Temperature and radiation effect on the RPV concrete cavity.

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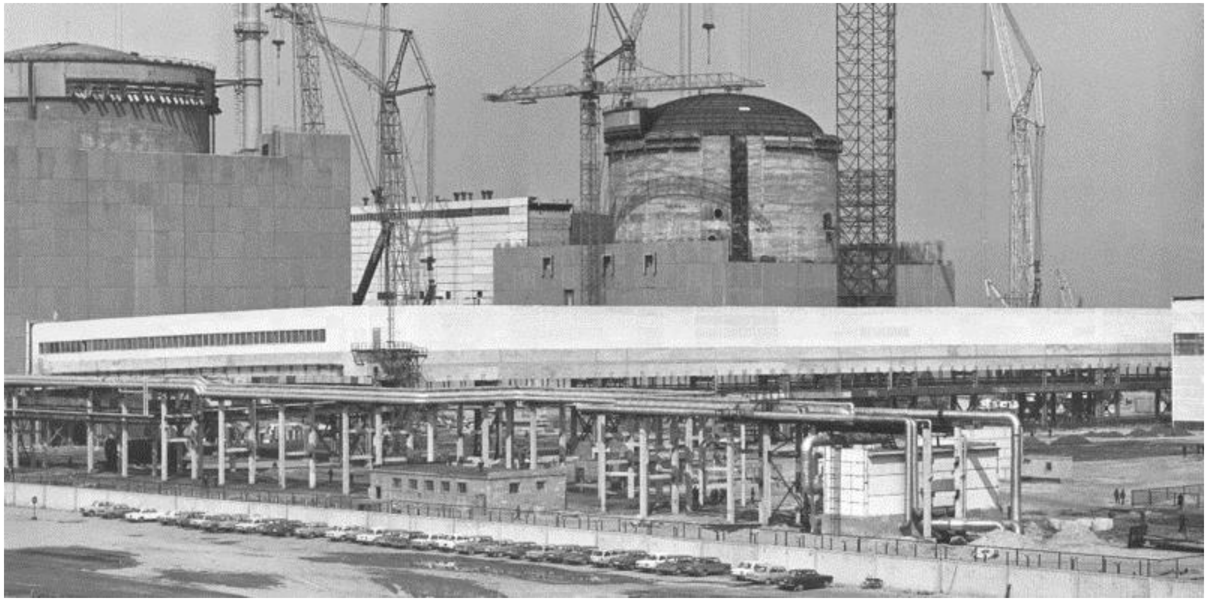
VVER 2013 Conference

NPP containment ageing

- More than 10 concrete degradation mechanism with influence on containment building
- RPV concrete cavity exposed to temperature and radiation loading is one of most critical damage mechanism
- No effective validated inspection procedure proposed for RPV cavity until now!



RPV cavity damage mechanisms

- Neutron and gamma rays irradiation has effect on concrete
- Changes of the concrete properties depend primarily on aggregates behaviour
- Irradiation exposure can induce volume change of aggregates
- Heat generated from radiation absorption (attenuation) in concrete may have detrimental effect on physical, mechanical and nuclear properties of the concrete

Influence of irradiation on mechanical properties

Long term exposure to radiation and thermal loading can result in degradation of mechanical properties of RPV concrete

- Neutron radiation more than 10^{19} n/cm ^{2} or 10^{10} rads (more than 40 years of operation) of dose for gamma radiation in some cases decreases tensile strengths, compressive strengths and modulus of elasticity and causes marked increase in volume
- High irradiation generates growth of calcite crystals, which decreases both size of pores and the strength of the concrete
- Radiation induced temperature has minor influence on changes of concrete properties

Damage mechanisms in NPPs

- **Following table shows ranking of importance for specified concrete damage mechanisms**
- **Identification of research gaps in three principle areas:**
  - Materials
  - Inspection
  - Prediction

Issue	Ranking	Research Gap Analysis		
		Materials	Inspection	Prediction

Ranking and gap analysis of damage mechanisms

Issue	Ranking	Research Gap Analysis		
		Mate-rials	Inspe-ction	Predi-ction
Chloride diffusion into concrete	High		X	X
Boric acid effects on concrete	High	X	O	X
Corrosion of reinforcing steel embedded in concrete	High		X	X
Radiation damage of reactor cavity concrete	High	X	?	?
Containment liner corrosion-accessible and inaccessible areas	High		X	
Post-tensioning tendon relaxation	High		X	
Leaching of the containment liner	High			X
Bulging of the containment liner	High			X
Freeze-thaw damage	High	X	X	X
Spent fuel pool liner stress corrosion cracking (welds)	High		X	X
Pre- and post-tensioning tendon corrosion/stress corrosion cracking	High		X	X
Concrete carbonation and effects on steel reinforcement	Medium		X	
Swelling due to alkali-aggregate reaction or delayed ettringite formation	Medium	X	X	X
Concrete creep, microcracking	Medium	X	X	X
Concrete dissolution effects on spent fuel pool liners	Medium		X	X
Boric acid attack of steel reinforcement	Medium	X	?	?
Water treatment chemical attack of concrete	Medium	X	?	?
Aggressive groundwater/External sulfate attack	Low		X	X
Thermal cycling/cooling towers (operational temperatures)	Low			X
Containment pressurization/depressurization (integrated leak rate test)	Low		X	X
Hydrogen embrittlement of post-tensioning tendons	Low		O	X
Thermal fatigue at penetrations	Low	X		X
Differential settlement of structures	Low			X
Spent fuel pool channel corrosion	Low		X	

Ranking and gap analysis of damage mechanisms

- radiation damage of reactor cavity concrete -

Issue	Ranking	Research Gap Analysis		
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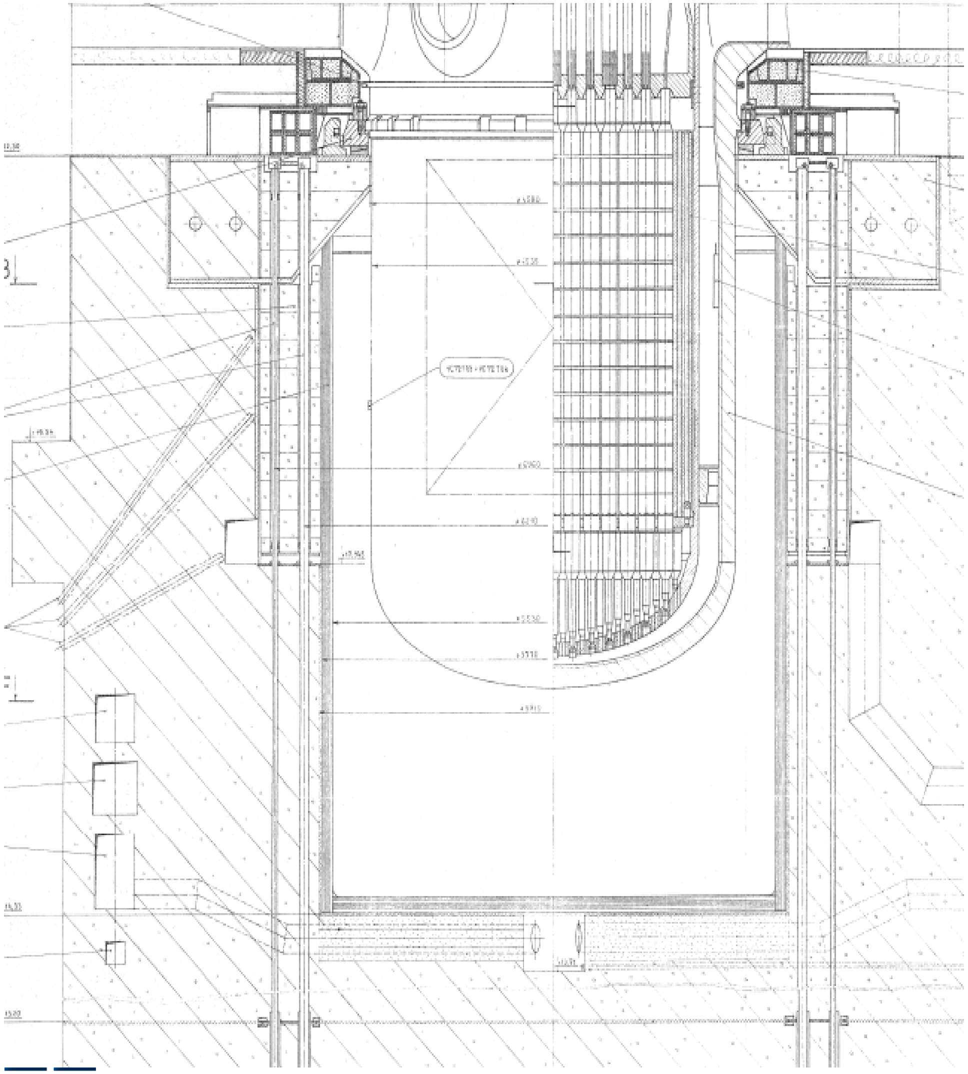
Chloride diffusion into concrete	High		X	X
Boric acid effects on concrete	High	X	O	X
Corrosion of reinforcing steel embedded in concrete	High		X	X
Radiation damage of reactor cavity concrete	High	X	?	?
Containment liner corrosion-accessible and inaccessible areas	High		X	
Post-tensioning	High		X	

- High ranking of damage mechanism
- Inspection and Prediction identified with question marks!

Design of VVER 1000/320 RPV cavity



- steel frame embedded in heavy concrete construction transfers weight of RPV to the cavity
- serpentine concrete segments, opposite to active core,serve as a biological shield
- ferrite steel cladding (11 mm thickness) on outer surface of biological shield
- structural concrete in the lower part of cavity
- ionization channels around cavity circumference formed by embedded steel pipes

Experimental Irradiation Project Proposal

- Irradiation damage simulation of RPV cavity concrete after long term operation of NPPs
- Cylindrical samples (50 x 100 mm) of NPP Temelín type RPV cavity concrete – ferro-serpentine concrete
- Irradiation of samples above neutron fluence 10^{19} n/cm^2
- Post irradiation examination of samples focused on changes of mechanical and microstructural properties
- NDE inspection technique testing on model segment of outer part of reactor cavity with ionization channels

Irradiation experiment

ÚJV

in cooperation with:

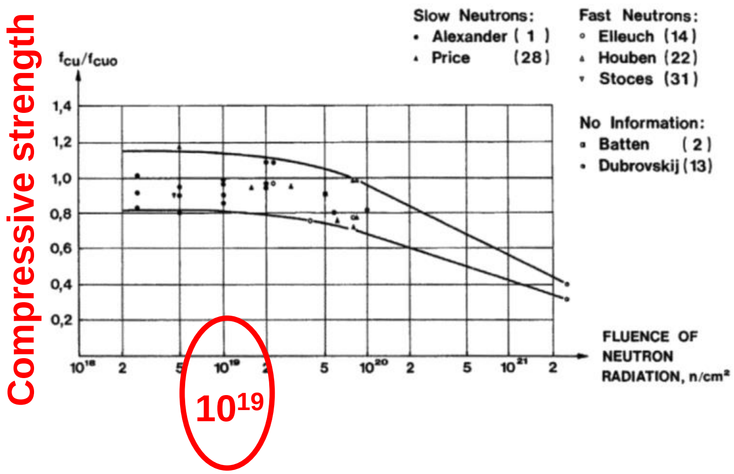
Centrum výzkumu Řež s.r.o.

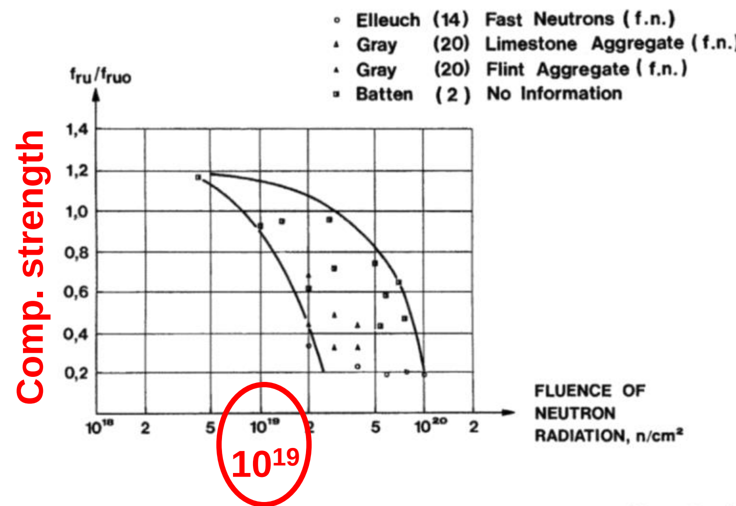
Research Centre Rez

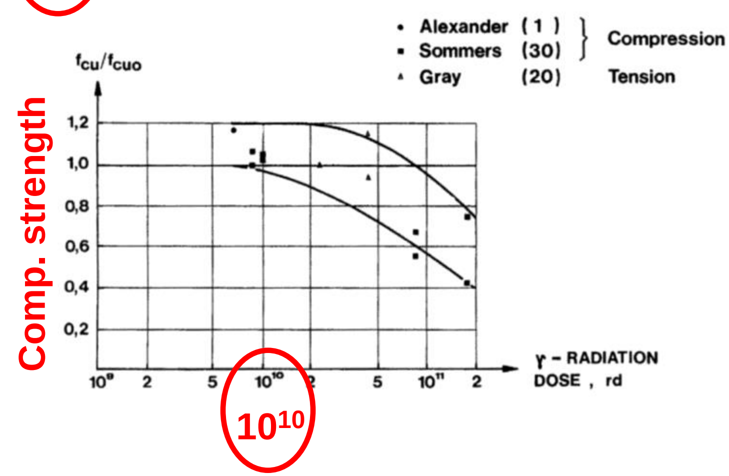
Člen skupiny ÚJV

Reasons for post irradiation testing

- Decisive mechanical parameters (strength and stiffness) of concrete decrease under exposure to neutron and gamma radiation.







- Only collection of incompatible experimental data is available. (by Hilsdorf)
- Systematic data for real structural materials is needed. (e.g. on cylindrical 50x100 mm specimens)

Irradiation experiment description

- Irradiation of concrete specimens in vertical channels of light water research reactor LVR-15
- Specimens in special aluminium capsules
- Thermocouples controlled temperature, temperature maintenance by passive systems
- Neutron monitors for neutron flux and fluence determination
- Monitoring of gas released from concrete sample during irradiation experiment

Post irradiation examinations

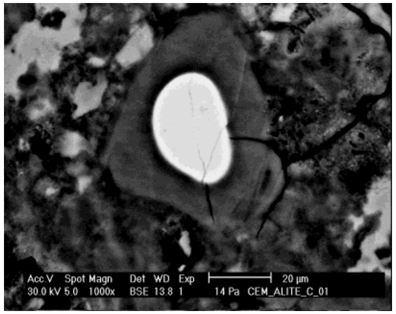
in cooperation with:

team: **P. Štemberk et al**.

CTU Prague

Post Irradiation Evaluation (PIE)

- Optical Polarization Microscopy
- Scanning Electron Microscopy and Microanalysis
- Nano Hardness Testing – Micromechanics
- Thermogravimetry and Differential Thermal Analysis



Optical polarization microscopy

ZEISS Axio Imager

Optical polarization microscopy

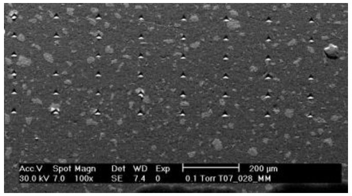
- **Detection of alteration processes in primary C-S-G gels (loss of bound water). Interpretation of alteration processes in concrete on micro-level**
- **Changes in structures on micro-level; i.e. occurrence of newly-formed shrinkage in consequence of mineral transformations and flux heat**
- **Occurrence of newly-formed mineral phases as a products of alteration processes**

Scanning electron microscopy and microanalysis

- EDX – elementary microanalysis & simultaneous element mapping
- WDS microprobe for precise elementary analysis
- BSED – phase and chemical contrast
- EBSD / OIM – electron diffraction & preferential orientation analyses of mineral aggregates
- Resolution 0.8 nm @ 15 kV
- Probe current 10 pA – 300 nA: both for sensitive materials & analysis

Nano hardness testing - micromechanics

- Detection of changes in microstructure from initial stages
- Decomposition of C-S-H gels on sub-micro level in elementar clusters
- Phase mineral alterations in all spectra of intensities
- Indication of newly-formed phases in consequence of exposure to radiation energy and heat flux
- Detection and measurement of changes in mechanical properties of exposed material on micro-level
- Interpretation of changes of mechanical properties on micro-level



Thermogravimetry and differential thermal analysis

- Identification and quantification of changes of phases in dependence on continual heat flux into the sample.

- The technique is based on the fact that when substance is heated, it undergoes reactions and phase changes that involve absorption or emission of heat. In DTA, the temperature of the test material is measured relative to that of an adjacent inert material.

- DTA can clearly identify the phase changes of material in original (intact) state, that is phase transformation in concrete due to irradiation.

NDE technique development and testing

in cooperation with:

Pavel Kudrna, Zdenek Prevorovsky, Milan Chlada, Josef Krofta, Jan Kober

Non-linear Elastic Wave Spectroscopy - NEWS

- **Methods selected for preliminary testing:**
  - Non-Linear Wave Modulation Spectroscopy - NWMS
  - Non-Linear Time reversal Method - NLTRM
  - Scaling Substraction Method - SSM

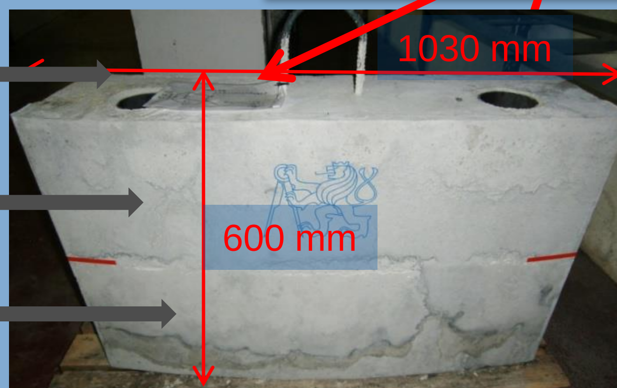
Original Biological Shielding Specimen and Specific Concrete Model Blocks

Part of the reactor biological shielding from NPP Greifswald

Facing steel plate 10 mm

Serpentine concrete

Ferro-serpentine concrete



- 2 model blocks
- 3 concrete compositions

Structural concrete

Facing steel plate 10 mm

Neutron flux measuring Channels

Steel tubes (Ionization Channels - IC)

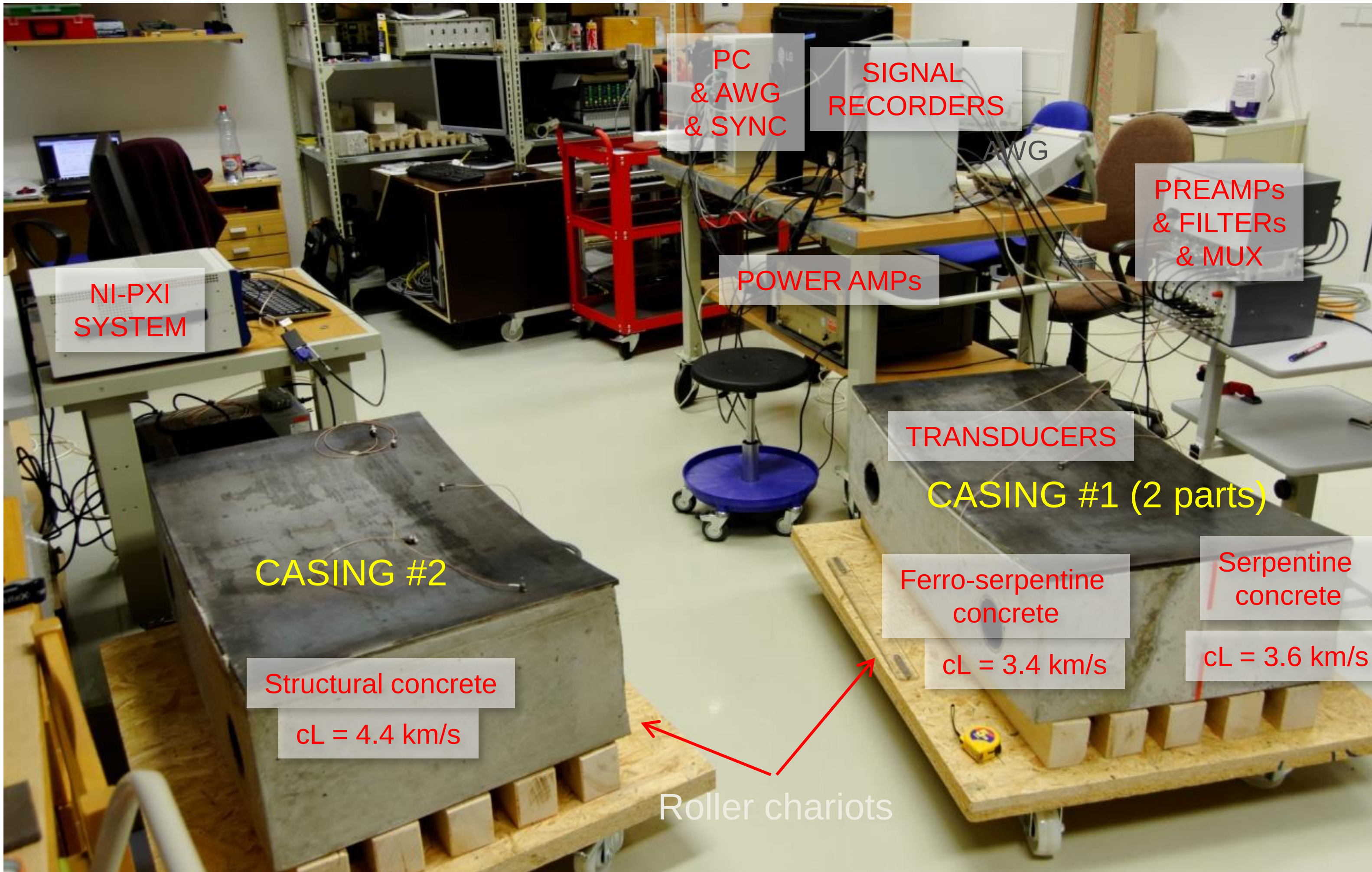
Two new manufactured model test blocks for NEWS methods testing – concrete composition

Ferro-serpentine concrete	kg/m3
Cement I 42,5	435
Drink water	241
Crushed aggregate (Bernatice quarry)	
0-2 mm	361
2-5 mm	136
4-8 mm	127
8-11 mm	42
11-16 mm	118
Glassfrit	280
Cast-iron L22	2118
Plasticizing admixture Stacheplast	2,26

Serpentine concrete	kg/m3
Cement I 42,5	499
Drink water	190
Crushed aggregate (Bernatice quarry)	
0-4 mm	690
8-16 mm	459
16-22 mm	527
Plasticizing admixture Stacheplast	4,1

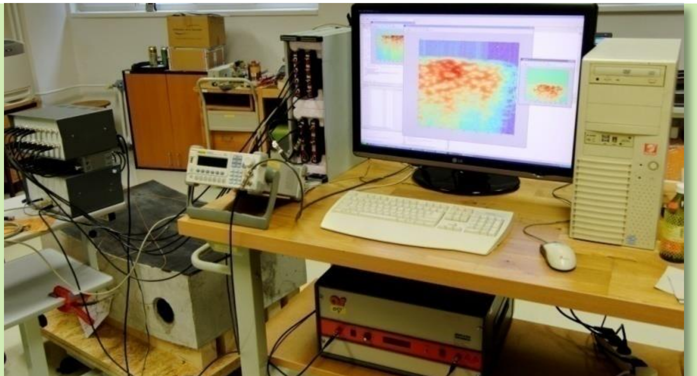
Structural concrete	kg/m3
Cement I 42,5	499
Drink water	190
Crushed aggregate (Dobkovičky quarry)	
0-4 mm	800
8-16 mm	100
16-22 mm	776
Plasticizing admixture Stacheplast	4,1

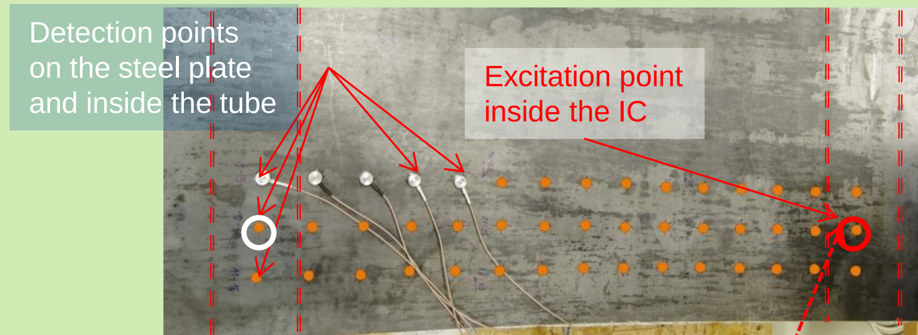
NEWS Equipment



c_L ... measured longitudinal wave celerity in the concrete

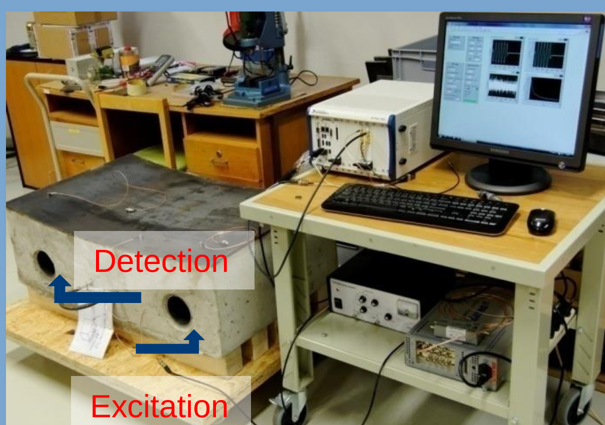
Wave propagation testing





LF PROBE FITTING INSIDE THE IC

NEWS Testing (SSM)



Non-linear Elastic Wave Spectroscopy – NEWS Method overview

- NRAS / NRUS (Nonlinear Resonant Acoustic / Ultrasonic Spectroscopy)
- SIMONRUS (Single-Mode NRUS)

❑ **NWMS (Non-linear Wave Modulation Spectroscopy)**

- SD (Slow Dynamics)
- NDIS (Nonlinear DISsipation / attenuation)
- Travelling Waves (Nonlinear ultrasonic wave transmission)

❑ **NLTRA (Nonlinear Time Reversal Acoustics)**

❑ **SSM (Scale Subtraction Method)**

Non-linear Elastic Wave Spectroscopy - NEWS

Three main classes of phenonema associated to the non-linear elastic elements in the test-blocks are:

- Amplitude dependence of the elastic constants and, consequently, of the wave speed which causes changes in the phases of the recorded signal
- Non-linear attenuation mechanisms, which influence the amplitude of the recorded signal
- Non-linear coupling in the wave equation, which allows the generation of higher-order harmonics, sidebands, or sub-harmonics

Advantages & Limitations of NEWS techniques:

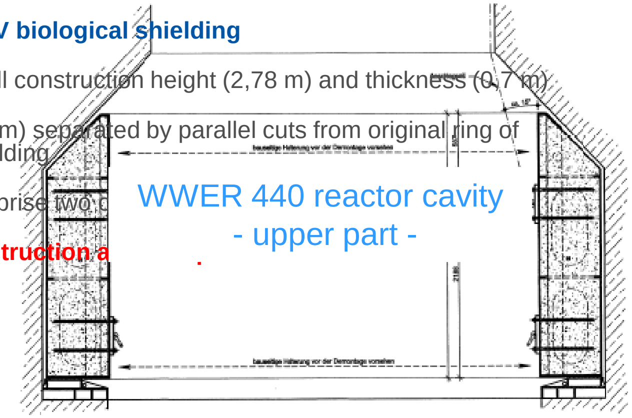
- Versatile tools for SHM
- High sensitive detection of defects and damaged zones
- Up to 1000x more sensitive than linear ultrasonic methods
- Detection of defects smaller than wavelength
- Distinguishing defects from pseudo-defects (e.g. structural notches)
- NDT/NDE at hidden places in complex structures
- Remote defect sensing relatively far from installed ultrasonic probes
- Material penetration depth (~ 0,01 - 1) m
- Low-amplitude interrogation of tested parts (e @ 10-9 - 10-4)

- Procedures are mostly global, and mostly reflect only presence
- of defects without their precise location solution is e.g. multiplexing of transmitting / receiving channels using dependency of nonlinearity on the wave paths ("pseudo-tomography")
- Size of defects cannot be easily determined

Future comparative works on unique segment of biological shielding from decommissioned NPP

- **NPP Greifswald Unit 5 (Germany) – trial run stopped in 1990**
- **WWER 440 type reactor – PWR of Russian construction**
- **UJV Rez in 2012 purchased a block of biological shielding as a surveillance material for complex testing**
- **Segment of steel lined serpentine concrete**
- **Documenta… story, recipe of c…**

- **Segment 1 of RPV biological shielding**
  - Represents full construction height (2,78 m) and thickness (0,7 m)
  - In width (1,62 m) separated by parallel cuts from original ring of biological shielding
  - Segment comprise two c…
  - **Original construction a…**



Segment No.	mass [kg]	max. dose rate 0.1 m distance [mSv/h]	max. dose rate 1 m distance [mSv/h]	contamination α [Bq/cm²]	contamination β/γ [Bq/cm²]	mass specific activity [Bq/g]
1	7250	6.500E-01	1.200E-01	<4.000E-02	7.000E-01	1.720E+03

Conclusions

- Irradiation Mock Up experiments are well prepared
- PIE (Post Irradiation Evaluation) is available, detail set up is under evaluation
- UT NDE on mock up samples was performed with use of three NEWS methods(NWMS,SSM and TR-ESAM). This area of work is in start up phase.

Thank you for your attention

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