Institute of Fundamental Technological Research
Polish Academy of Sciences

Microstructure and physical properties of shielding concrete after long term operation of Polish research reactor

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Outline

- Purpose of the research
- Historical view
- Containment coring procedure
- Physical properties: strength and permeability
- Mineral composition and phase composition
- Microstructure: damage of aggregate
- Concluding remarks

Purpose of the research

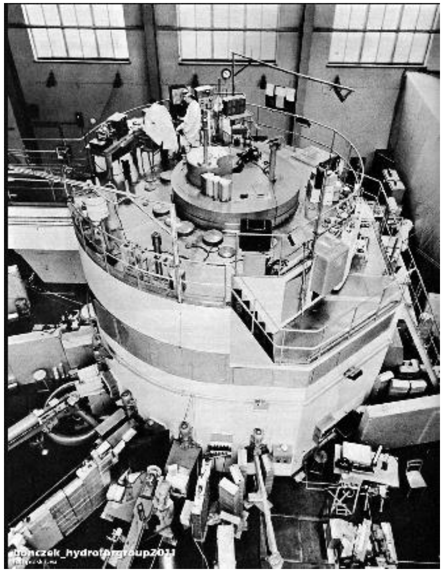
The aim of the study was to identify the present condition of concrete shielding wall after 37 years of EWA experimental reactor operation.

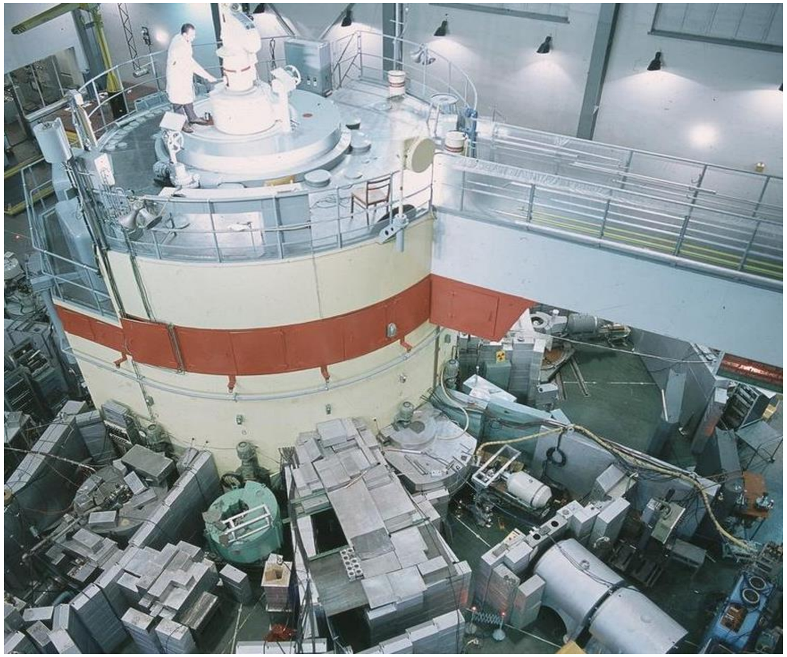
Important:

The original concrete mix design is unknown so no direct comparison of material properties is possible.

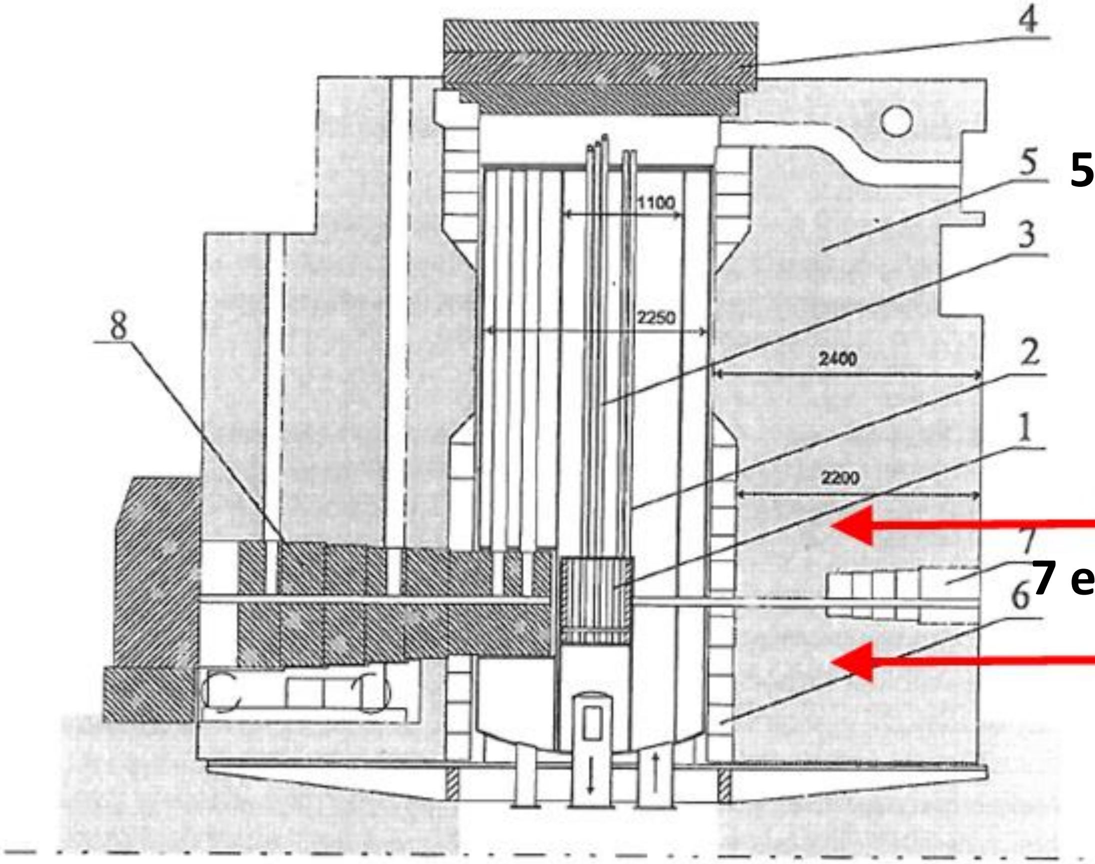
Historical view

- EWA (**E**xperimental-**W**ater-**A**tomic) is located at National Centre for Nuclear Research in Poland
- Research reactor Experimental Water Atomic type, „made in" the USSR
- Thermal power 10 MWt, neutron fluence reached 10^{14} n/cm^{2}s
- Time operation of the reactor: June 1958 – February 1995 (37 years)
- Fuel has been removed until 2002





Containment coring procedure



5 concrete shield (220 ÷ 240 cm)

Location of drilling

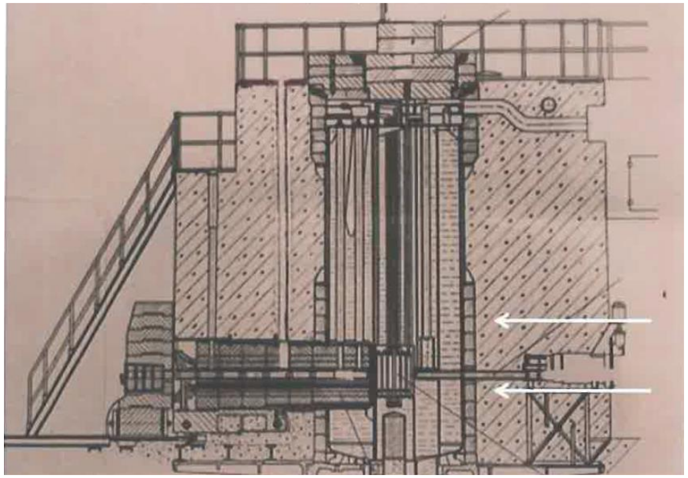
7 experimental horizontal channel

Location of drilling

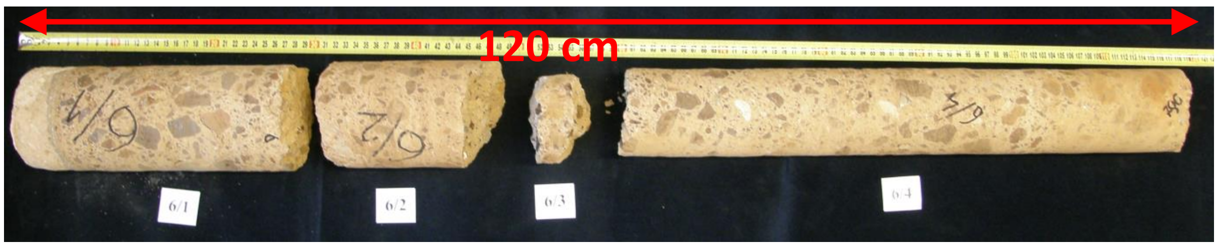
Cores dia.100mm were taken from the containment wall

Containment coring procedure




Containment coring procedure



Examples of the cores and material taken from the reactor concrete shield

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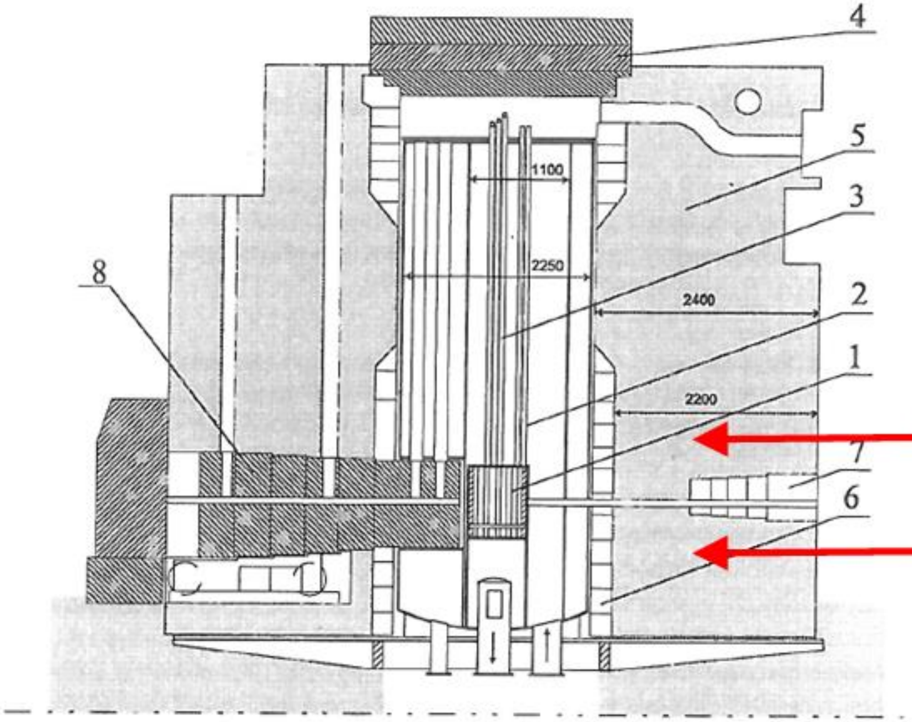
Compressive strength and density

Diameter 100 mm

Height 100 mm

Density 2470 ÷ 3080 kg/m^3

Compressive strength 28.3 ÷ 30.6 MPa



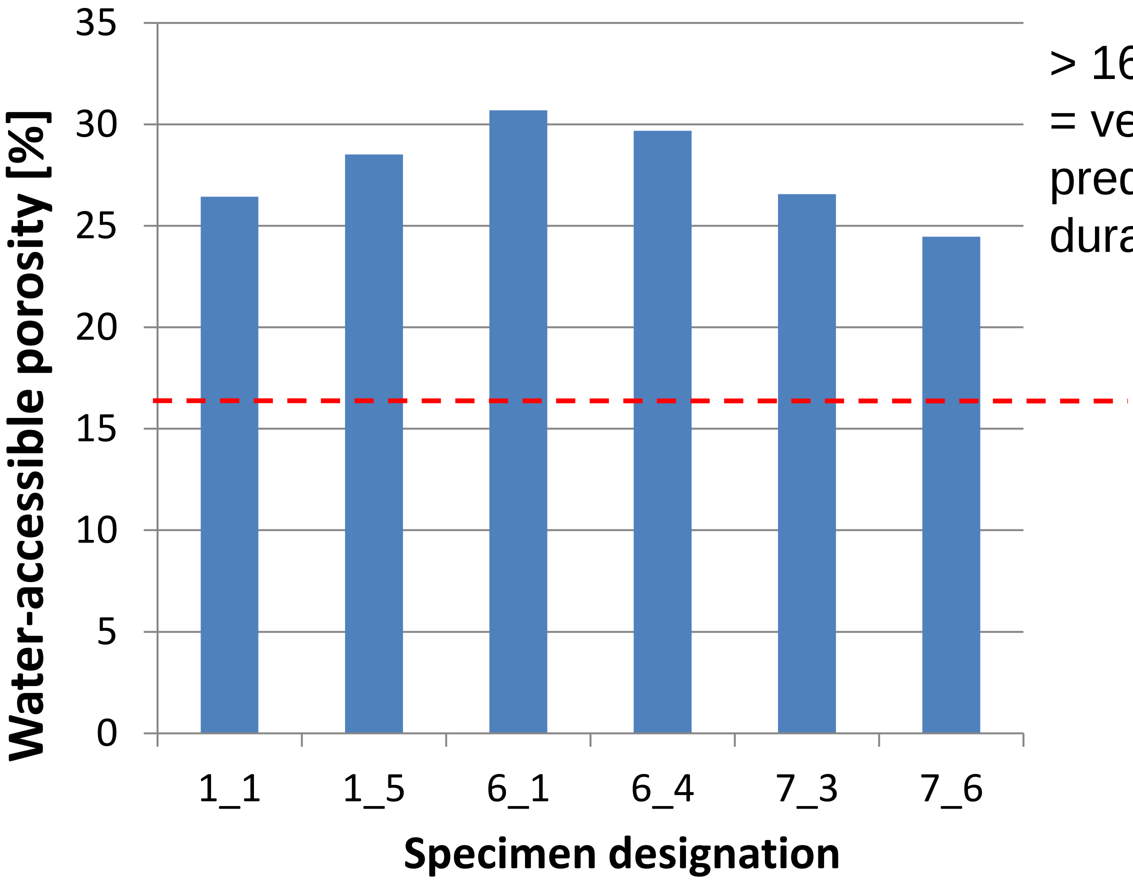
From the archives:
design density 3700 kg/m^3

density 2500 kg/m^3;
f_c= 30.6 MPa (27.6 ÷ 32.7 MPa)

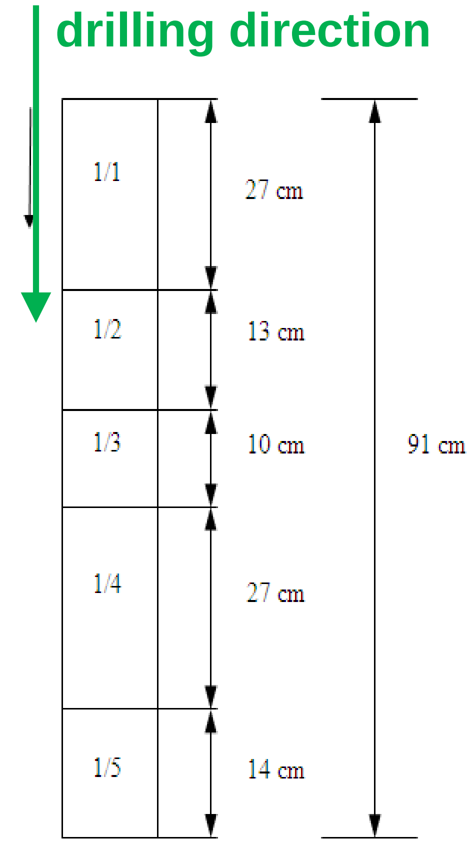
density 3100 kg/m^3;
f_c= 28.3 MPa (27.3 ÷ 29.2 MPa)

Concrete permeability: open porosity

NF P18-459



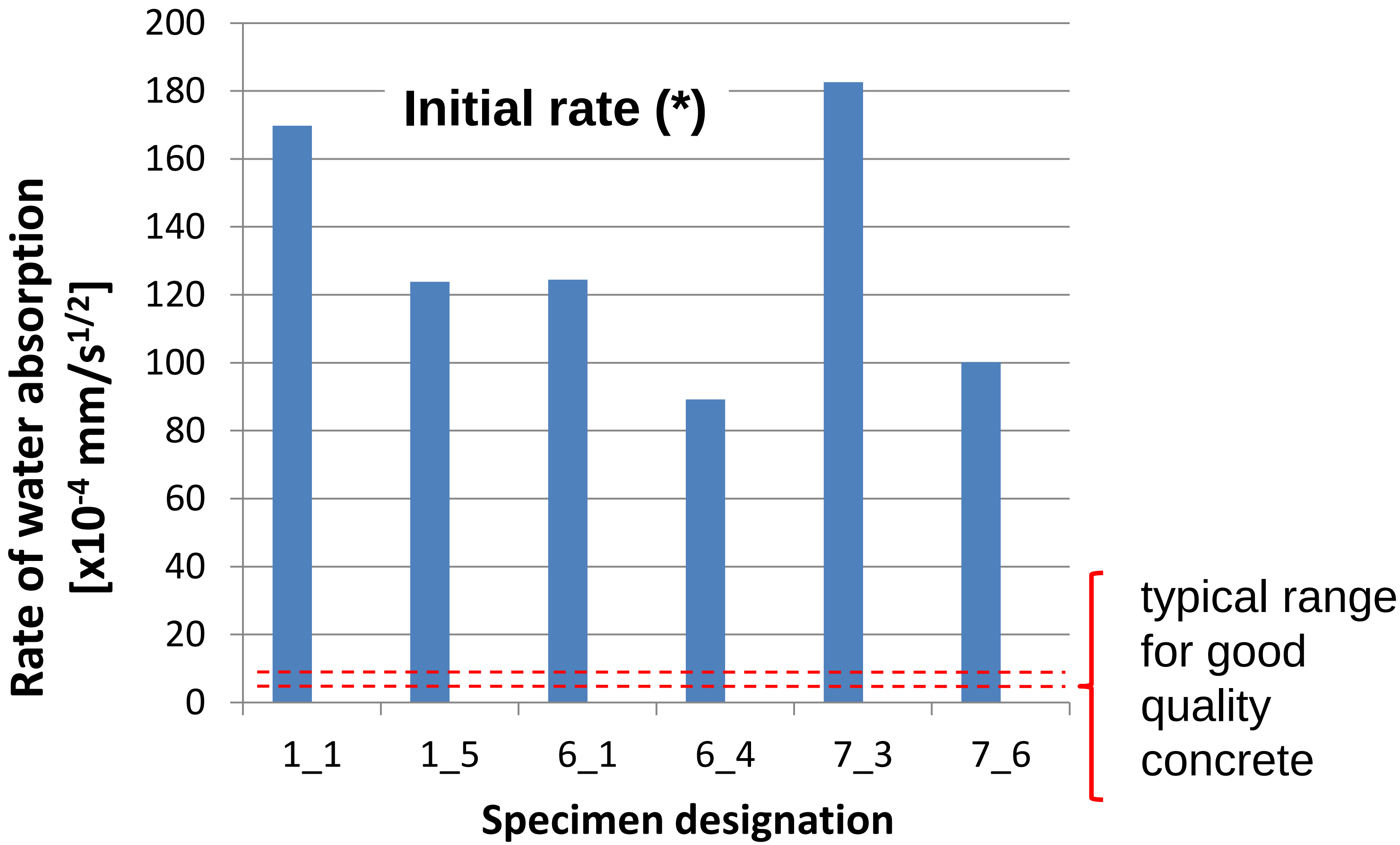
> 16%
= very low predicted durability



After Baroghel-Bouny (2006) &IFFSTAR 2010:
above 16% = very low durability, ..., from 6 to 9% = very high durability

Concrete permeability: rate of absorption

ASTM C1585



(*) the secondary absorption rate not determined

Mineral aggregate characterization

Macroscopic analysis

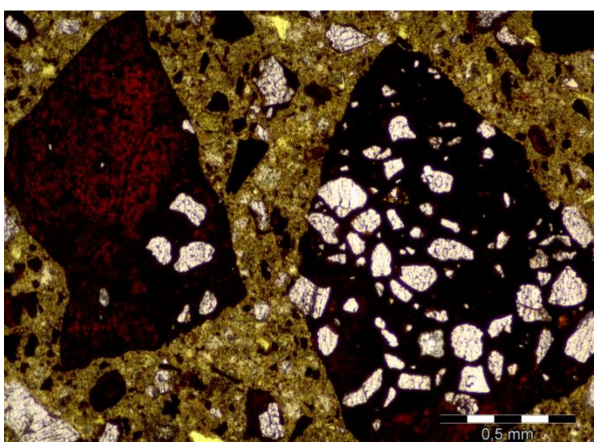
Coarse aggregate:

- iron ore – limonite
- max. grain size 29 mm
- content 26-34 %

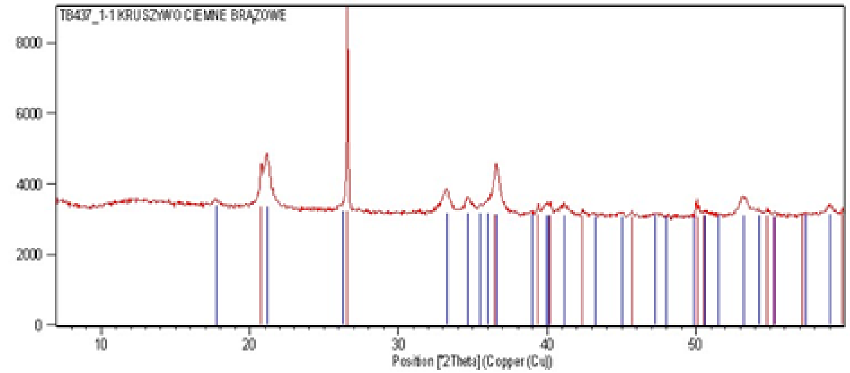
Fine aggregate:

- iron ore – limonite
- silicious sand 0-2 mm

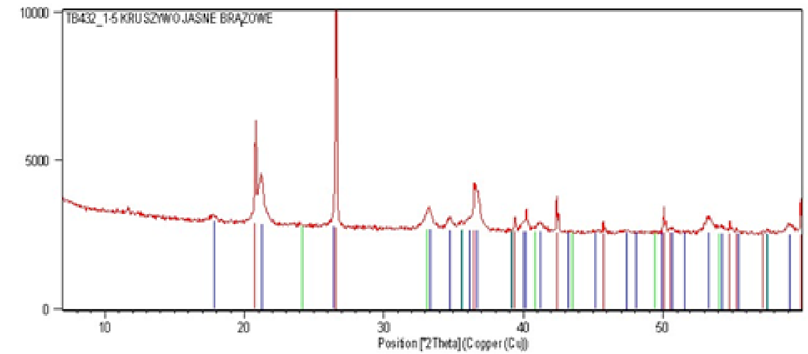
Steel filler with different size and shape, content ~25%



XRD analysis



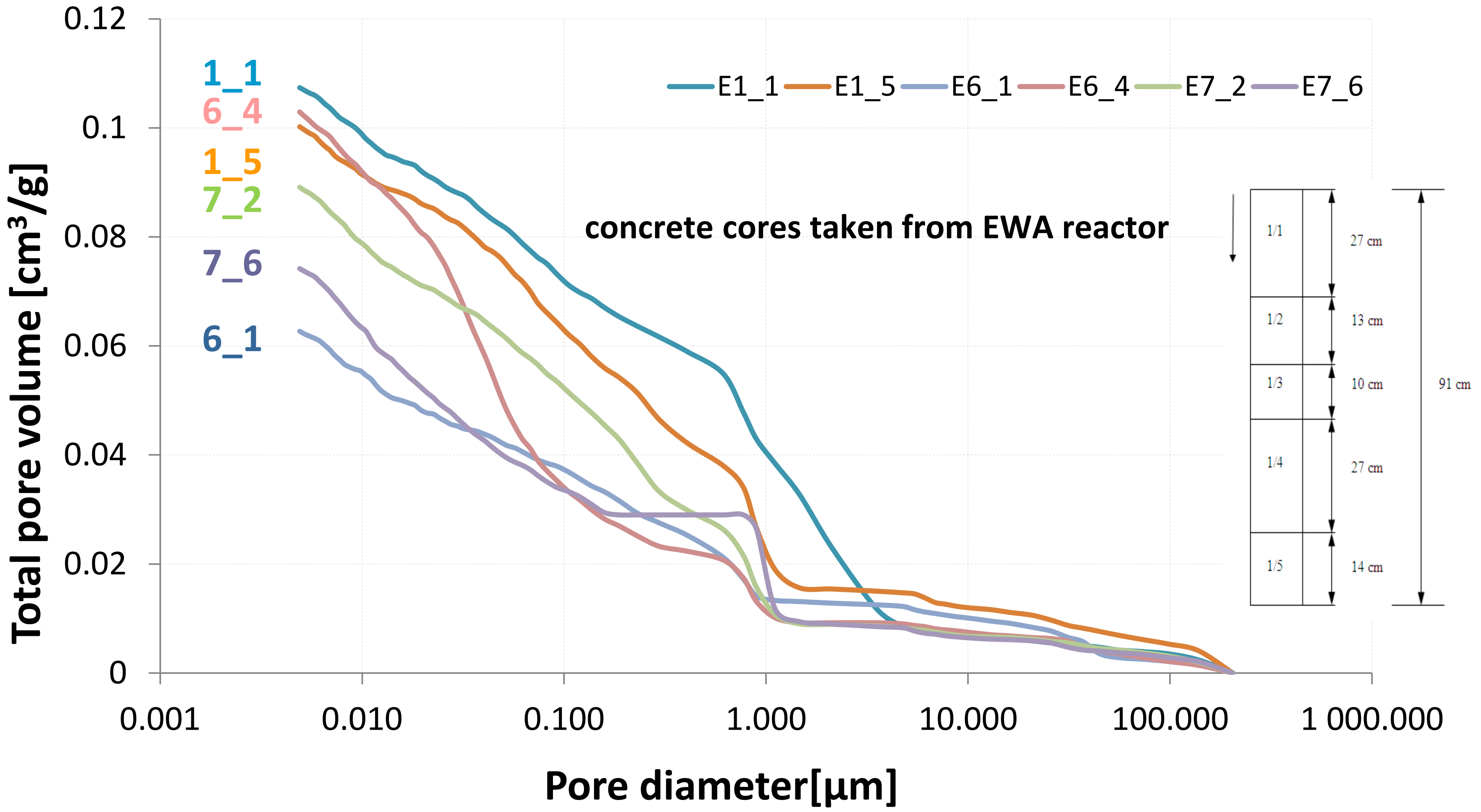
Quartz SiO_2 Goethite $FeO(OH)$



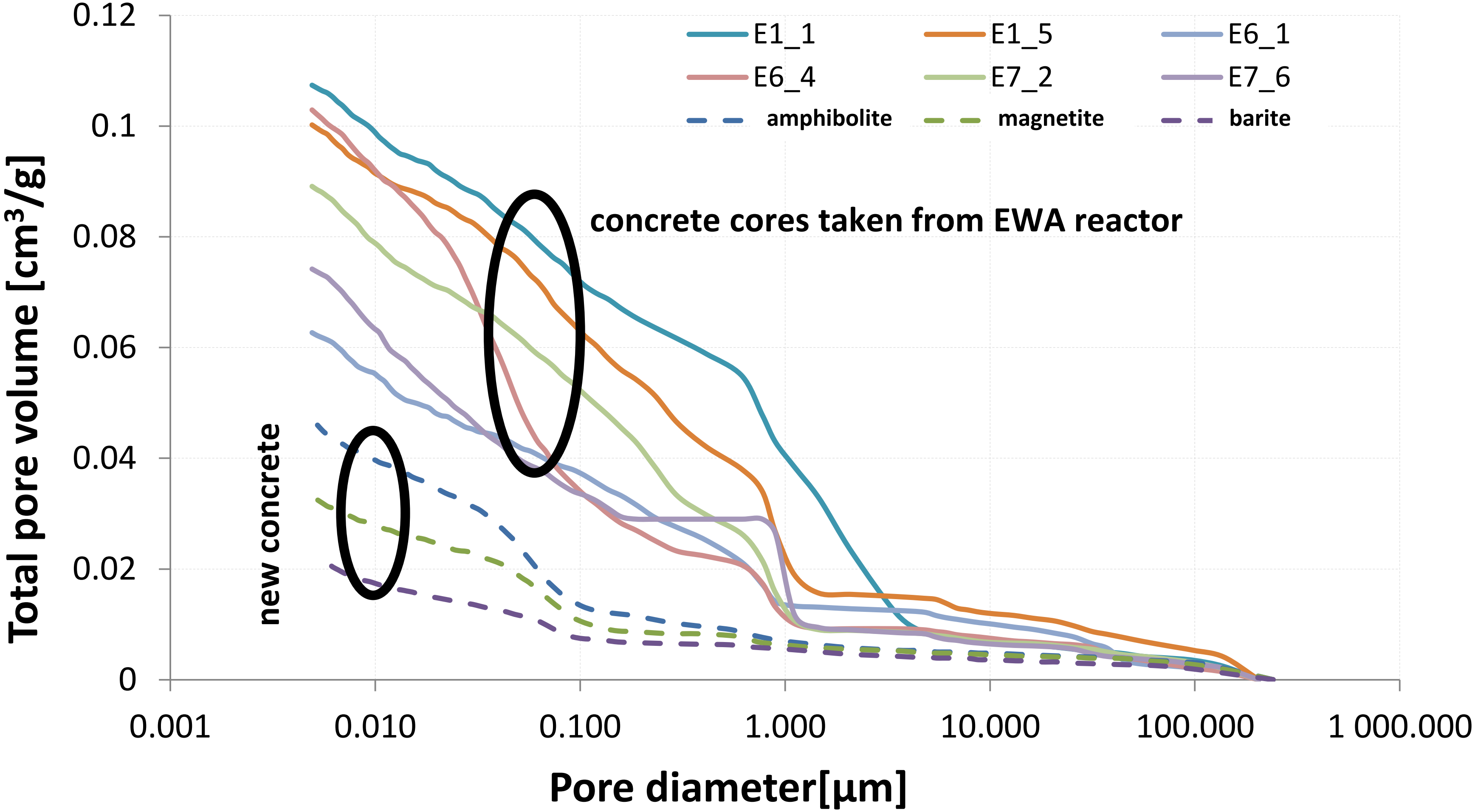
Quartz SiO_2 Goethite $FeO(OH)$

Hematite Fe_2O_3

Matrix porosity (MIP mercury intrusion porosimetry)



Matrix porosity (MIP mercury intrusion porosimetry)



Matrix phase composition

XRF method

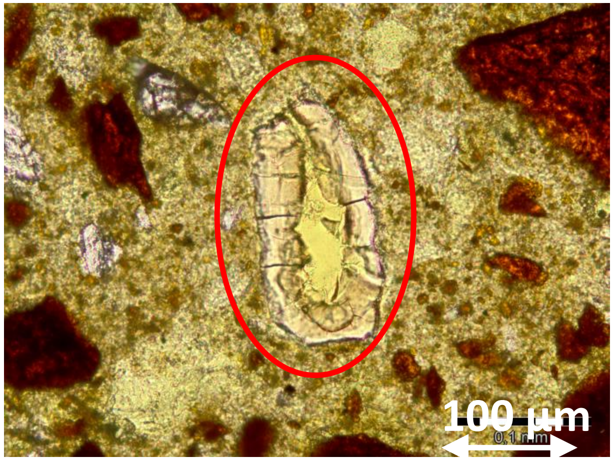
constituent	Core no 1		Core no 6		Core no7	
	outer part	inner part	outer part	inner part	outer part	inner part
LOI	13.22	12.18	11.72	12.83	12.01	12.02
SiO_2	35.92	36.78	36.76	36.21	35.54	35.33
Al_2O_3	3.69	3.50	3.61	3.59	3.54	3.49
Fe_2O_3	28.73	31.77	32.99	29.16	32.68	33.57
CaO	15.68	13.07	12.12	15.45	13.47	12.79
MgO	0.43	0.38	0.41	0.47	0.38	0.37
SO_3	0.51	0.41	0.38	0.50	0.40	0.40
K_2O	0.40	0.35	0.40	0.34	0.36	0.37
Na_2O	0.10	0.09	0.10	0.10	0.09	0.09
P_2O_5	0.92	1.04	1.09	0.94	1.09	1.12

	Core no 1		Core no 6		Core no7	
	outer part	inner part	outer part	inner part	outer part	inner part
content of the chemicaly bound water, %	6.6	7.6	7.6	5.9	7	6.8
content of the chemically bound water without iron ore, %	10.2	9.6	9.7	6.2	10.4	10.3

Damage of aggregates

Microscopic analysis: 100 cm from the outer surface of concrete shield

Thin sections

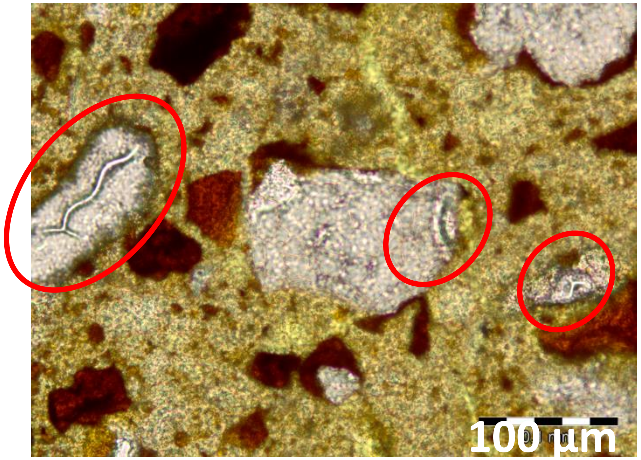


After > 30 years of reactor operation

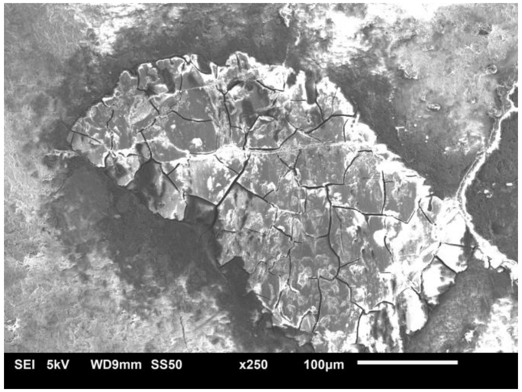
Possible signs of ASR gel

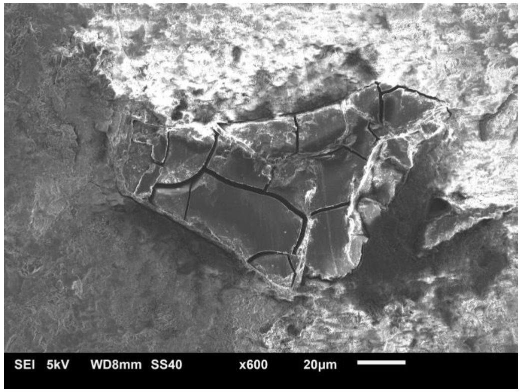
Cracking of aggregate (quartz in limonite aggregate)

Changes in form of quartz (sand fraction)

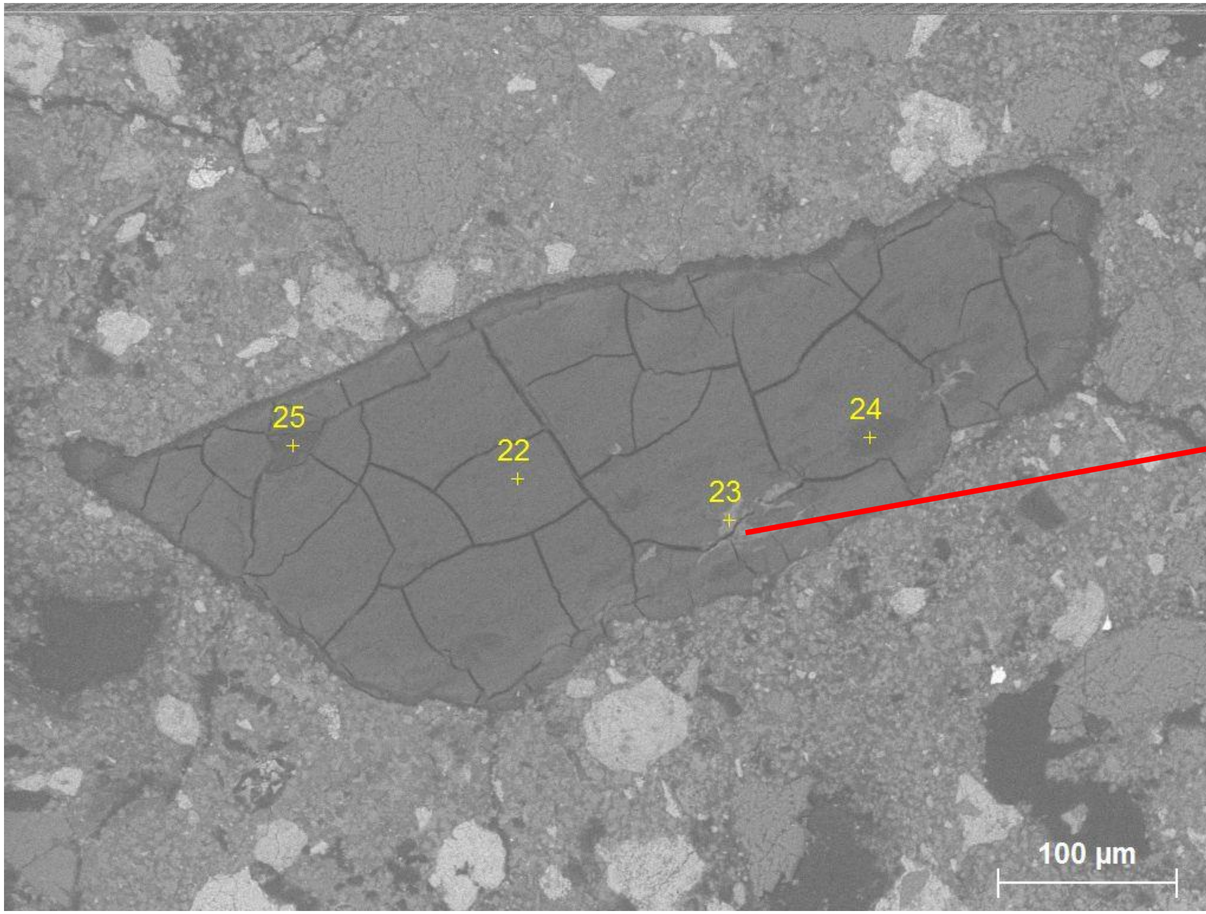


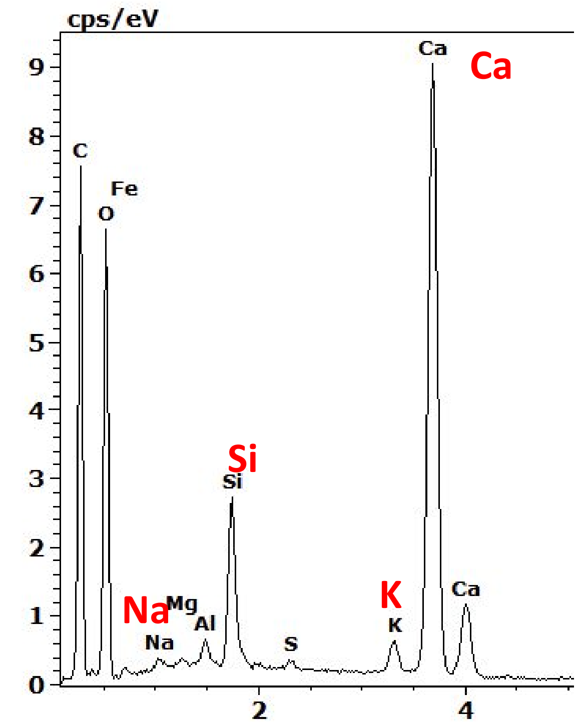
SEM





Damage of aggregates

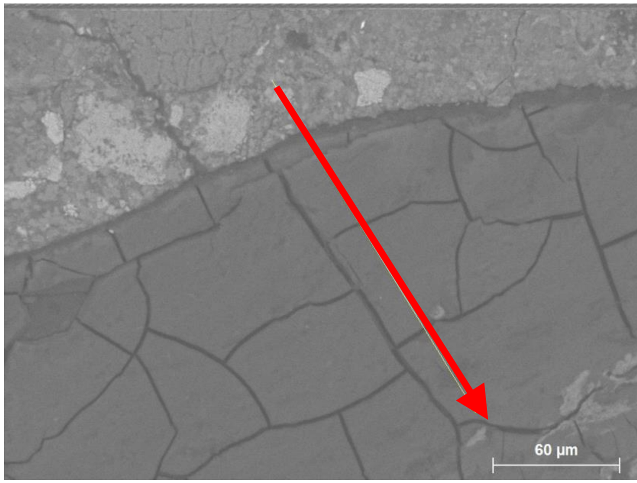




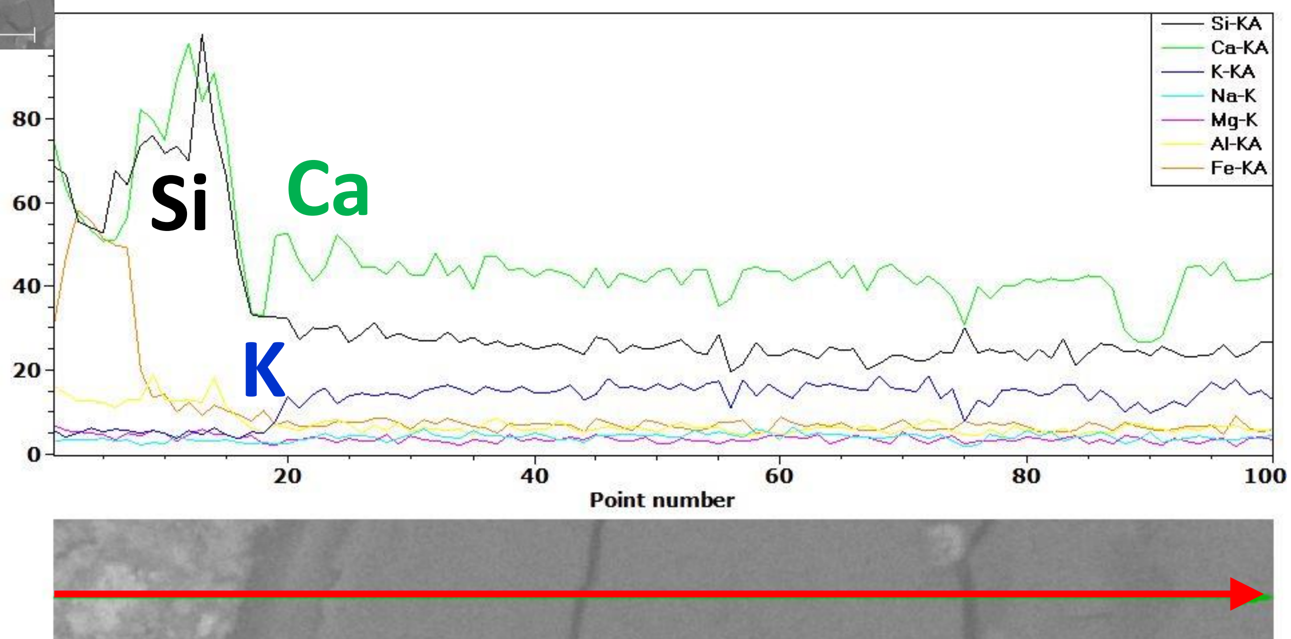
SEM EDS

core 6-1 (thin section): ASR gel

Damage of aggregates



SEM EDS

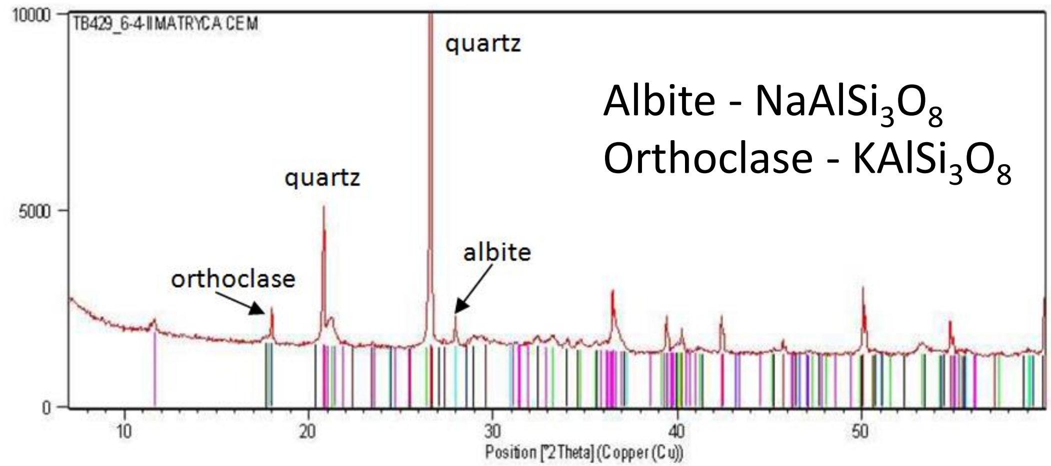


Presence of the feldspar in the matrix

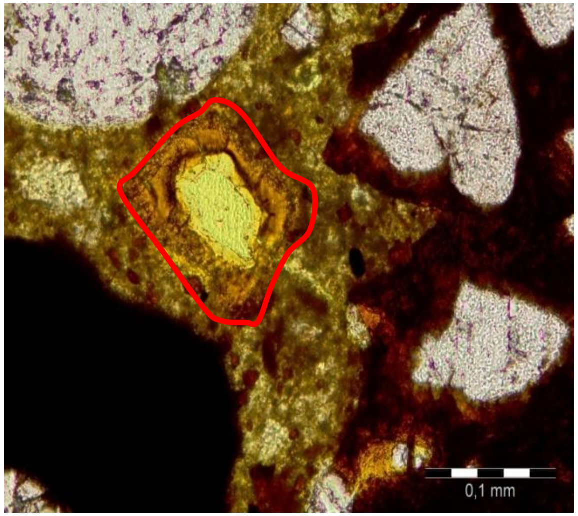
in a fine aggregate - silicious sand 0-2 mm

↓

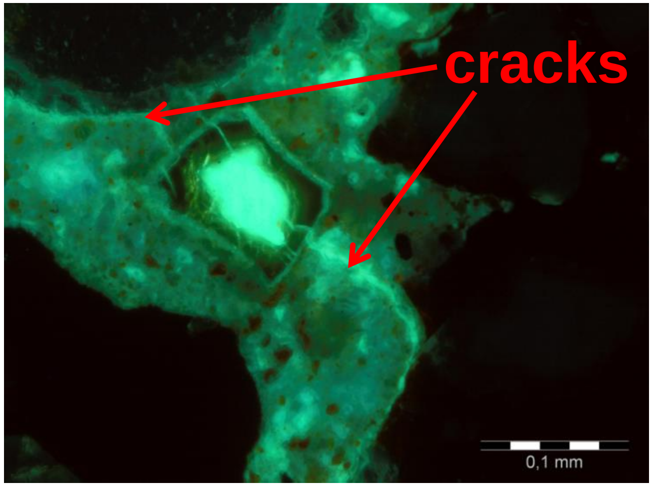
source of the alkali



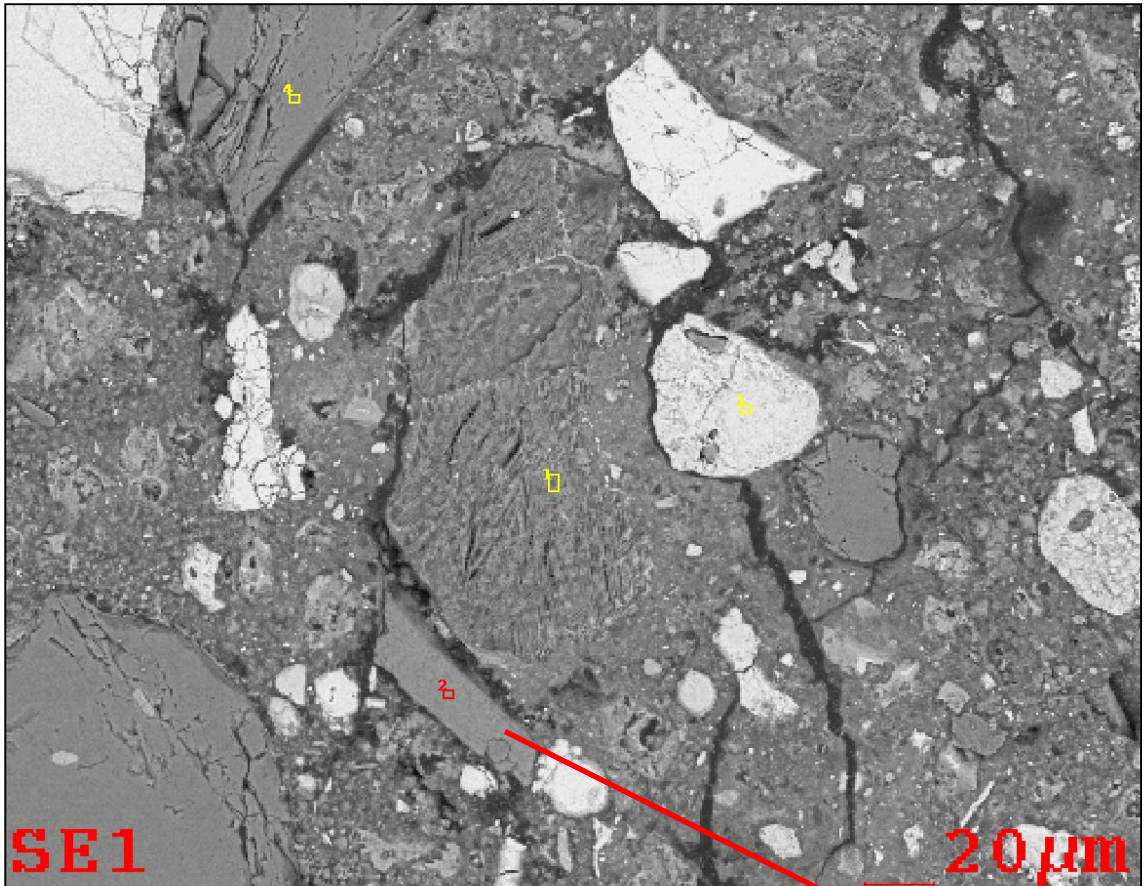
„Feldspar shape"



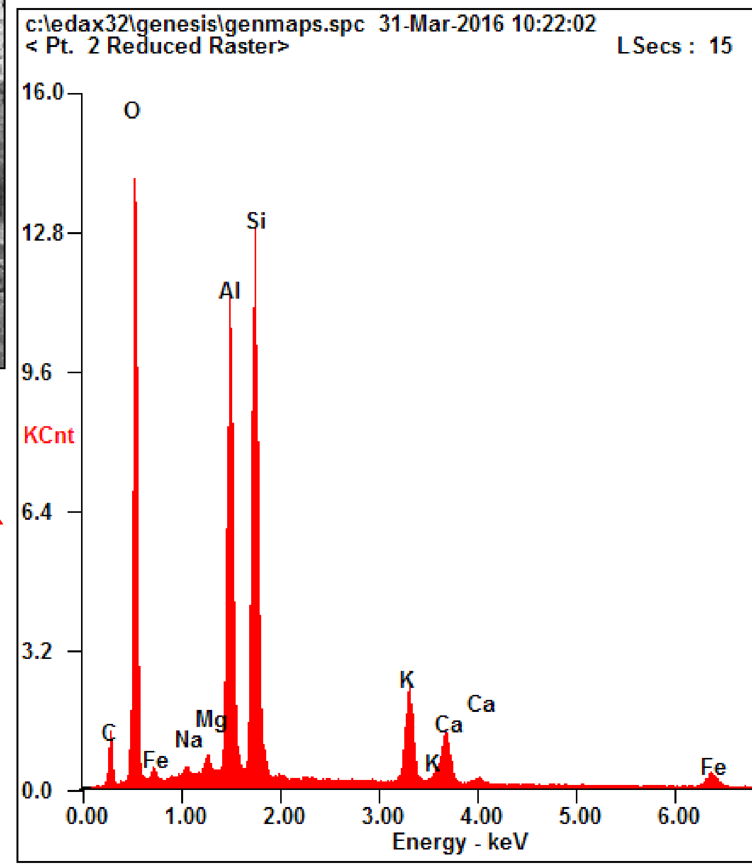
PLL



UV



core 7-6 (polished surface)



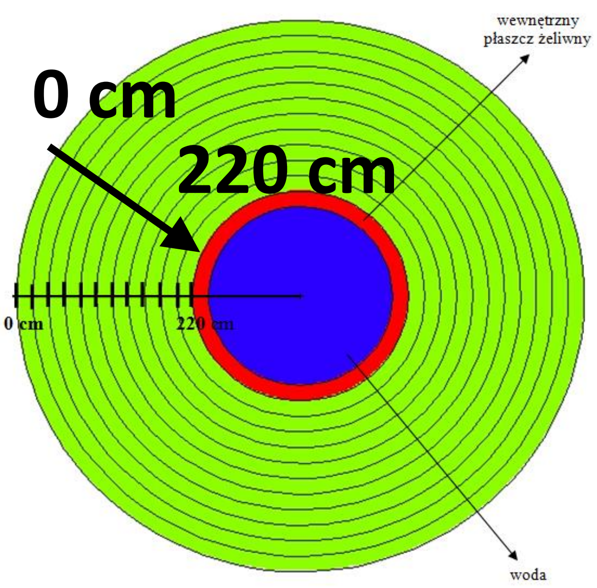
Ortoclase (K-feldspar) - $KAlSi_3O_8$

Concluding remarks

1) Experiments revealed substantial damage to concrete in the reactor shield.
2) Concrete compressive strength was 28-31 MPa and the density 2500 – 3100 kg/m^3.
3) Concrete permeability evaluated using ASTM C 1585 and NF P18-459 revealed its poor resistance to water transport.
4) High matrix porosity was found using MIP.
5) The content of the chemically bound water in cement hydration products was from 5.9 to 7.6%.
6) Microstructural evaluation revealed numerous cracks in cement matrix, in quartz grains and in goethite grains.

Any influence of radiation on concrete shield?

- hard to say :-(
- rather not, but the quality of the concrete in the shield does not correspond to actual technology due to its heterogeneity and excessive permeability
- there were no specimens to compare, any reference specimens
- at depth 100cm gamma radiation dose = $7 \cdot 10^{-6}$ Gy, at 220 cm near the tank $\gamma = 3 \cdot 10^{+3}$ Gy
- at depth 100cm neutron flux density less by 6 orders of magnitude



	neutron flux density[n/cm²s]	Gamma dose [Gy]
0 cm	$1{,}6 \cdot 10^{+1}$	$1{,}4 \cdot 10^{-14}$
100 cm	$1{,}45 \cdot 10^{+7}$	$7 \cdot 10^{-6}$
220 cm	$2 \cdot 10^{+14}$	$3{,}4 \cdot 10^{+3}$

Based on Report: K.Tymińska, J.Ośko, A. Niepokólczycka-Fenik, Modelowanie reaktora EWA i szacunkowe określenie strumieni w czasie 30 lat eksploatacji, NCBJ 2016

Thank you for your attention

Acknowledgements
The financial support by Polish National Centre for Research and Development (Project V4-506 Korea/2/2018) is gratefully acknowledged.