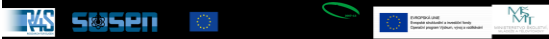



Non-destructive Testing of Mechanical Properties of NPP Biological Shielding Concrete

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Research Centre Rez
June 2019



Agenda



1. Basic information about Research Centre Rez
2. Background
3. Objective of R&D projects for NDT of irradiated concrete
4. Existing R&D projects
5. Upcoming R&D projects
6. Conclusions



1. Basic information about Research Centre Rez



- Research organization founded on October 9, 2002 as a 100% subsidiary of Nuclear Research Institute Rez (ÚJV Řež, a.s.)
- Significant research and experimental infrastructure including LVR-15 and LR-0 research reactors and technological experimental loops
- Research, development and innovation in the field of power engineering, especially nuclear, primarily pre-commercial research for the Nuclear Research Institute Rez
- Since 2012 - the SUSEN project under the Operational Program Research and Development for Innovation of the European Regional Development Fund - significant development of infrastructure and the whole company (> 95 million EUR)
- Involvement in the Jules Horowitz Reactor research reactor construction project
- 400 employees, out of which 325 are for main employment



1. Basic information about Research Centre Rez



Where to find us:



The area of the Science and Technology Park
Morseova 1244/4, Plzeň

The area of NRI Group:
Hlavní 130
250 68 Husinec-Řež



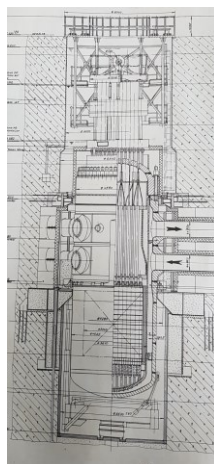
2. Background

Concrete structures exposed to neutron radiation may exhibit cracking and deterioration, therefore it is needed to find appropriate non-destructive testing methods for assessing their structural integrity. The nonlinear spectroscopy of elastic waves (NEWS) was chosen and developed for non-destructive crack detection in concrete.

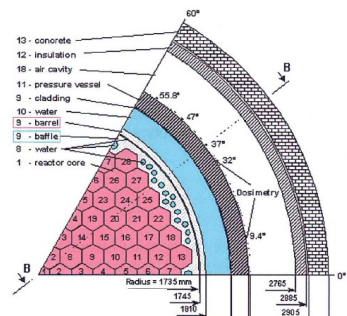
In order to test the biological shielding concrete of NPPs with the VVER 440 reactors a mechanical manipulator was developed. Results from testing the manipulator on the concrete block from NPP Greifswald (Germany) are presented. Further, the results of the conventional non-destructive and destructive testing methods are compared to the results obtained by NEWS.



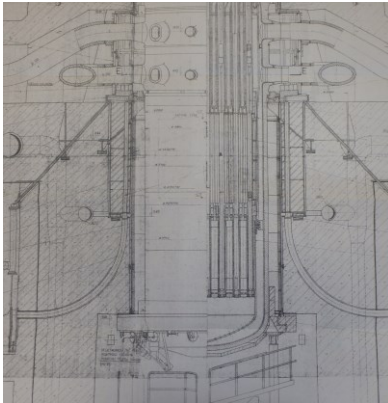
2. Background – Temelin NPP, VVER 1000 reactor



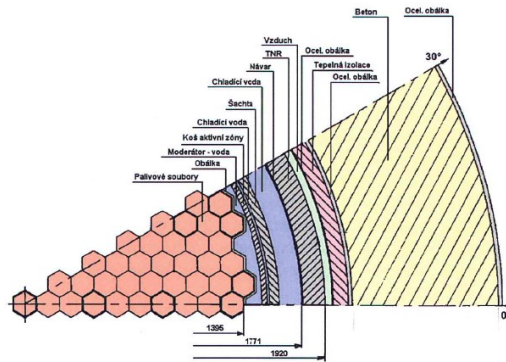
Concrete distance from core center: 2905 mm



2. Background – Dukovany NPP, VVER 440 reactor



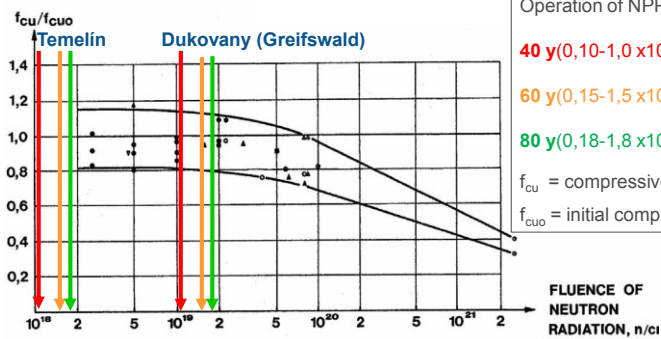
Concrete distance from
core center: 2370 mm



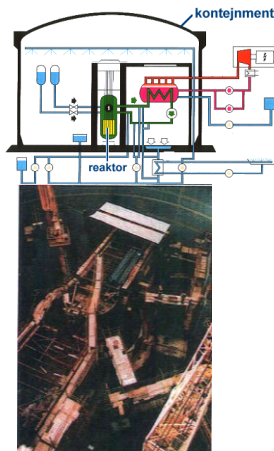
2. Background – influence of neutron radiation



Forecast of Czech NPPs after 40, 60 or 80 years



2. Background – influence of neutron radiation



Forecast – cont.

In case of assessment based on available documentation, it is possible to state in terms of irradiated concrete:

- Both units 1 and 2 of Temelín NPP will sustain much longer than 60 or 80 years.
- All 4 units of Dukovany NPP may reach design values for concrete properties after 40 year operation.



3. Objective of R&D projects for NDT of irradiated concrete

Two goals:

1. Development of **NDT for crack detection** in irradiated concrete of VVER type reactors
2. Development of **NDT for Quantification of irradiated concrete damage**

1) Methods

- Techniques of nonlinear elastic waves (NEWS) method:
 - NWMS (two-frequency mixing technique)
 - NRUS (resonance-based technique)
- Neutron noise

2) Damage parameters

- Parameters of NEWS or neutron noise depending on the modulus of concrete elasticity, which characterizes the amount and size of irradiated concrete cracks



3. Objective of R&D projects for NDT of irradiated concrete



Principles of NEWS method - NWMS technique (nonlinear wave modulation spectroscopy)

The dynamic elastic behavior of most solid materials cannot be described by a linear theory. As a first approach, the one-dimensional constitutive relation between the stress σ and the strain ϵ can be expressed by equation:

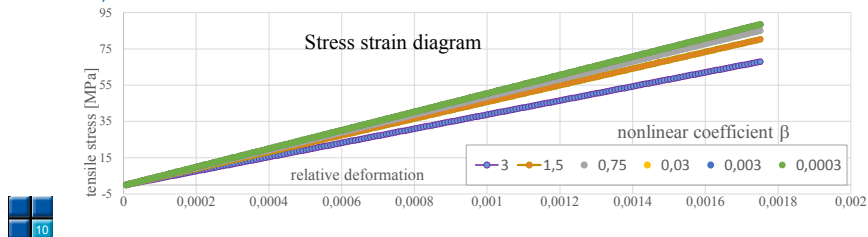
$$\sigma = \int K_0 (1 - \beta \epsilon) d\epsilon$$

where K_0 is the linear modulus of elasticity and β is the first order nonlinearity coefficient

(see Stress Strain diagram below for $K_0 = 39\,000$ MPa and for $\beta \leq 3.0$)



Figure - Position of transducers on test specimen



3. Objective of R&D projects for NDT of irradiated concrete



Principles of NEWS method - NWMS technique (nonlinear wave modulation spectroscopy) – cont.

Two signals of different frequencies f_1 and f_2 of amplitudes A_1 and A_2 , respectively, are mixed together in investigated concrete sample in order to obtain their intermodulation, i.e. the sum frequency $f_{12} = f_1 + f_2$ of amplitude A_{12} .

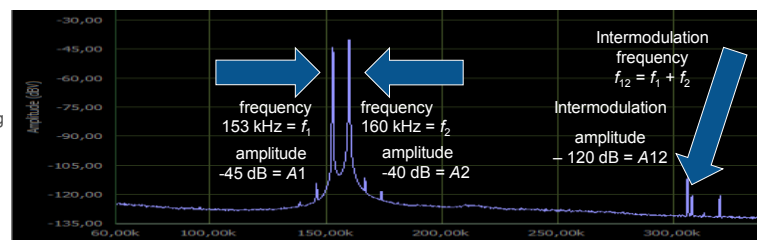
Non-linear coefficient beta is expressed as:

$$\beta = \frac{A_{12}}{A_1 + A_2} \quad (= 10^{((-120 + 45 + 40)/20)} = 10^{(-35/20)} = 0.0178 \text{ V}^{-1} \text{ – calculation for the example shown in the figure below})$$

where: A_1 and A_2 are amplitudes of mixed signals,

A_{12} is amplitude of their intermodulation frequency $f_{12} = f_1 + f_2$.

Figure demonstrating the principle of the NWMS method



3. Objective of R&D projects for NDT of irradiated concrete

Principles of NEWS method - NRUS technique (nonlinear resonant ultrasound spectroscopy)

The resonance method examines the change in the resonance frequency of the controlled concrete depending on the amplitude of the excitation. In this type of cracked concrete sample testing, the non-linear behavior is manifested by a decrease in the resonant frequency with increasing amplitude of the excitation (i.e. a resonance frequency shift occurs):

$$\Delta f_r = f_{r,max} - f_{r,min} \text{ [Hz]}$$

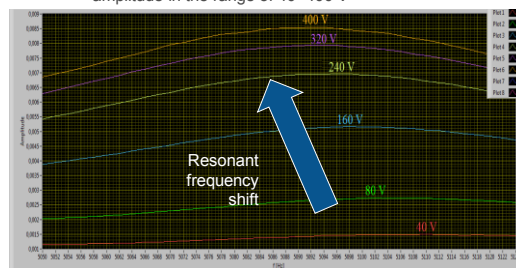
where:

Δf_r ... resonance frequency shift [Hz],

$f_{r,max}$... resonant frequency at low excitation amplitude [Hz],

$f_{r,min}$... resonant frequency at high excitation amplitude [Hz].

Figure - Resonance frequency changes observed during the experiment, when the resonance frequency shift was measured at 5–20 kHz by increasing the excitation signal amplitude in the range of 40–400 V



4. Existing R&D projects

1. MVČR (Ministry of Interior of the Czech Republic) - Security Research Program of the Czech Republic
 - Project of Concrete Biological Shielding Inspection (NWMS Technique)
2. IPNOP (The IPNOP projects are intended to promote, explore feasibility and/or realize new concepts that are of relevance to Research Centre Rez but difficult to be financed and implemented by means of external grants. The aim is to prepare ideas for the next step which should be either implementation of a solution or building a strong position for future calls for tenders, both public and private).
 - Project of Concrete Crack Monitoring via neutron noise
3. Patent
 - manipulator for measurement of concrete properties by NEWS method in ionization channels

Project completion dates:

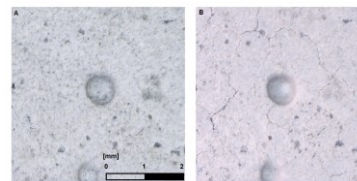
MVČR: 04/2019

IPNOP: 06/2019

Patent: 12/2018

Figure – Changes of the sample:

- surface before heating (A)
- surface after heating in the furnace and cooling to the room temperature (B)



4. Existing R&D projects – outputs from MVČR project

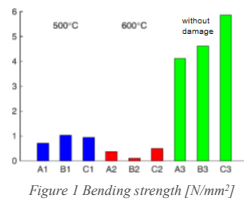


Figure 1 Bending strength [N/mm²]

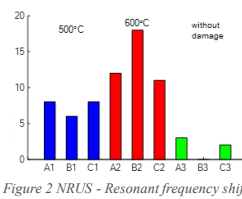


Figure 2 NRUS - Resonant frequency shift [Hz]

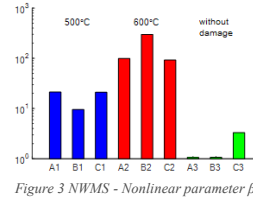


Figure 3 NWMS - Nonlinear parameter β change [-]

Destructive and non-destructive methods were applied to concrete samples that were subjected to thermal stress at 500° C and 600° C in order to break the concrete structure.

The NRUS method correlates with the measured strength values by an indirect ratio and appears to be a less sensitive indicator of the change in concrete structure than the NWMS method. The advantage of this method is that at a low degree of damage it shows a zero change in resonance frequency and therefore there is no need for comparative measurement to demonstrate the change in structure.

The NWMS nonlinear beta parameter shows an exponential dependence on tensile strength. It is very sensitive to the first material defects at lower firing temperatures, while a slower increase occurs at subsequent higher firing temperatures.



4. Existing R&D projects – outputs from MVČR project



Patent - Remote controlled manipulator was developed in order to enable:

- to move up and down along the ionization channel near core
- turn around its axis in the most deteriorated area
- put the probes onto the steel liner in the ionization channel.
- avoid the contamination of the operators of the NEWS measurement

Figure – Scheme of VVER 440 RPV with ionization channel

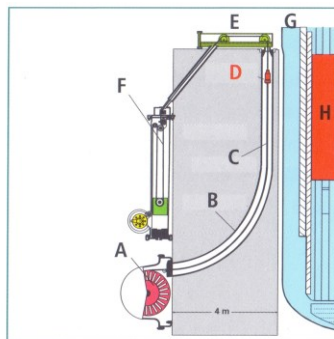


Figure – Manipulator development



4. Existing R&D projects – measurement on concrete block from Greifswald NPP



Figures - Manipulator assembly



4. Existing R&D projects – measurement on concrete block from Greifswald NPP



Figures - Measurement realization



5. Upcoming R&D projects



1. MVČR II – Verification of concrete properties of NPP biological shielding after neutron irradiation – already approved by MVČR
2. Public project - R&D of diagnostic system for measuring damaged concrete, methods: NWMS + NRUS + LRUS (= linear resonance method) Project – under preparation
3. Recherche of criteria for critical values of strength of biological shielding concrete

Duration:

- MVČR II: 2019-2022
- Public project: 2021-2023



6. Conclusions



The long-term objectives (2015 – 2023) of Research Centre Rez, by which all R&D projects in the field of irradiated concrete will be concluded, are:

- Prototype of diagnostic equipment for measurement of irradiated concrete of biological shielding for NPP (for example for Dukovany NPP)
- Verified procedure for inspection of irradiated concrete of biological shielding via techniques of NEWS method



Thank you for your attention

<http://cvrez.cz/>

