the inner steel liner
- Triple redundancy of emergency reactor core cooling systems
- One 1000 MW turbine generator for each reactor Unit
- Unit 1 was put to Operation in 2000 (Unit 2 in 2002)

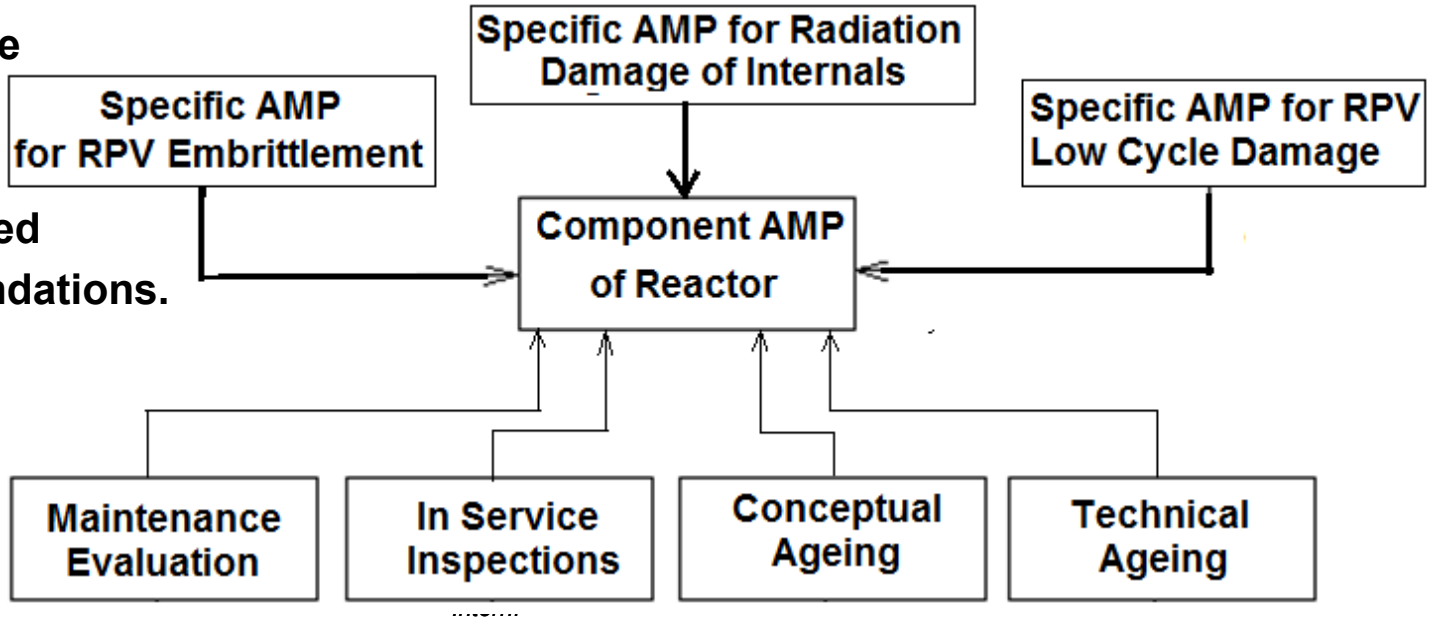
ORGANISATIONAL CHART OF ČEZ, A.S.

LTO DEPARTMENTT IS RESPONSIBLE FOR AMPS AND TLAAS



Ageing management programmes (AMPs)

- Two types of AMPs
  - **Component specific AMP** – it is focused on components (**reactor**, steam generator, main circulation pump, main closing valve, …)
  - **Specific AMP** - it is focused on degradation mechanism (**low-cycle fatigue**, flow accelerated corrosion, **radiation embrittlement**, …)
- **Specific AMPs were created according to generic attributes prescribed by IAEA recommendations.**



Component Specific AMP for the Reactor

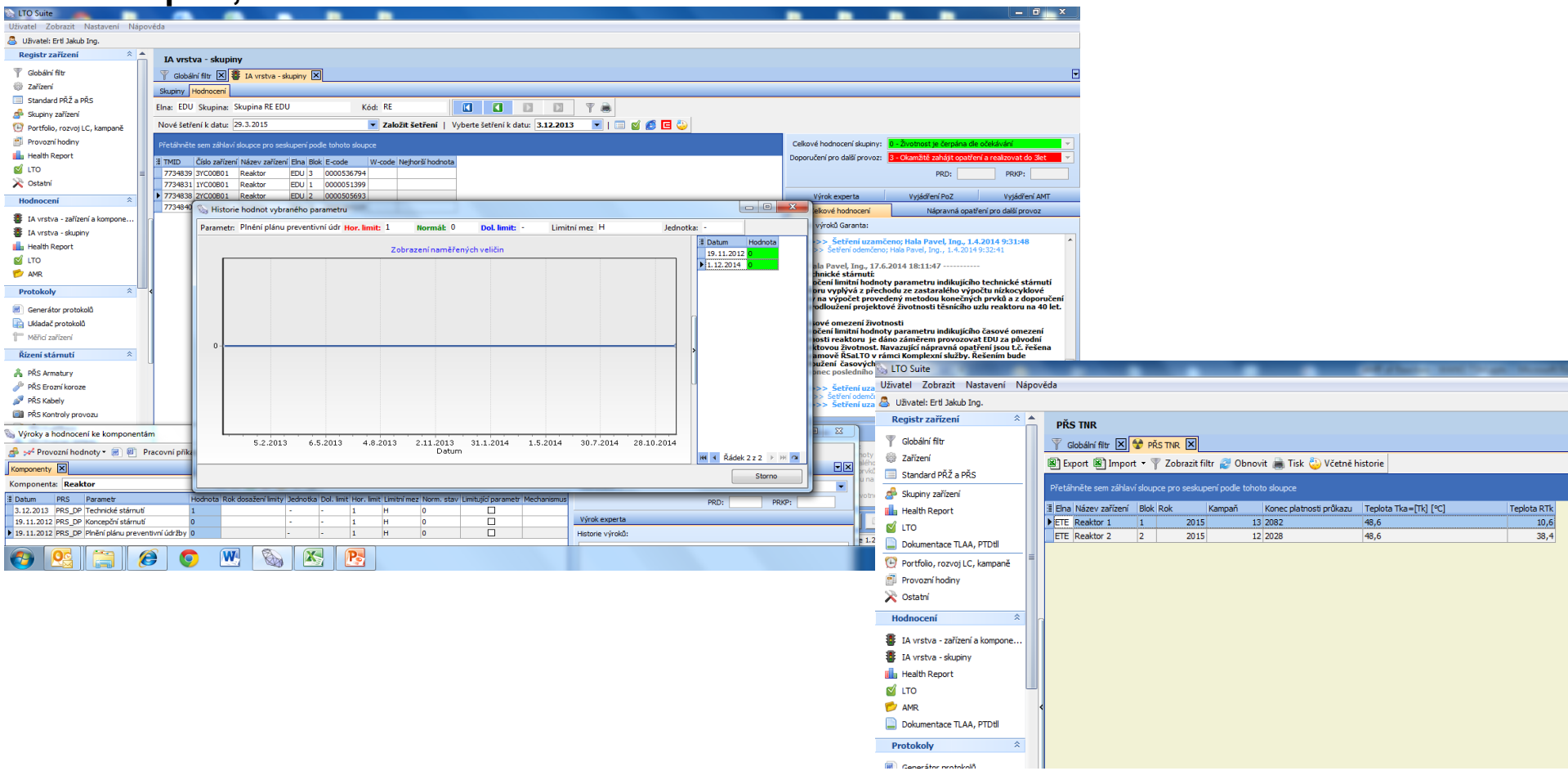
- *Documents of the programme*
  - ČEZ_TST_0033 - Component specific AMP for the reactor
- *Classification of equipment for plant life management*
  - Reactor – Equipment
  - Reactor Pressure Vessel
  - Reactor Internals
  - Reactor Control Rod Drives
  - Reactor Upper block
  - Reactor Sealing Node
- *Monitored functions in the programme*
  - Integrity
  - Control of the control rod
- *Degradation mechanisms / ageing effects affecting the monitored equipment functions*
  - radiation embrittlement
  - fatigue
  - mechanical wear
  - corrosion
  - swelling
  - creep
  - IASCC
  - thermal ageing

Component Specific AMP for the Reactor

VVER 1000							
Communication level	Parametr	Parametr Code	Unit	Upper Limit	Lower Limit	Normal Value	Note
Equipment	Performance of preventive maintenance plan	TSTPŘŽP0002	-				
Equipment	Conceptual ageing	TSTPŘŽP0003	-				
Equipment	Technical ageing	TSTPŘŽP0004	-				
Reactor set (RPV)	Critical temperature of brittleness	TSTPŘŽP0012	[°C]				
Reactor set (RPV)	Low cycle fatigue	TSTPŘŽP0008	[%]				
Reactor set (upper block)	Low cycle fatigue	TSTPŘŽP0008	[%]				
Reactor set (sealing node)	Low cycle fatigue	TSTPŘŽP0008	[%]				
Reactor set (RPV)	Stress corrosion cracking	TSTPŘŽP0007	-				
Reactor set (RVI)	Stress corrosion cracking	TSTPŘŽP0007	-				
Reactor set (RPV)	Performance of preventive maintenance plan	TSTPŘŽP0002	-				
Reactor set (RVI)	Performance of preventive maintenance plan	TSTPŘŽP0002	-				
Reactor set (sealing node)	Performance of preventive maintenance plan	TSTPŘŽP0002	-				
Reactor set (RPV)	Limitation of lifetime	TSTPŘŽP0010-01	[roky]				
Reactor set (upper block)	Limitation of lifetime	TSTPŘŽP0010-02	[roky]				
Reactor set (RVI)	Limitation of lifetime	TSTPŘŽP0010-03	[roky]				
Reactor set (sealing node)	Limitation of lifetime	TSTPŘŽP0010-04	[roky]				
Reactor set (RVI)	High cycle fatigue	TSTPŘŽP0014	-				
Reactor set (RVI)	Swelling/Creep	TSTPŘŽP0013	-				

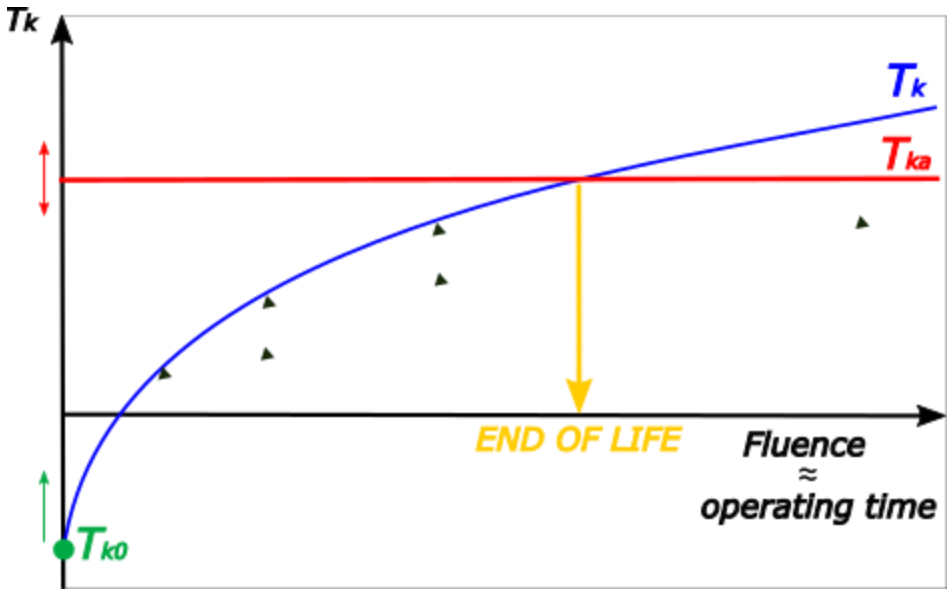
Main Software Used for Ageing Management of RPV and Lifetime Assessment of Reactor

- AMP outputs are stored in software LTOs and incorporated to **Health Reports, Safety Report, Periodic Lifetime Assessment**



Specific AMP for RPV Embrittlement

- **Documents**
  - ČEZ_ME_0780 Ageing Management Programme for RPV Embrittlement.
- The assessment of RPV embrittlement is performed in accordance with international methodology VERLIFE and Czech normative technical documentation A. M. E.
- The surveillance program is conducted by predefined harmonogram.



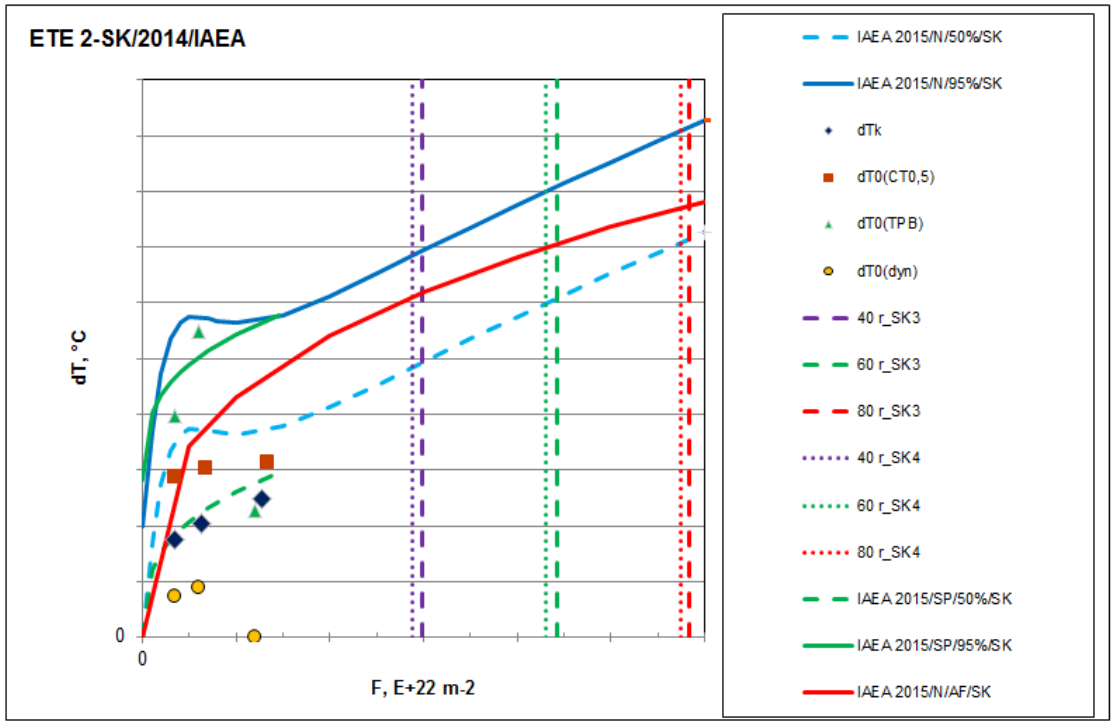
- We use surveillance program results for predictions of critical temperature of brittleness <u>in the case of Dukovany NPP</u>.

Specific AMP for RPV Embrittlement

- The surveillance program of Temelin RPV is at the beginning stage.

- We are not able to use results of surveillance program for predictions of critical temperature of brittleness.

- **We are obliged to use normative curves for embrittlement assessment.**.

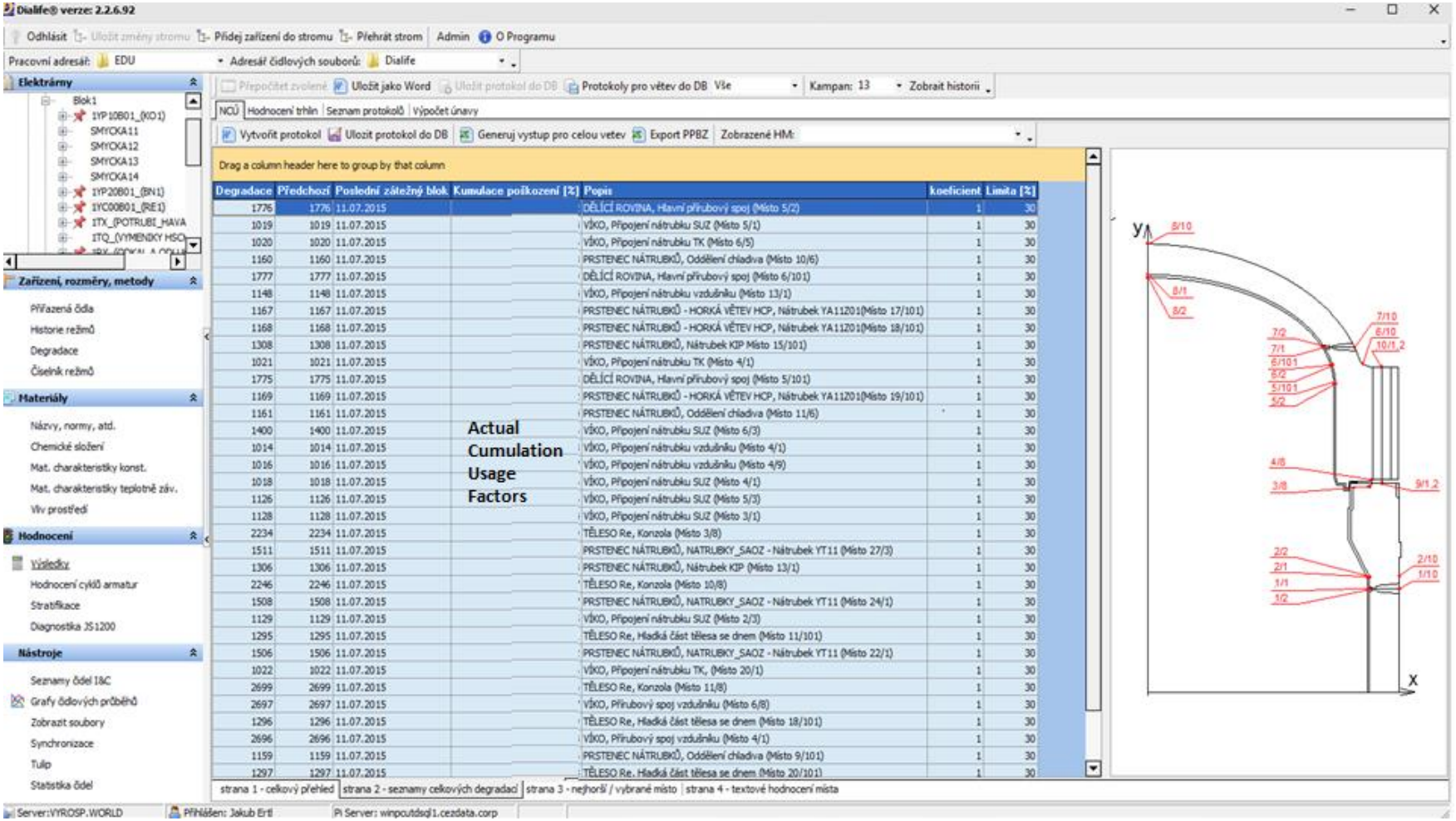


- New prediction formula for WWER-1000 RPV materials is based on results from the analysis of the database of surveillance specimen test results (after re-analysis of neutron fluence and reconstitution of specimens realized within European projects TACIS, TAREG and Russian projects)

Specific AMP for Low – Cycle Fatigue of RPV

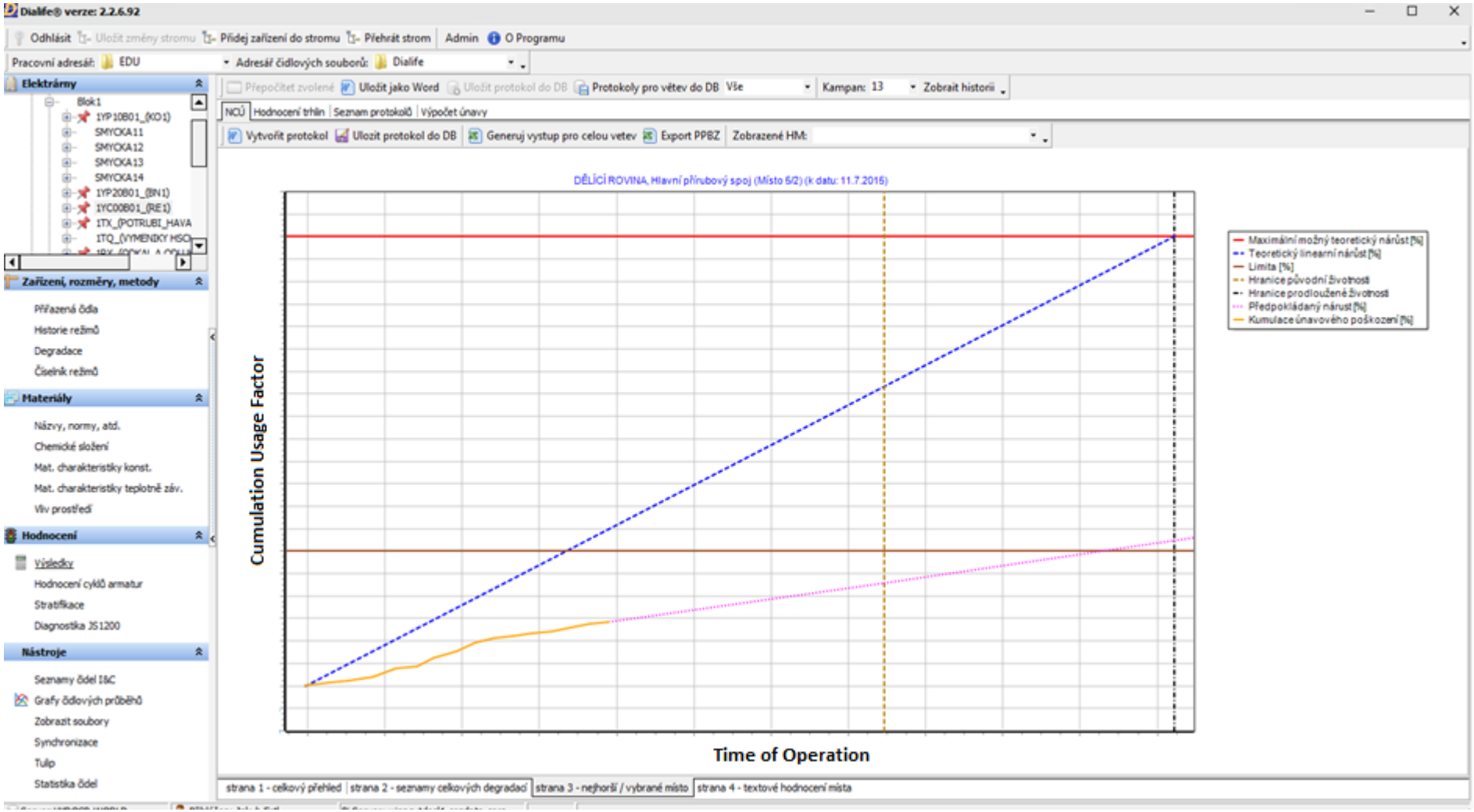
- ***Documents***
  - *ČEZ_ME_0780 Ageing Management Programme for RPV Embrittlement.*
- **The Ageing Management Program for low-cycle fatigue consists of the following periodic activities:**
  - Collection of data necessary for evaluating fatigue of the equipment
  - Evaluation of the measured operating parameters
  - Calculation of the accumulation of fatigue (CUF)
  - Prediction of the residual fatigue lifetime
  - Proposal and implementation of corrective measures
  - SW DIALIFE is the executive tool of this AMP
  - The limit value for total fatigue is **100%.**
  - Acceptance criteria of further operation are specified (40%, 60% and 80%) and appropriate corrective actions are defined when every acceptance criterion is reached
  - AMP outputs are stored in software LTOs and incorporated to **Health Reports, Safety Report, Periodic Lifetime Assessment**

Specific AMP for Low – Cycle Damage of RPV



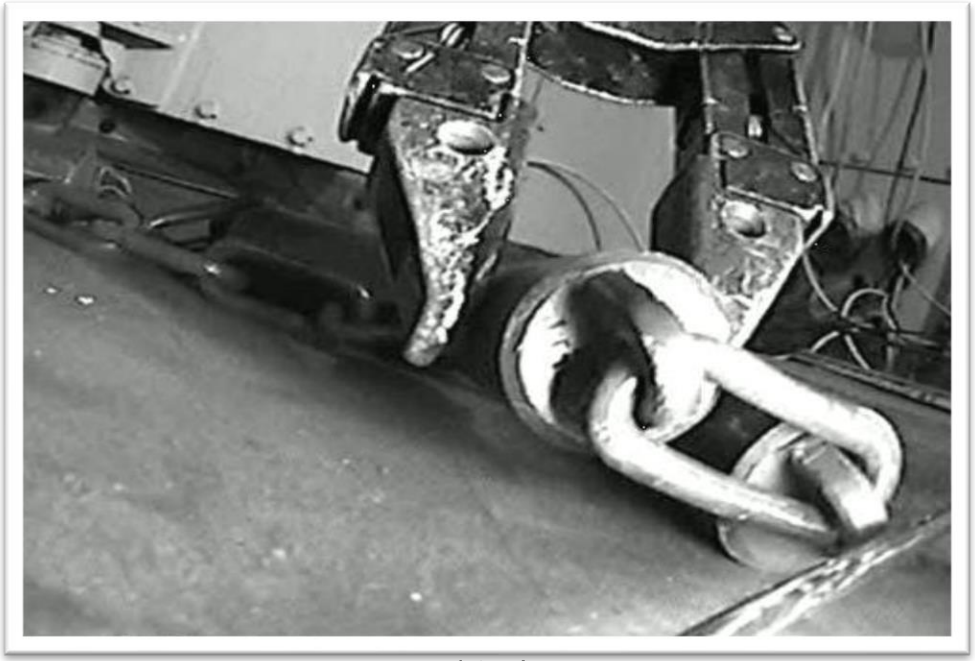
Interní

Specific AMP for Low – Cycle Damage of RPV



SURVEILLANCE PROGRAMS IN DUKOVANY NPP

- STANDARD SURVEILLANCE PROGRAM
- SUPPLEMENTARY SURVEILLANCE PROGRAM
- EXTENDED SURVEILLANCE PROGRAM



STANDARD SURVEILLANCE PROGRAM

Designed:	before beginning of operation
Monitored materials:	basic material, weld metal, heat affected zone
Types of tests:	Charpy test Fracture toughness test Tensile test

Program conception:

Monitoring of RPV material properties changes depending on operating time (40 years) with respect to:

- ✓ radiation embrittlement,
- ✓ thermal ageing,
- ✓ determination of irradiated materials of RPV after regenerative annealing.

STANDARD SURVEILLANCE PROGRAM

It was designed by Škoda JS at the knowledge level of 1970s. It was obvious (in 1990s during program evaluation) that the program is not enough for evaluation of status and prediction of residual lifetime of RPV.

The main shortcomings were:

- ✓ Temporality of program (5 years) – the approach was adequate to the knowledge of 1970s. A new approach was needed for a long term operation (to demonstrate knowledge of the state and to determine residual lifetime).
- ✓ Acceleration coefficient of surveillance specimens irradiation was too high.
- ✓ Impossibility to evaluate the irradiation temperature.
- ✓ Large uncertainty in fluence determination (insufficient number of monitors + unknown orientation of tested specimens against core).
- ✓ Absence of welding material.

SUPPLEMENTARY SURVEILLANCE PROGRAM

Start:	in 1997 at 4th block. Inserting and withdrawing according to the schedule, ending in 2023
Monitored materials:	basic material, weld metal, cladding, reference material
Types of tests:	Charpy test Fracture toughness test Tensile test

Program conception:

Monitoring of RPV material properties changes depending on operating time (40 years) with respect to:

- ✓ radiation embrittlement,
- ✓ radiation embrittlement after regenerative annealing,
- ✓ monitoring of irradiation conditions

It was designed by ÚJV Řež in cooperation with Škoda JS – shortcomings of standard surveillance program were removed.

EXTENDED SURVEILLANCE PROGRAM

Start:	in 2010, inserting and withdrawing according to the schedule, ending in 2050
Monitored materials:	basic material, weld metal, cladding, reference material, heat affected zone, welding repair material
Types of tests:	Charpy test Fracture toughness test Tensile test

Program conception:

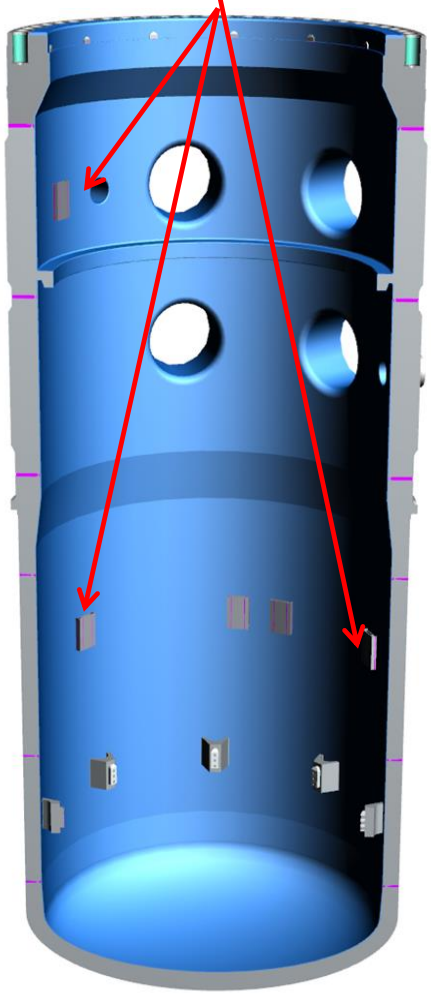
Monitoring of RPV material properties changes depending on operating time (up to 80 years) with respect to:

- ✓ radiation embrittlement,
- ✓ radiation embrittlement after regenerative annealing,
- ✓ monitoring of irradiation conditions.

SURVEILLANCE PROGRAM IN TEMELIN NPP

- **Six** containers are determined for the effect of radiation embrittlement, **two** for the effect of annealing and for the re-embrittlement effects, if necessary - all containers are located on inner RPV surface in the beltline region
- **Two** containers are determined for the effect of thermal aging – the containers are located above the core
- **Design of containers and holders allow withdrawal and also re-loading of new containers.**
- Three containers determined for the effect of radiation embrittlement were withdrawn from each unit

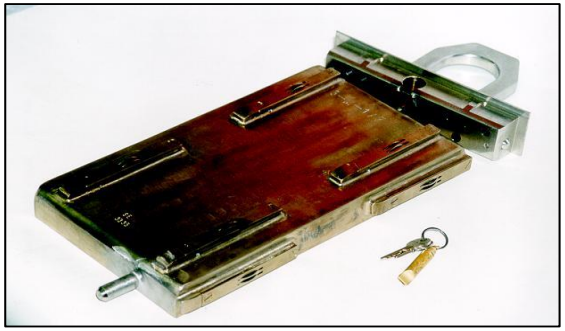
Location of Containers



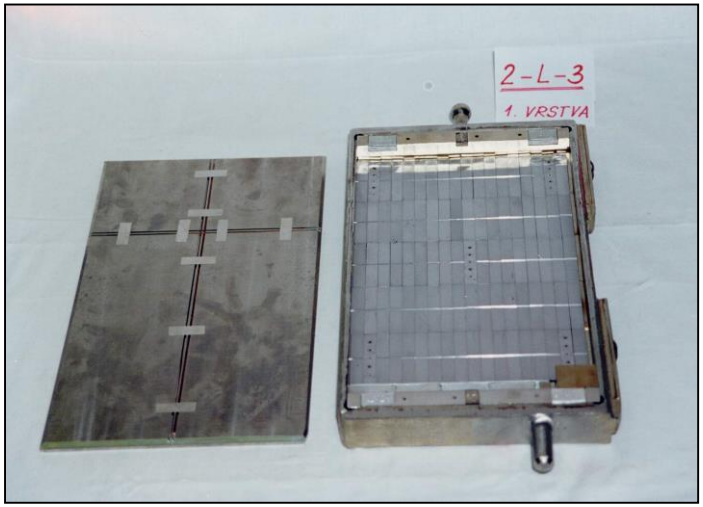
UNIT 1	UNIT 2
2004	2005
2008	2009
2012	2013

SURVEILLANCE PROGRAMS IN TEMELIN NPP

FLAT TYPE CONTAINER
200 X 300 X 25 mm

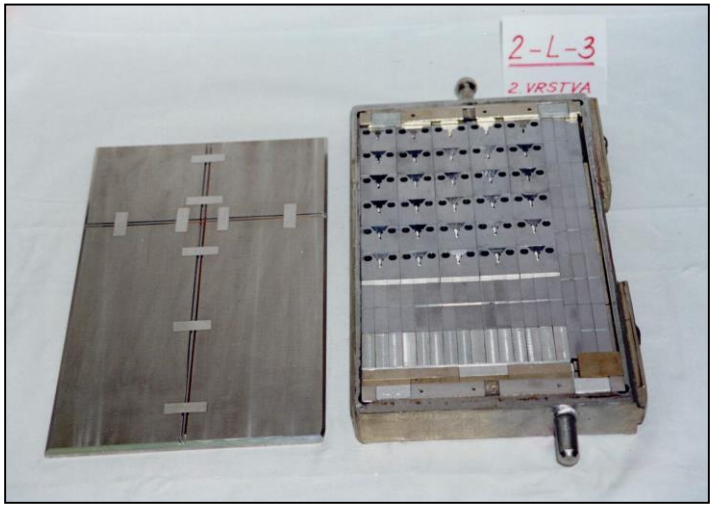


First layer



LOCATION OF CONTAINERS ON RPV WALL

Second layer



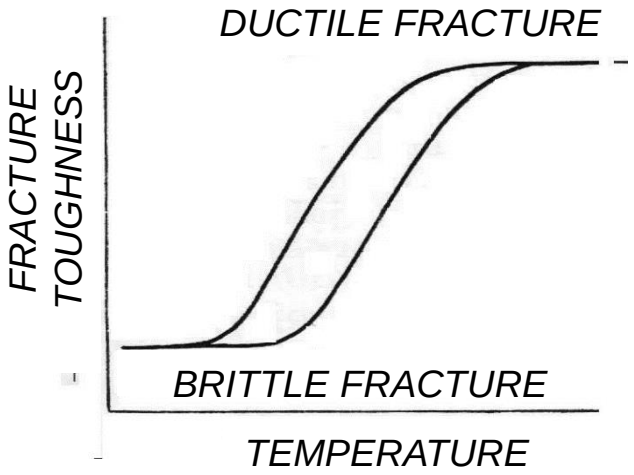
SURVEILLANCE PROGRAMS IN TEMELIN NPP

SPECIMENS TYPES

- **TENSILE SPECIMENS** – base metal and weld metal
- **SPECIMENS FOR IMPACT NOTCH TOUGHNESS** - base metal (24), weld metal (24), heat affected zone (24), JRQ (32) and materials from other WWER-1000 units (12 per material);
- **SPECIMENS FOR STATIC FRACTURE TOUGHNES OF CT 0.5 TYPE** - base metal (15) and weld metal(15);
- **SPECIMENS OF „COD“ (TPB) TYPE** – base metal (14), weld metal (14), heat affected zone(14), first and second layer of austenitic cladding (14), JRQ (14), and materials from other WWER-1000 units (12 per material);

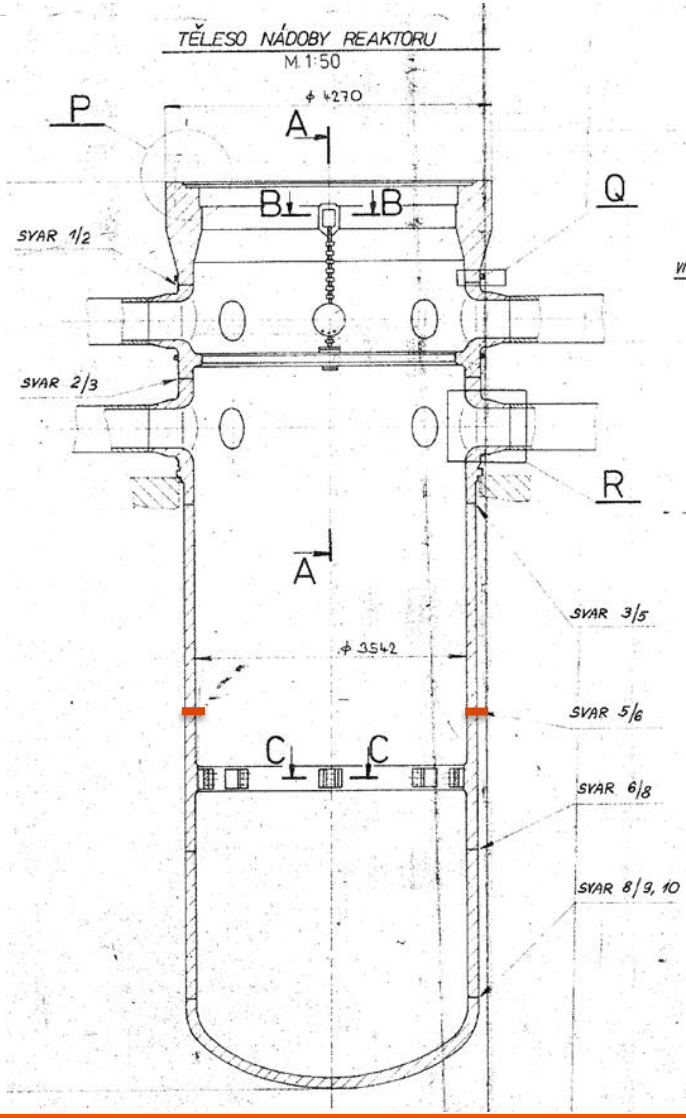
EVALUATION PROCESS

- Radiation damage of basic material in the location of maximum fluence and radiation damage of 5/6 weld is based on shifts of transient temperature



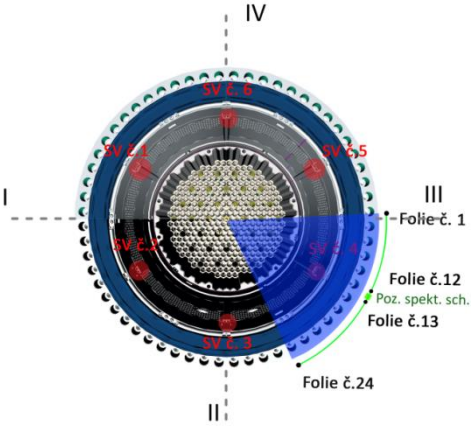
- Evaluation inputs:
  - fast neutron fluence,
  - transient temperature limit value

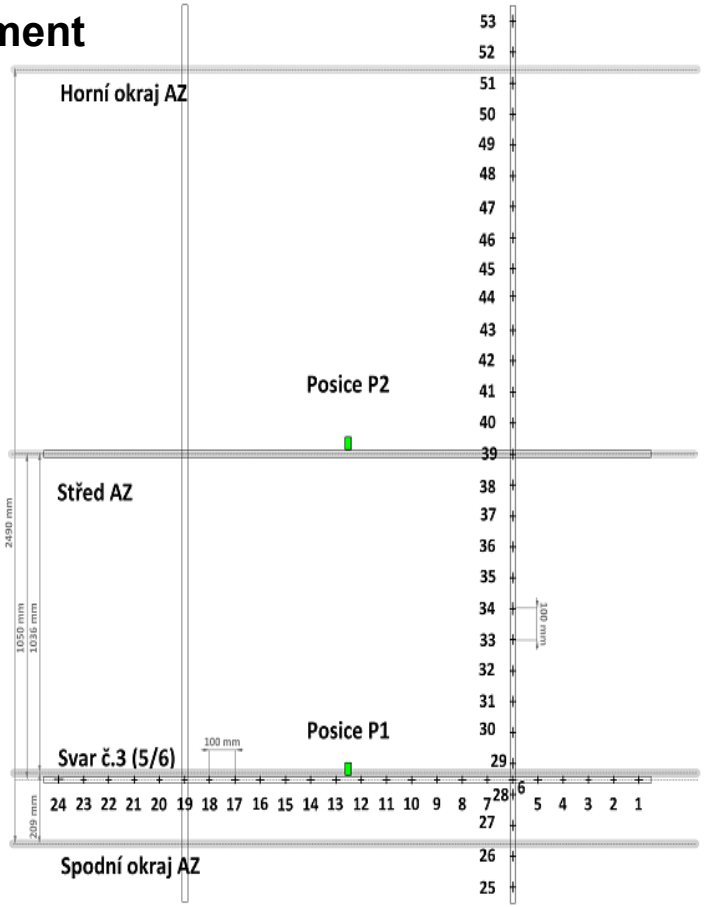
- Two types of evaluations:
  - **Shift of critical brittleness temperature**
  - **Determination of reference temperature**



FLUENCE

- **RPV fluence is determined by calculation corrected by measurement in surveillance program and by ex-vessel measurement**
- Inserting/withdrawing of rack for ex-vessel measurement is done manually through inspection hole for NDT under reactor
- Rack is situated behind surveillance specimens channel with dosimetric chain

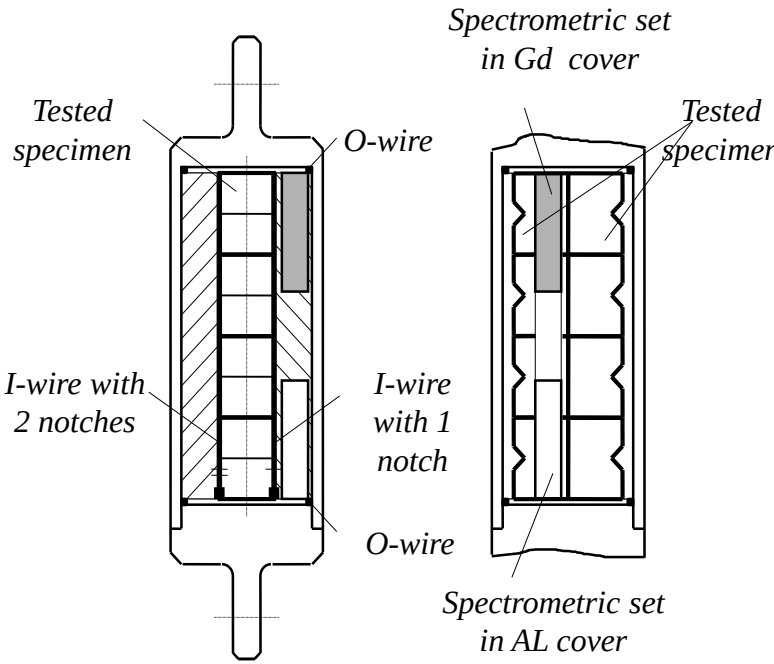


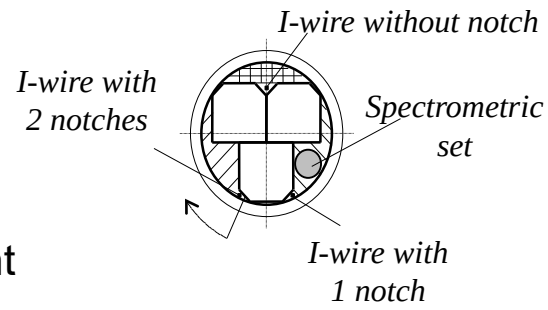


Interní

FLUENCE – SURVEILLANCE PROGRAM MEASUREMENT DUKOVANY NPP

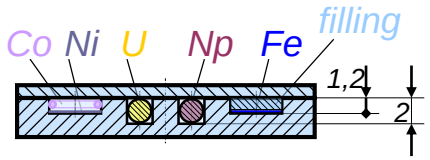
- 2 O-wires (container rotation against core, determination of azimutal fluence distribution in container)
- 3 I-wires (determination of axial fluence high distribution in container)
- 2 spectrometric sets (determination of neutron fluence spectrum)
- Programs BASA CF, SAND and relative fluence distribution model is used
- Fluence is determined in the container axis in axial container centre and in geometric centre of individual specimens
- Input spectrum from 1-M-1 and 1-M-2 measurement in surveillance program

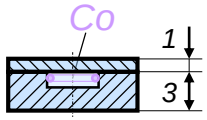


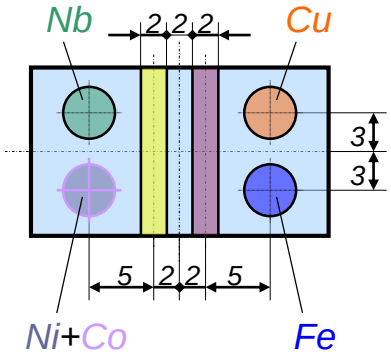


FLUENCE – SURVEILLANCE PROGRAM MEASUREMENT TEMELIN NPP

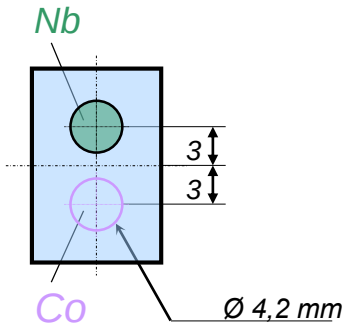
- **Cu, Fe wires in container cap**
- **12 spectrometric sets in stainless steel capsules per container**
  - 8 large spectrometric sets
  - 4 small spectrometric sets
- **Large spectrometric set**
  - Consists of Co, Cu, Fe, Nb, Ni detectors; metal discs ∅4 x 0,1mm
  - Large sets in bottom part of container contain fission detectors NpO_2, UO_2
- **Small spectrometric set**
  - Consists of Co, Nb detectors ; metal discs ∅4 x 0,1mm







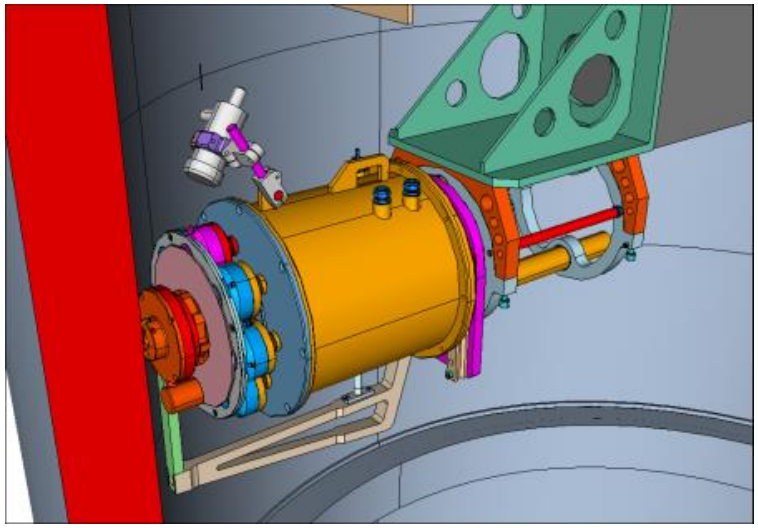
Large spectrometric set

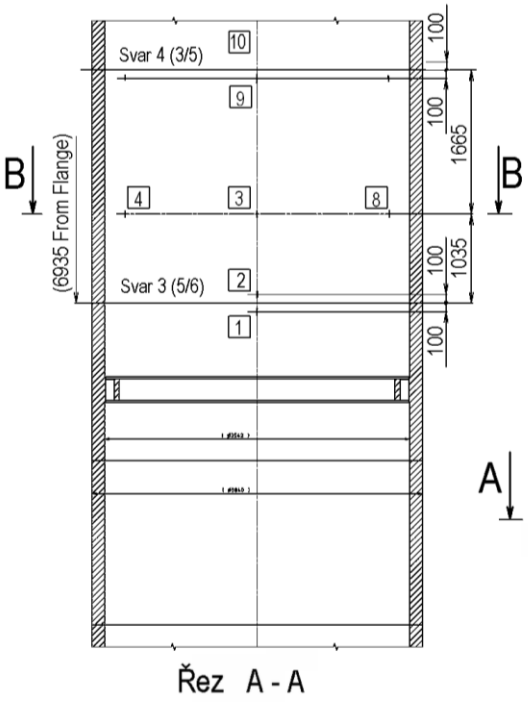


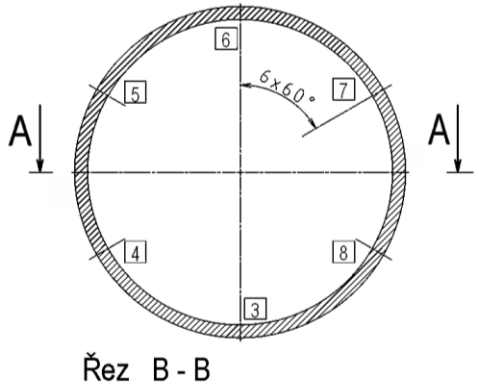
Small spectrometric set

SAMPLES FROM RPV CLADDING

- Samples of Dukovany RPV cladding were taken from 3th block in 2005 and 2017
- It was taken 8+16 samples in total
- Goal: qualification of fluence evaluation







SPECIFIC AMP FOR RADIATION DAMAGE OF ITNERNALS – UNDER CONSTRUCTION

Corrosion-mechanical-fatigue material properties of RVI EDU

Real properties under operating conditions

Properties derived from „**default state**“ material properties

Verlife material curves – in the case of insufficient information about real materials

Operational data

Regimes and parameters of operation

Postulated cracks according to Verlife

(in the case of insufficient SCP)

Agieng management due to the following degradation mechanisms:

LCF, HCF

IASCC, SCC

NE, TE

Swelling + Creep

Damage (operation)

Abrasion (vibration)

Obsolescence

Evaluator know-how

World best-practice and scientific experiences

1. Information about operating other NPPs
2. Scientific publications
3. Changes (proposals) to world-recognizes standards

Verlife: evaluation of critical incident

1. Fatigue crack initiation (LCF, HCF)
2. IASCC crack initiation
3. LEA initiation
4. Unstable crack growth
5. Lost of component integrity
6. Unallowable geometric changes

ISI program finding evaluation

It provides information about material state in dependence on quality and qualification used NDT methods

Operating findings evaluation

1. Regulation (and others) infringement
2. Unexpected incidents

Vibration measurements

1. Accelerometer data measurement
2. Evaluation frequency changes of sceleton curves
3. Validity verification of made fatigue calculations (non-exceding fatigue limit)

Technical and conceptual ageing evaluation

Configuration power plant changes evaluation and their impacts on RVI ageing management program

1. Equipment configuration changes
2. Operating and governing documentation
3. Information source changes

Interní

Program outputs in:

1. RVI lifetime
2. RVI availability
3. Corrective measures into own AMP RVI
4. Corrective measures into other AMPs and activities with an influence on ageing management
5. Way of future NPP operation

Legend

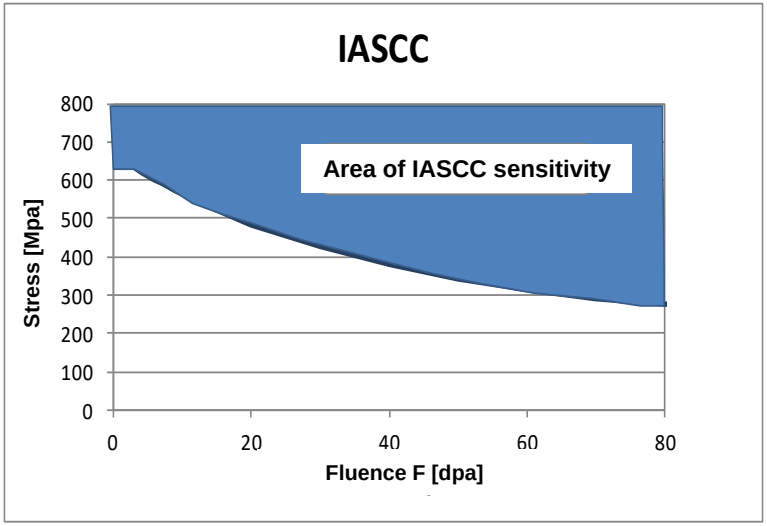
Input data into RVI AMP

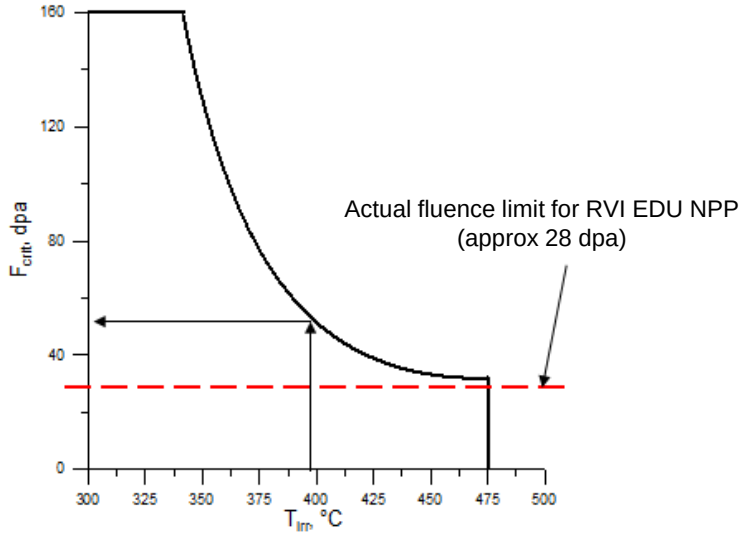
Documentation

Outputs

LIFETIME ASSESSMENT OF RVI

- **Lifetime Assessment of RVI Report**
  - lifetime assessment according to IAEA Verlife Appendix C – degradation mechanisms – low cycle fatigue, high cycle fatigue, IASCC, LEA, swelling, creep





Critical curve for LEA estimation according to VERLIFE.

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS ?