



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***



-
- **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

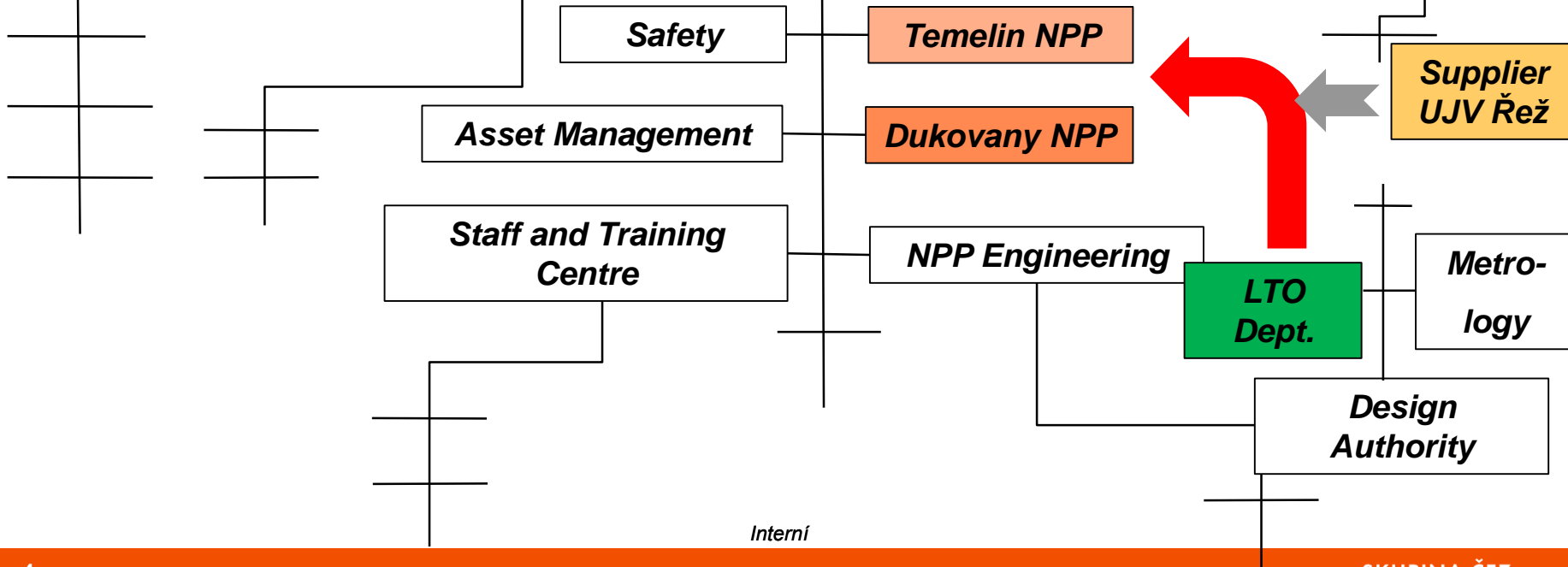
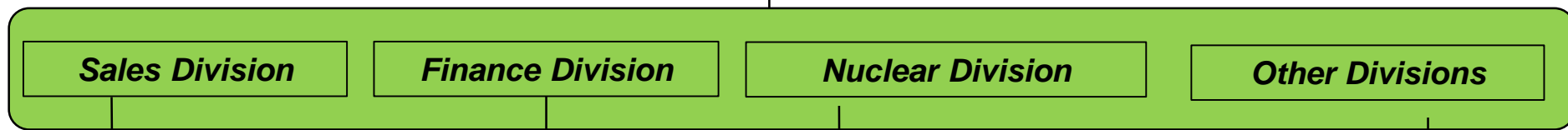
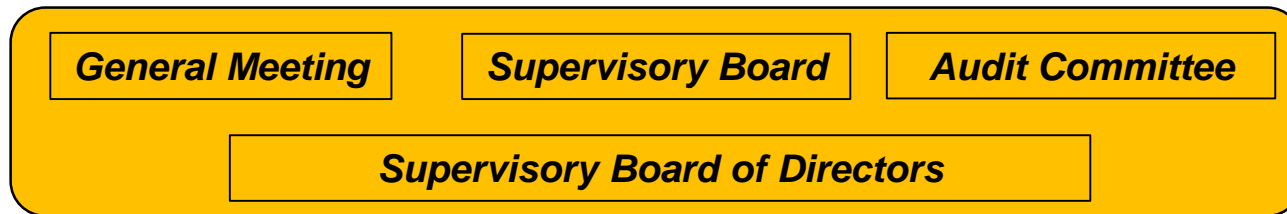


- **Two Units WWER 1000/V320 type, four-loop primary circuit**
- Each reactor loop has a horizontal steam generator and main circulation pump
- Containment made of sealed reinforced concrete with the inner steel liner
- Triple redundancy of emergency reactor core cooling systems
- One 1000 MW turbine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



ORGANISATIONAL CHART OF ČEZ, A.S.

LTO DEPARTMENT IS RESPONSIBLE FOR AMPs AND TLAAs

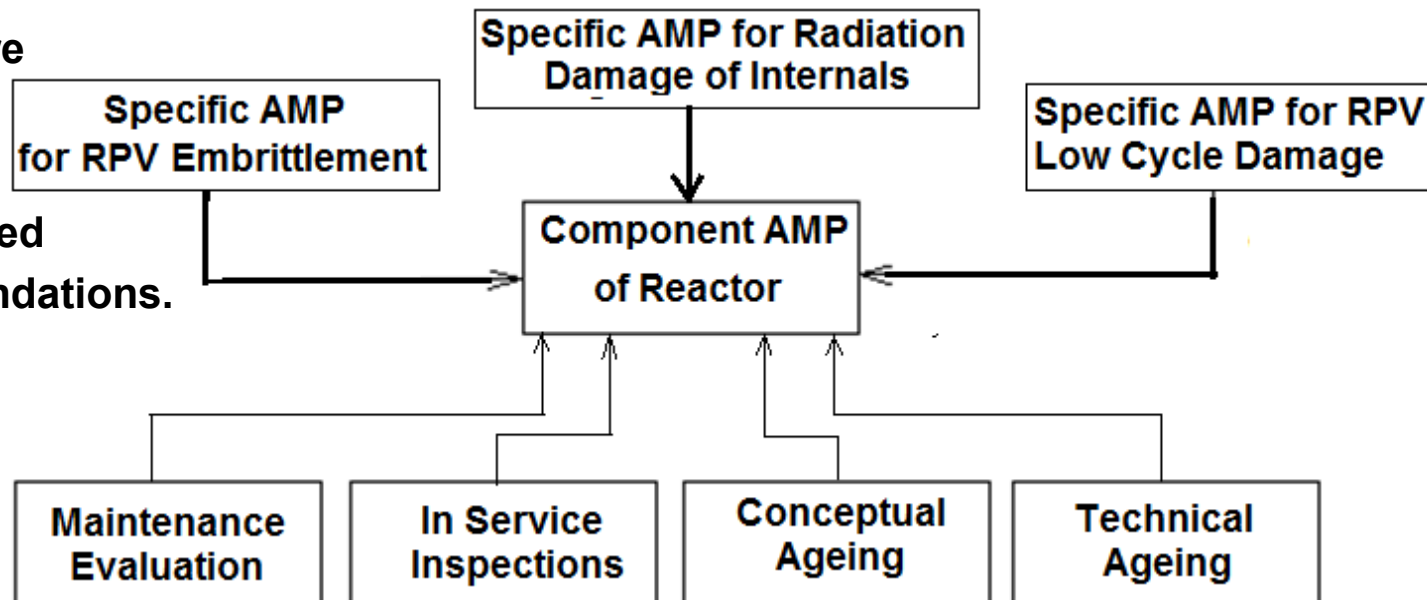


AGEING MANAGEMENT PROGRAMMES (AMPs)



- 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

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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**

The screenshot displays the LTO Suite software interface. The main window shows a table of reactor components with columns for TMID, číslo zařízení, název zařízení, Elna, Blok, E-code, and W-code. A graph window is open, showing a plot of 'Zobrazení naměřených veličin' (Display of measured variables) over time from 5.2.2013 to 28.10.2014. The graph shows a horizontal line at zero. A 'Výroky experta' (Expert's conclusions) window is also visible, containing text about technical sturdiness and lifetime assessment.

TMID	Číslo zařízení	Název zařízení	Elna	Blok	E-code	W-code	Nejhorší hodnota
7734839	3YCO0B01	Reaktor	EDU	3	0000536794		
7734831	1YCO0B01	Reaktor	EDU	1	0000051399		
7734838	2YCO0B01	Reaktor	EDU	2	00000505693		

Datum	Hodnota
19.11.2012	0
1.12.2014	0

Datum	PRŠ	Parametr	Hodnota	Rok dosažení limity	Jednotka	Dol. limit	Hor. limit	Limitní mez	Norm. stav	Limitující parametr	Mechanismus
3.12.2013	PRŠ_DP	Technické stárnutí	1	-	-	1	H	0			
19.11.2012	PRŠ_DP	Koncepční stárnutí	0	-	-	1	H	0			
19.11.2012	PRŠ_DP	Plnění plánu preventivní údržby	0	-	-	1	H	0			

Elna	Název zařízení	Blok	Rok	Kampaň	Konec platnosti průkazu	Teplota Tka=[°C]	Teplota RTk
ETE	Reaktor 1	1	2015	13	2082	48,6	10,6
ETE	Reaktor 2	2	2015	12	2028	48,6	38,4

SPECIFIC AMP FOR RPV EMBRITTLEMENT



Documents

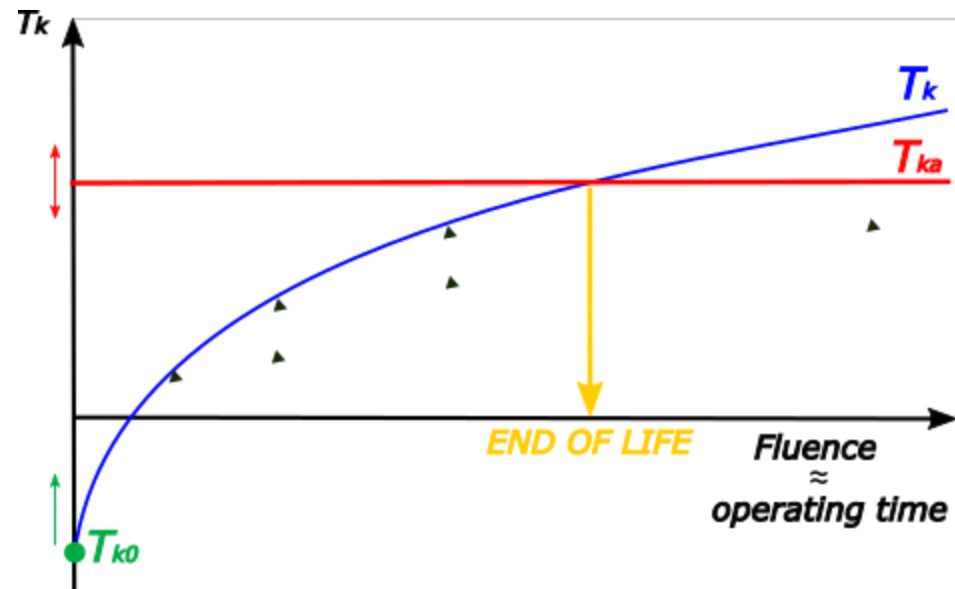
➤ ČEZ_ME_0780 Ageing Management Programme for RPV Embrittlement.

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 in the case of Dukovany NPP.



SPECIFIC AMP FOR RPV EMBRITTLEMENT



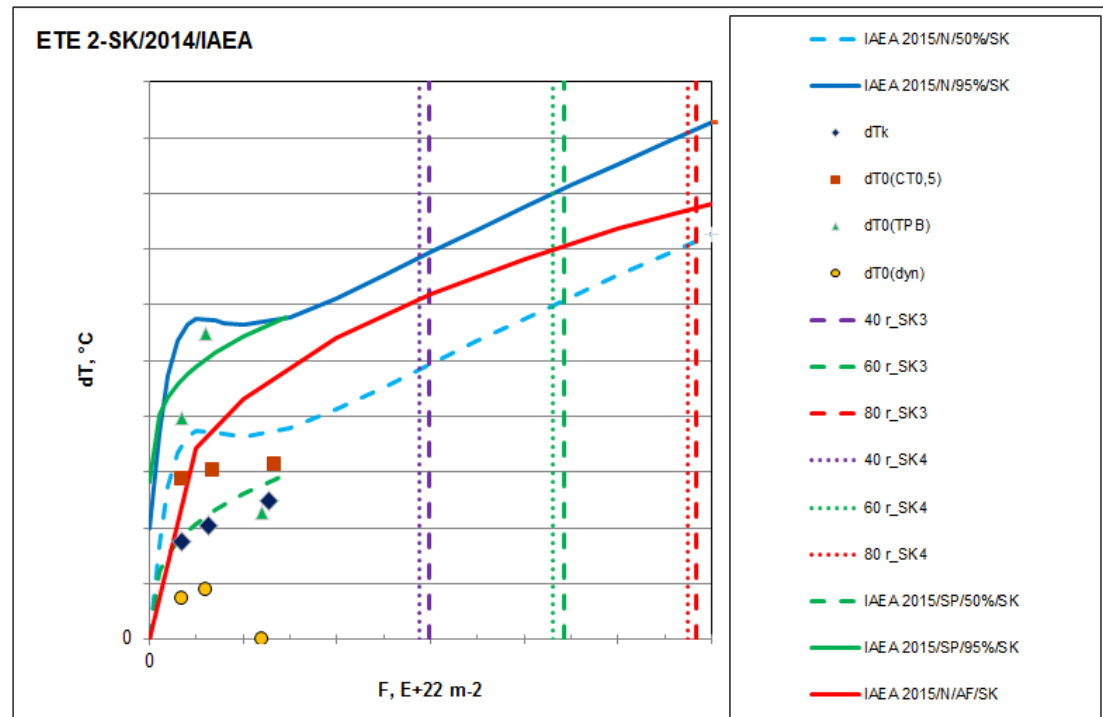
- The surveillance program of Temelin RPV is at the beginning stage.



- 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



Dialife® verze: 2.2.6.92

Pracovní adresář: EDU Adresář číselových souborů: Dialife

Elektrárny

Blk1

- 1YP10801_(KO1)
- SMYOKA11
- SMYOKA12
- SMYOKA13
- SMYOKA14
- 1YP20801_(BN1)
- 1YC00801_(RE1)
- ITX_POTRUBI_HAVA
- ITQ_VYTMENKY_HSC

Zařízení, rozměry, metody

Přivázané čísla

Historie režimů

Degradace

Číselné režimů

Materiály

Názvy, normy, atd.

Chemické složení

Mat. charakteristky konst.

Mat. charakteristiky teplotně záv.

Viv prostředí

Hodnocení

Výsledky

Hodnocení cyklů amatur

Stratifikace

Diagnostika JS1200

Nástroje

Seznamy čísel IAC

Grafy číselových průběhů

Zobrazit soubory

Synchronizace

Tulp

Statistika čísel

Drag a column header here to group by that column

Degradace	Předchozí	Poslední závažný blok	Kumulace poškození [%]	Popis	Koeficient	Limita [%]
1775	1776	11.07.2015		DĚLÍCI ROVINA, Hlavní přírubový spoj (Místo 5/2)	1	30
1019	1019	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 5/1)	1	30
1020	1020	11.07.2015		VÍKO, Připojení nátrubku TK (Místo 6/5)	1	30
1160	1160	11.07.2015		PRSTENEC NÁTRUBKŮ, Oddělení chladiva (Místo 10/6)	1	30
1777	1777	11.07.2015		DĚLÍCI ROVINA, Hlavní přírubový spoj (Místo 6/10)	1	30
1148	1148	11.07.2015		VÍKO, Připojení nátrubku vzdušniku (Místo 13/1)	1	30
1167	1167	11.07.2015		PRSTENEC NÁTRUBKŮ - HORKÁ VĚTEV HCP, Nátrubek YA11201(Místo 17/10)	1	30
1168	1168	11.07.2015		PRSTENEC NÁTRUBKŮ - HORKÁ VĚTEV HCP, Nátrubek YA11201(Místo 18/10)	1	30
1308	1308	11.07.2015		PRSTENEC NÁTRUBKŮ, Nátrubek KIP Místo 15/10)	1	30
1021	1021	11.07.2015		VÍKO, Připojení nátrubku TK (Místo 4/1)	1	30
1775	1775	11.07.2015		DĚLÍCI ROVINA, Hlavní přírubový spoj (Místo 5/10)	1	30
1169	1169	11.07.2015		PRSTENEC NÁTRUBKŮ - HORKÁ VĚTEV HCP, Nátrubek YA11201(Místo 19/10)	1	30
1161	1161	11.07.2015		PRSTENEC NÁTRUBKŮ, Oddělení chladiva (Místo 11/6)	1	30
1400	1400	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 6/3)	1	30
1014	1014	11.07.2015		VÍKO, Připojení nátrubku vzdušniku (Místo 4/1)	1	30
1016	1016	11.07.2015		VÍKO, Připojení nátrubku vzdušniku (Místo 4/9)	1	30
1018	1018	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 4/1)	1	30
1126	1126	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 5/3)	1	30
1128	1128	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 3/1)	1	30
2234	2234	11.07.2015		TĚLESO Re, Konzola (Místo 3/8)	1	30
1511	1511	11.07.2015		PRSTENEC NÁTRUBKŮ, NÁTRUBKY_SAOZ - Nátrubek YT11 (Místo 27/3)	1	30
1306	1306	11.07.2015		PRSTENEC NÁTRUBKŮ, Nátrubek KIP (Místo 13/1)	1	30
2246	2246	11.07.2015		TĚLESO Re, Konzola (Místo 10/8)	1	30
1508	1508	11.07.2015		PRSTENEC NÁTRUBKŮ, NÁTRUBKY_SAOZ - Nátrubek YT11 (Místo 24/1)	1	30
1129	1129	11.07.2015		VÍKO, Připojení nátrubku SUZ (Místo 2/3)	1	30
1295	1295	11.07.2015		TĚLESO Re, Hladká část tělesa se dnem (Místo 11/10)	1	30
1506	1506	11.07.2015		PRSTENEC NÁTRUBKŮ, NÁTRUBKY_SAOZ - Nátrubek YT11 (Místo 22/1)	1	30
1022	1022	11.07.2015		VÍKO, Připojení nátrubku TK, (Místo 20/1)	1	30
2699	2699	11.07.2015		TĚLESO Re, Konzola (Místo 11/8)	1	30
2697	2697	11.07.2015		VÍKO, Přírubový spoj vzdušniku (Místo 6/8)	1	30
1296	1296	11.07.2015		TĚLESO Re, Hladká část tělesa se dnem (Místo 18/10)	1	30
2696	2696	11.07.2015		VÍKO, Přírubový spoj vzdušniku (Místo 4/1)	1	30
1159	1159	11.07.2015		PRSTENEC NÁTRUBKŮ, Oddělení chladiva (Místo 9/10)	1	30
1297	1297	11.07.2015		TĚLESO Re, Hladká část tělesa se dnem (Místo 20/10)	1	30

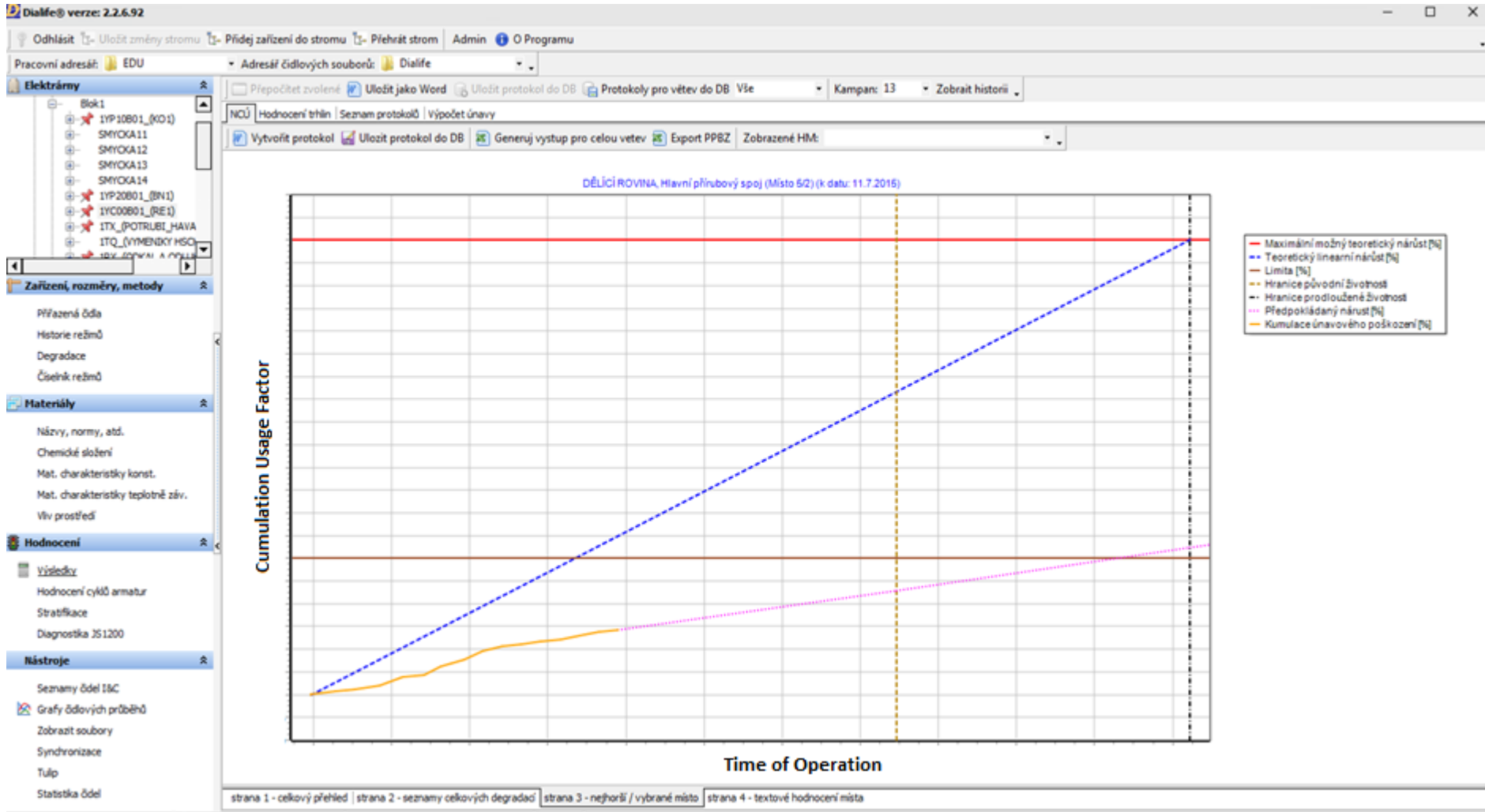
Actual Cumulation Usage Factors

strana 1 - celkový přehled | strana 2 - seznamy celkových degradací | strana 3 - nejhorší / vybrané místo | strana 4 - textové hodnocení místa

Server: VYROSP.WORLD | Přihlášen: Jakub Ertl | IP Server: winpcoutd1g1.cezdata.com

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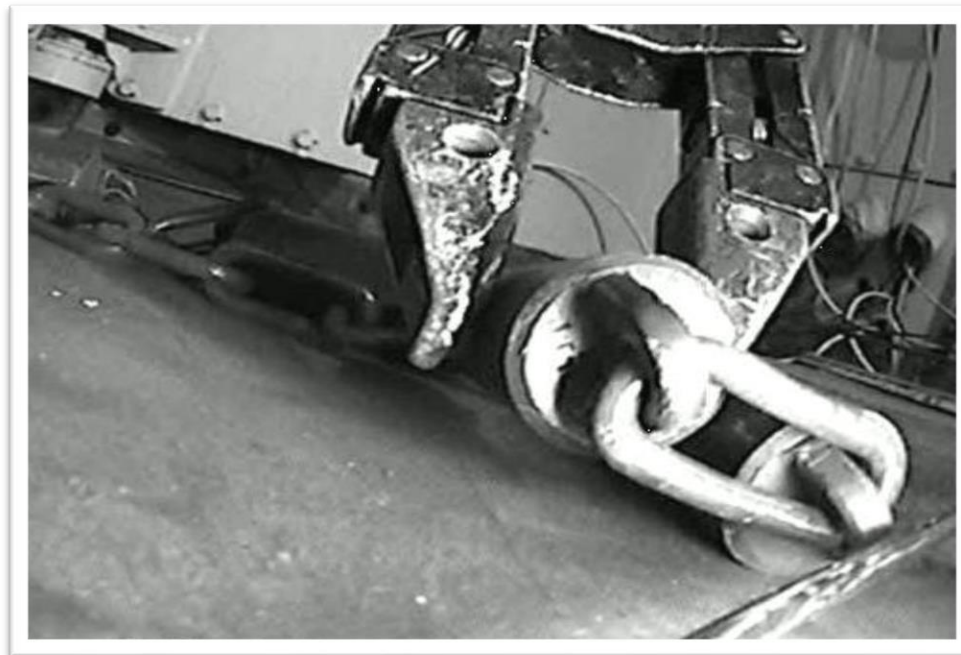
SPECIFIC AMP FOR LOW – CYCLE DAMAGE OF RPV



SURVEILLANCE PROGRAMS IN DUKOVANY NPP



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



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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.

Interní

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:

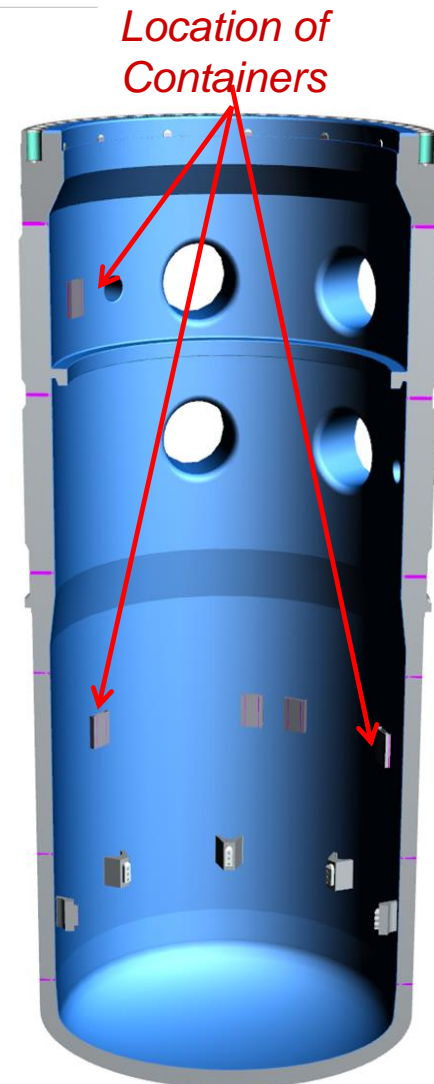
Monitoring of RPV material properties changes depending on operating time (up to 80 years) with respect to:

- ✓ 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



UNIT 1

2004

2008

2012

UNIT 2

2005

2009

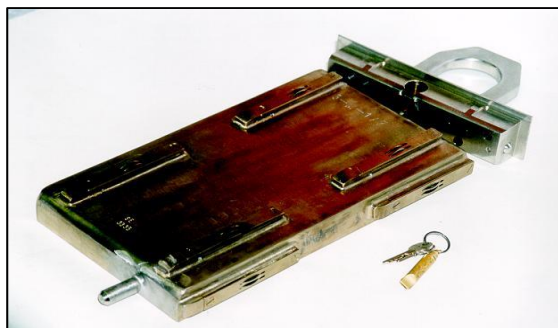
2013

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SURVEILLANCE PROGRAMS IN TEMELIN NPP



FLAT TYPE CONTAINER
200 X 300 X 25 mm

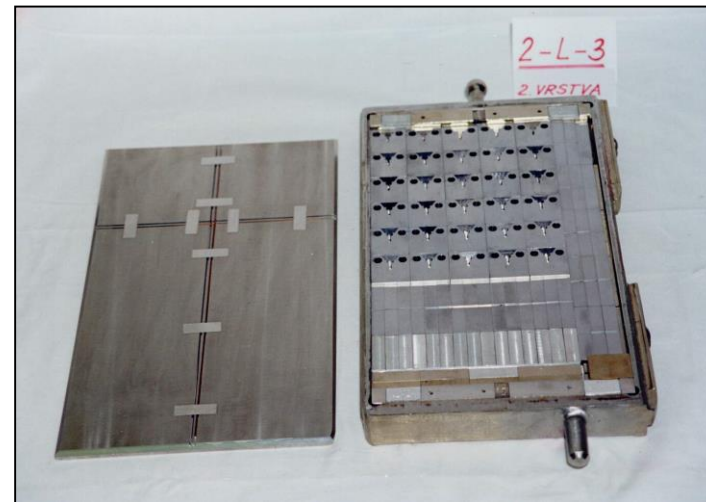
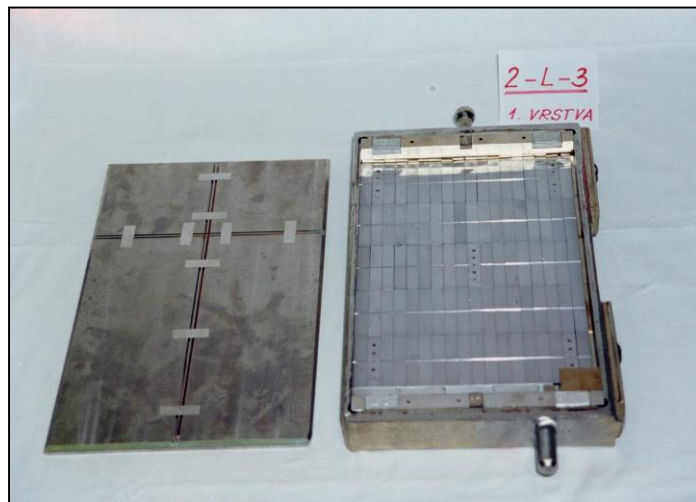


First layer

LOCATION OF CONTAINERS ON RPV WALL



Second layer



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SURVEILLANCE PROGRAMS IN TEMELIN NPP

SPECIMENS TYPES

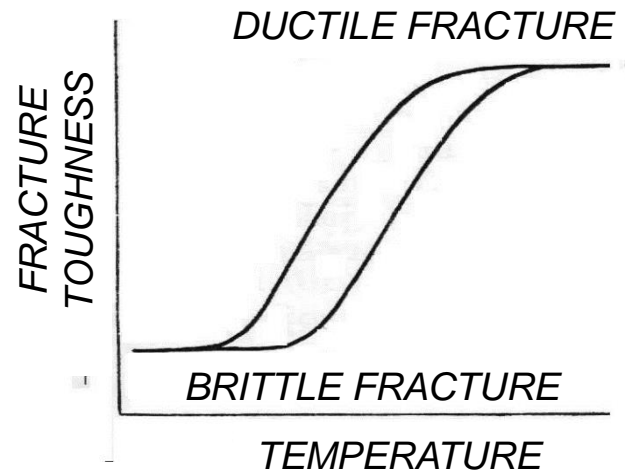


- **TENSILE SPECIMENS** – base metal and weld metal
- **SPECIMENS FOR IMPACT NOTCH TOUGHNESS** - base metal (24), weld metal (24), heat affected zone (24), JRQ (32) and materials from other WWER-1000 units (12 per material);
- **SPECIMENS FOR STATIC FRACTURE TOUGHNES OF CT 0.5 TYPE** - base metal (15) 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);

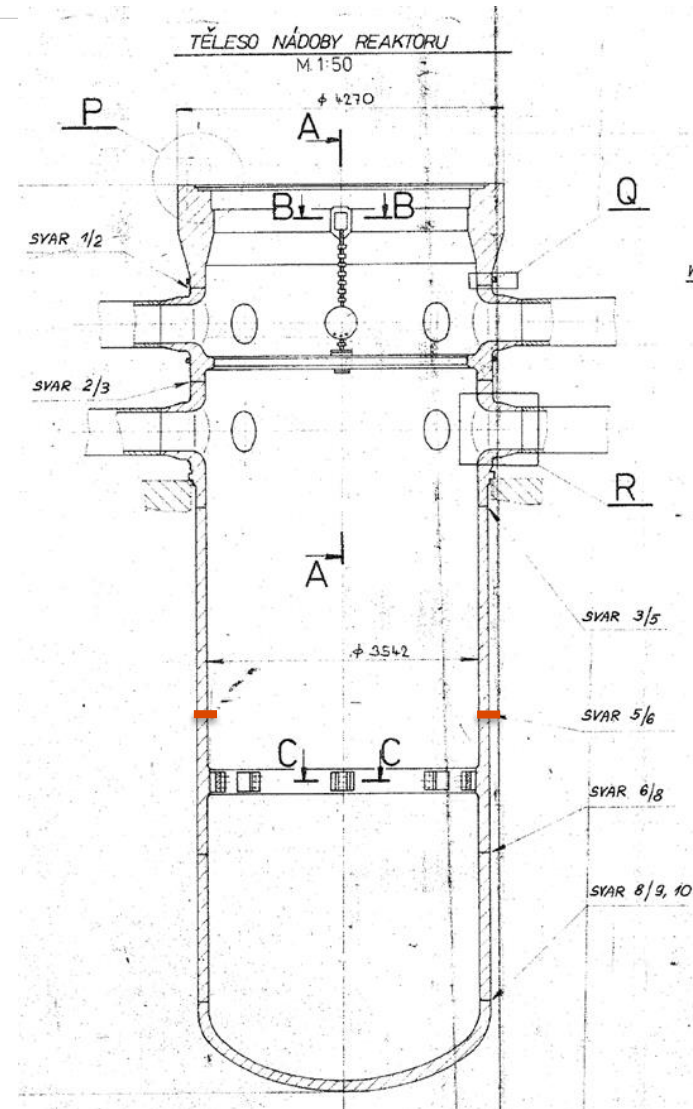
EVALUATION PROCESS



- 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



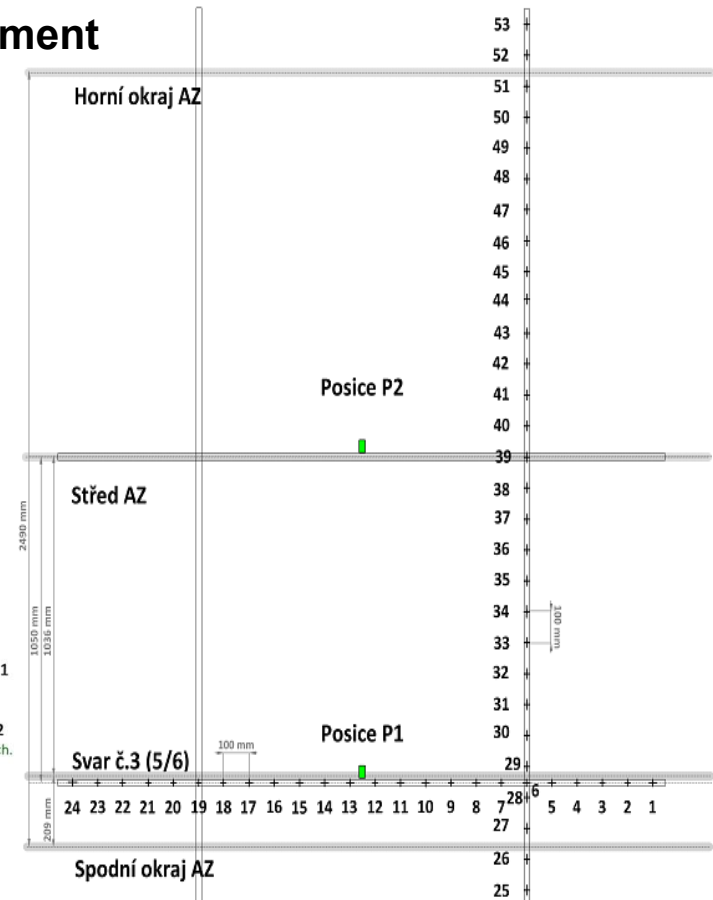
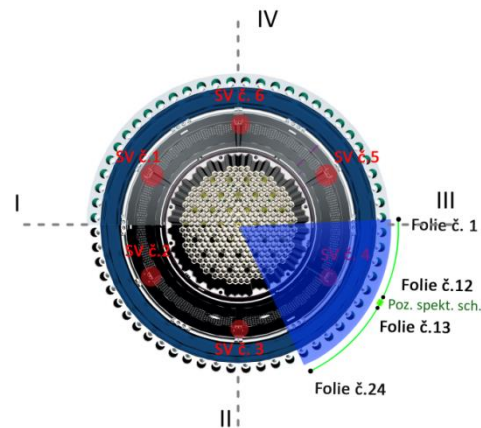
- Evaluation inputs:
 - fast neutron fluence,
 - transient temperature limit value
- Two types of evaluations:
 - **Shift of critical brittleness temperature**
 - **Determination of reference temperature**



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- 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

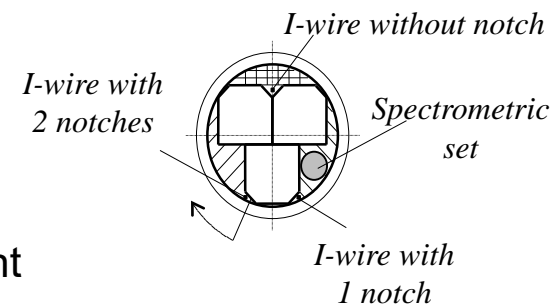
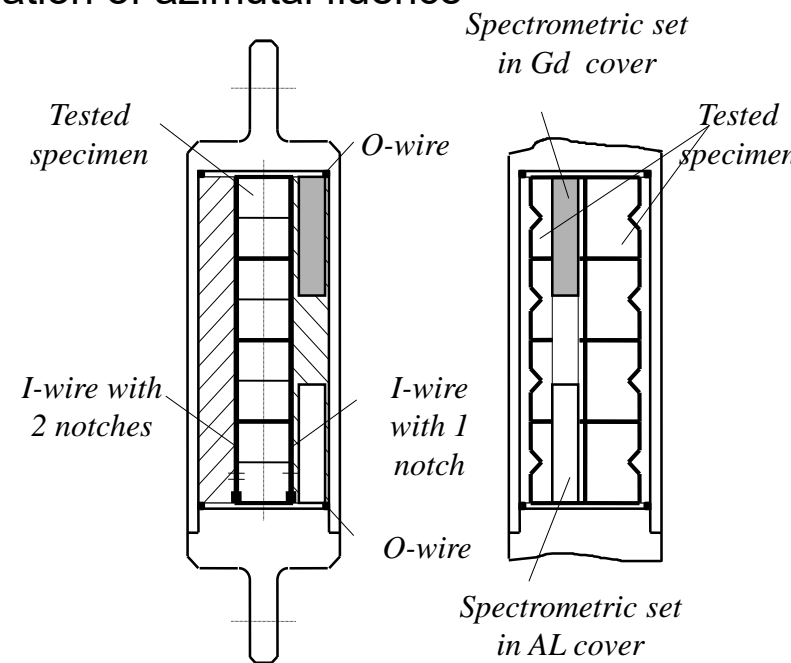


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FLUENCE – SURVEILLANCE PROGRAM MEASUREMENT DUKOVANY NPP



- 2 O-wires (container rotation against core, determination of azimuthal 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



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FLUENCE – SURVEILLANCE PROGRAM MEASUREMENT TEMELIN NPP



- **Cu, Fe wires in container cap**

- **12 spectrometric sets in stainless steel capsules per container**

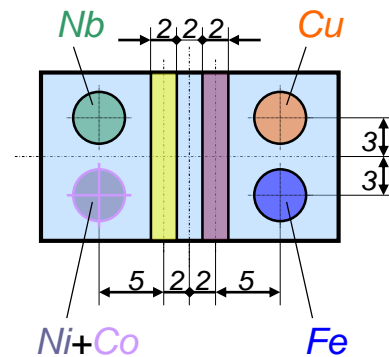
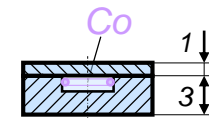
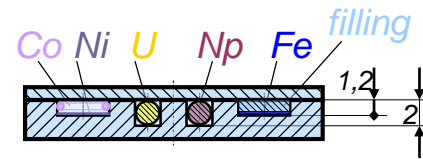
- 8 large spectrometric sets
- 4 small spectrometric sets

- **Large spectrometric set**

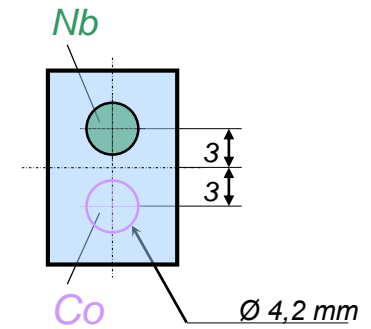
- Consists of Co, Cu, Fe, Nb, Ni detectors; metal discs $\varnothing 4 \times 0,1\text{mm}$
- Large sets in bottom part of container contain fission detectors NpO_2 , UO_2

- **Small spectrometric set**

- Consists of Co, Nb detectors ; metal discs $\varnothing 4 \times 0,1\text{mm}$



Large spectrometric set

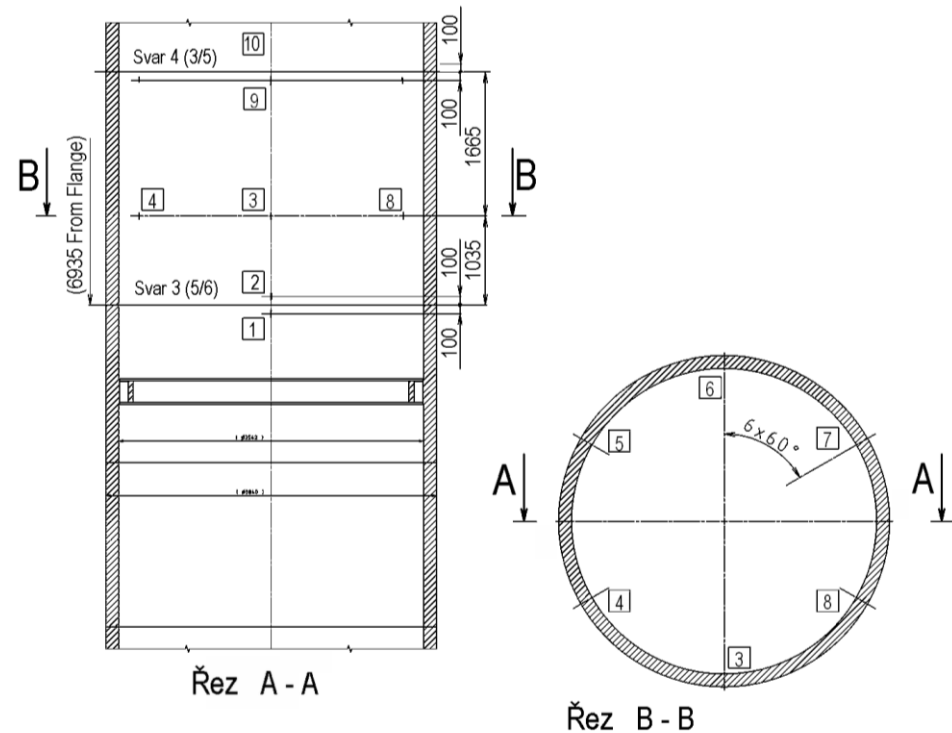
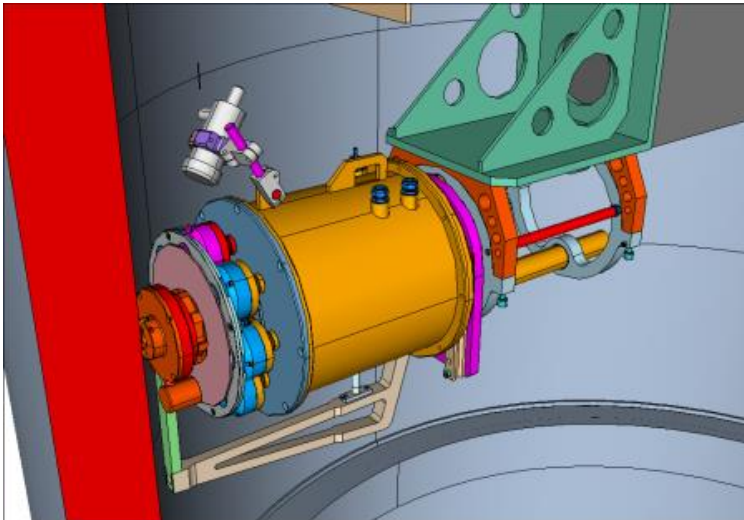


Small spectrometric set

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 INTERNALS – 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)

Ageing 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

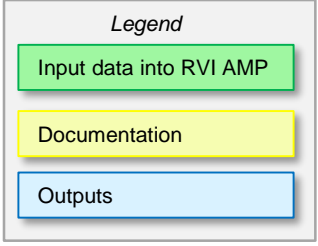
Operating findings evaluation
1. Regulation (and others) infringement
2. Unexpected incidents

Vibration measurements
1. Accelerometer data measurement
2. Evaluation frequency changes of skeleton 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

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

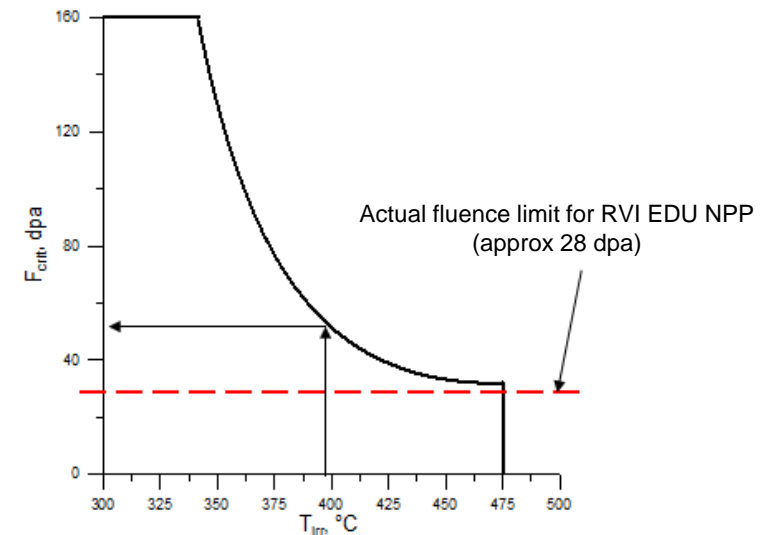
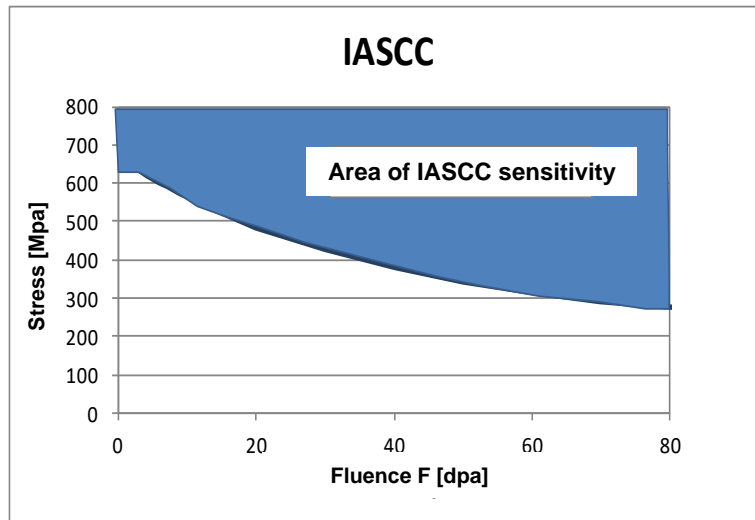


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■ Lifetime Assessment of RVI Report

- 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 ?

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