



ACTIVATION PROPERTIES OF NEUTRON SHIELDING MATERIALS

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Introduction

- European Spallation Source ESS ERIC, Lund, Sweden

- Brightest neutron source



- Massive shielding volume

- Space & budget issues



- New shielding material:

- PE-B4C concrete



Study of activation properties,
irradiation experiment & simulation



γ -emitting isotopes only!

Composition study for
MCNP + Cinder90 simulation

Samples and analysis

- Metal samples

- 5x5x5 mm³ cubes
- Al, Cu, stainless steel
- NAA, XRF, validation

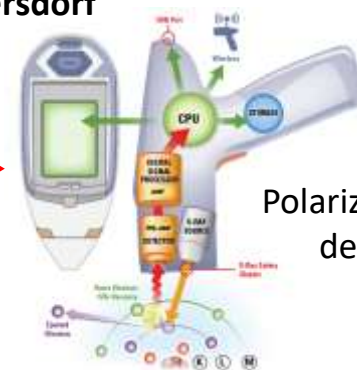


XRF @ IAEA Seibersdorf

Composition



Pellet



Polarizing XRF device



Fine grain

- Concrete samples (grain):

- Reference concrete
- PE-B4C concrete
- Skanska concrete



First grain



PGAA @BRR

Composition



HPGe detector

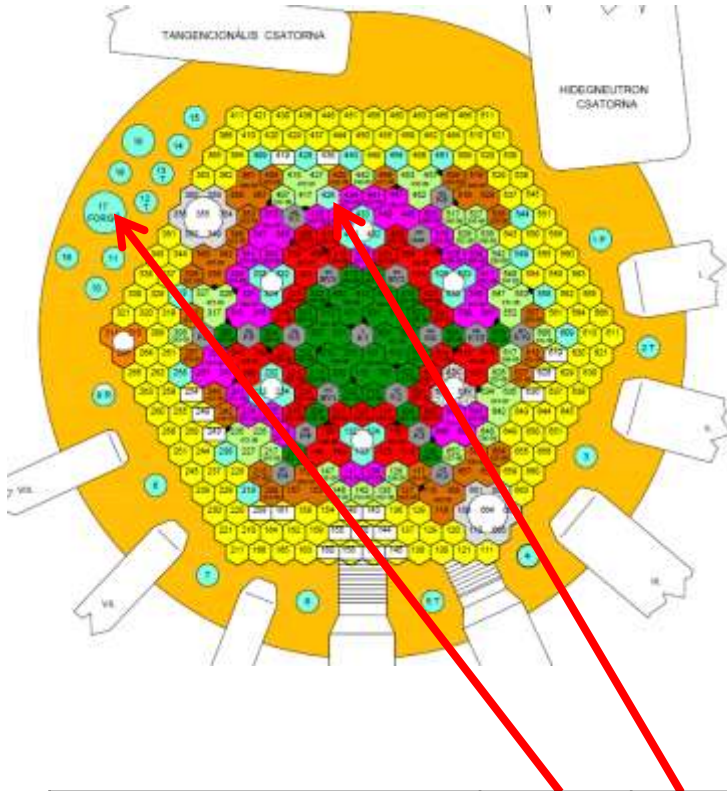
NAA @BRR

Activation & Composition

BRR – Budapest Research Reactor

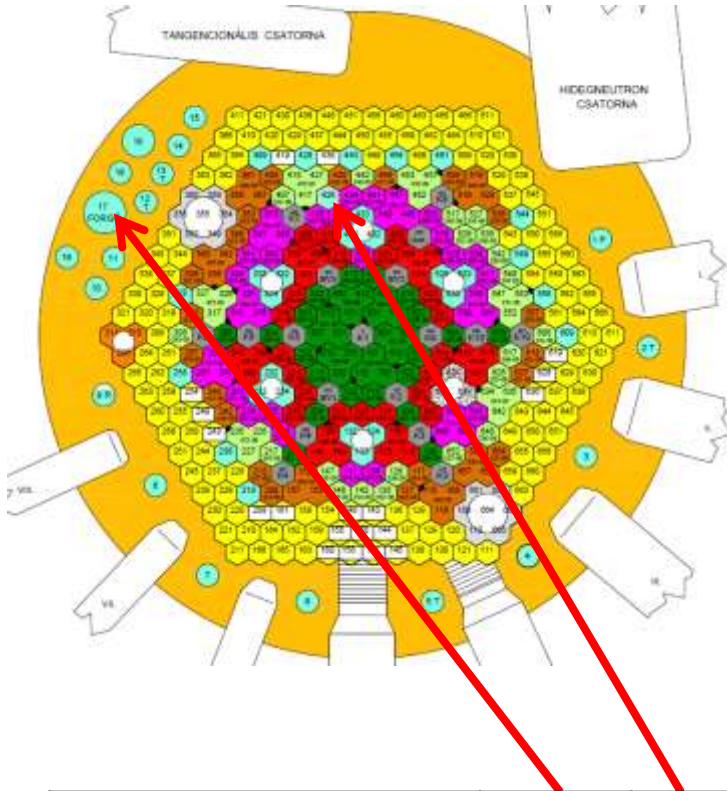
- VVR-type research reactor
 - light water-cooled and moderated tank type reactor with a beryllium reflector
 - low enriched uranium fuel (LEU: 19.9% ^{235}U)
- nominal thermal power: 10 MW
- maximal thermal flux: $2.1 \times 10^{14} \text{ n/cm}^2\text{s}$
- Reactor „campaign”: 10 effective days
+ break for weekend
~ 160 operational days/year, flexible timetable

Neutron irradiation of concrete samples – Measurement and simulation



Channel	Thermal	Fast
Thermal flux [1/(cm ² *s)]	2.00E+13	5.00E+13
Epithermal flux [1/(cm ² *s)]	4.30E+11	3.80E+12
Fast flux [1/(cm ² *s)]	1.30E+12	4.70E+13

Neutron irradiation of concrete samples – Measurement and simulation

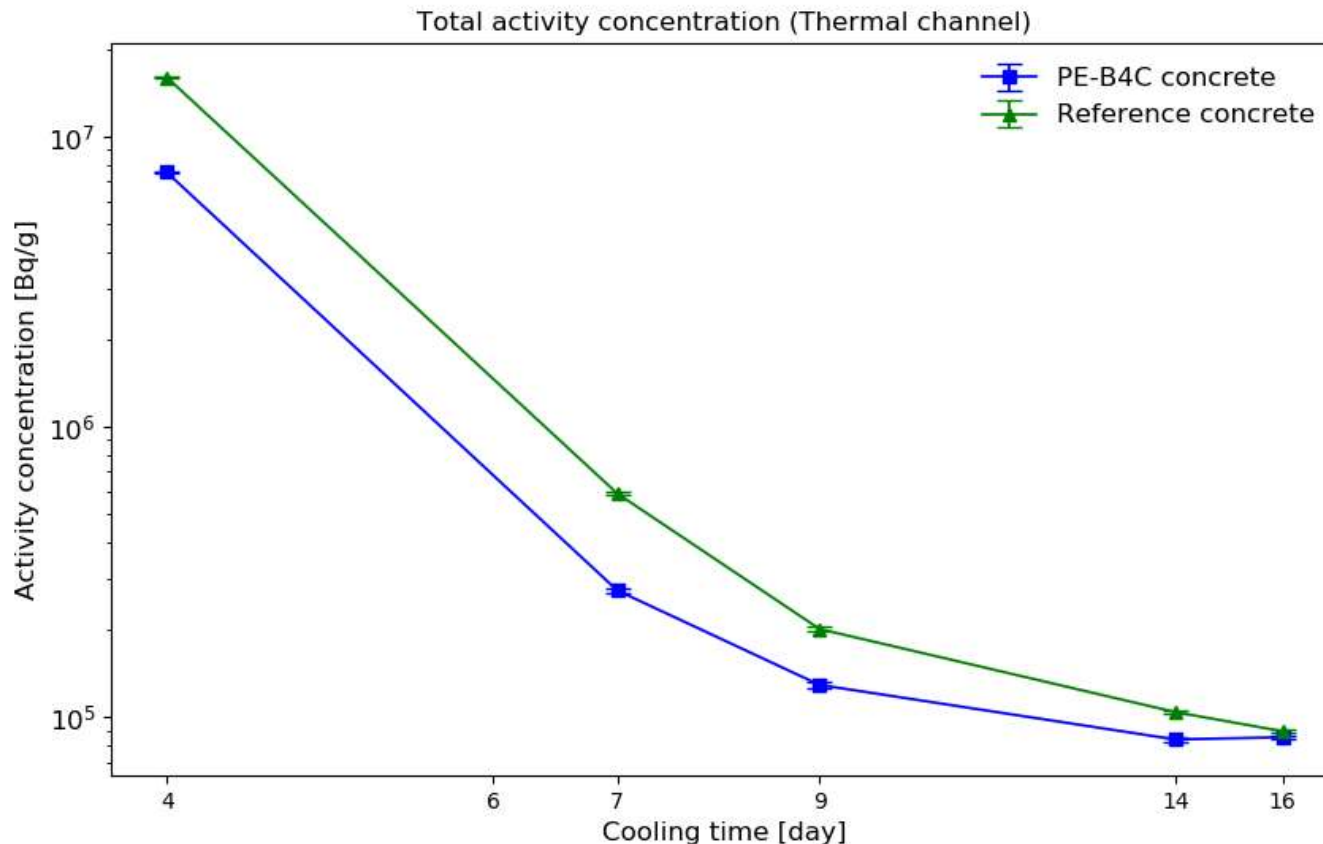


- Irradiation:
 - 2h in 'Thermal channel'
 - 2h in ,Fast channel'
- Gamma spectroscopy:
 - HPGe detector
 - low background measurement chamber
- Cooling time: 4 days
- Follow-up time: 18 days
- Measurement time: 10 – 110 mins
- Deadtime: 20 – 2 %

Channel	Thermal	Fast
Thermal flux [1/(cm ² *s)]	2.00E+13	5.00E+13
Epithermal flux [1/(cm ² *s)]	4.30E+11	3.80E+12
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Decay of measured activity concentration – ‘thermal’ channel

Measurement



- Significantly lower neutron-induced activity in PE-B4C concrete



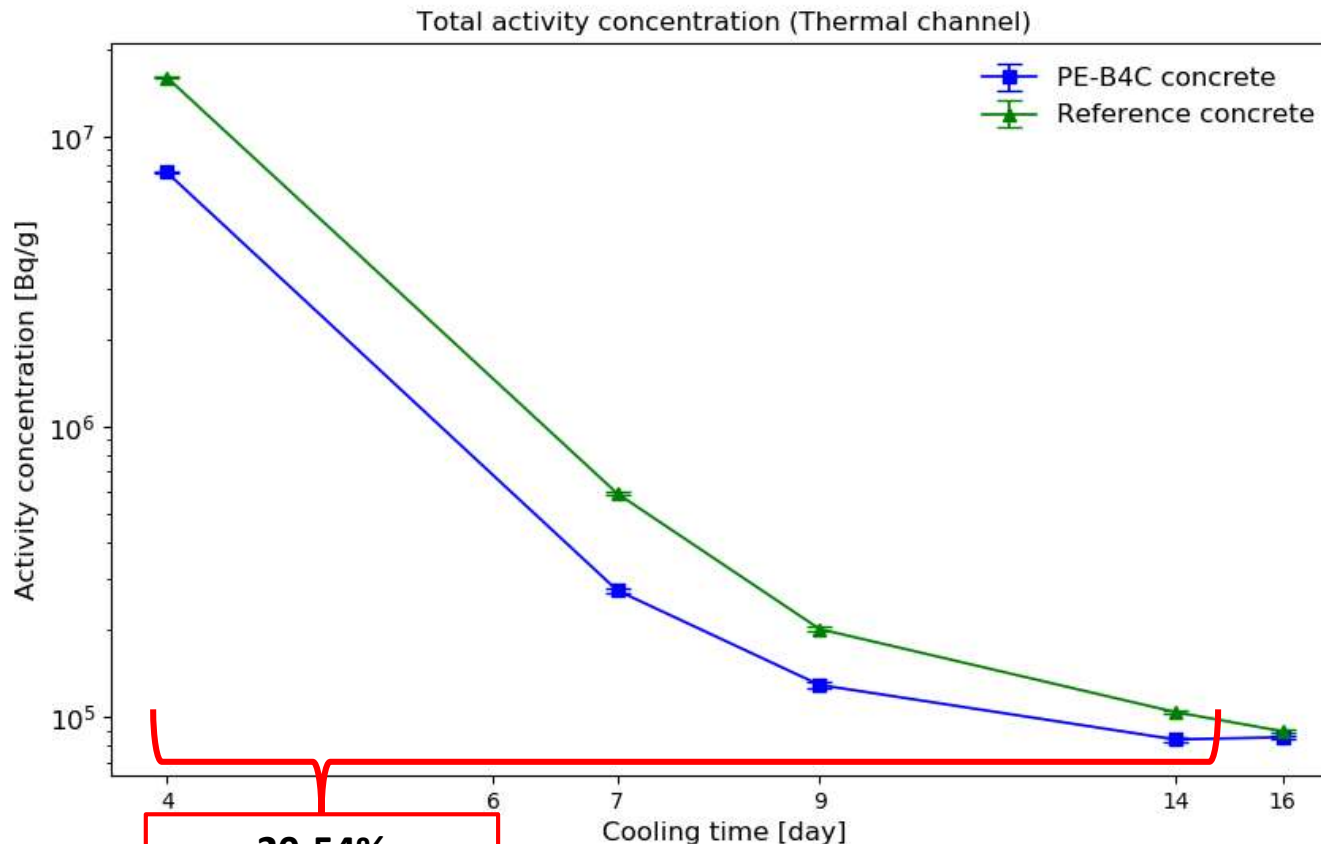
- ~50% lower during the **1st week** of cooling



- Key difference for maintenance

Decay of measured activity concentration – ‘thermal’ channel

Measurement



- Significantly lower neutron-induced activity in PE-B4C concrete

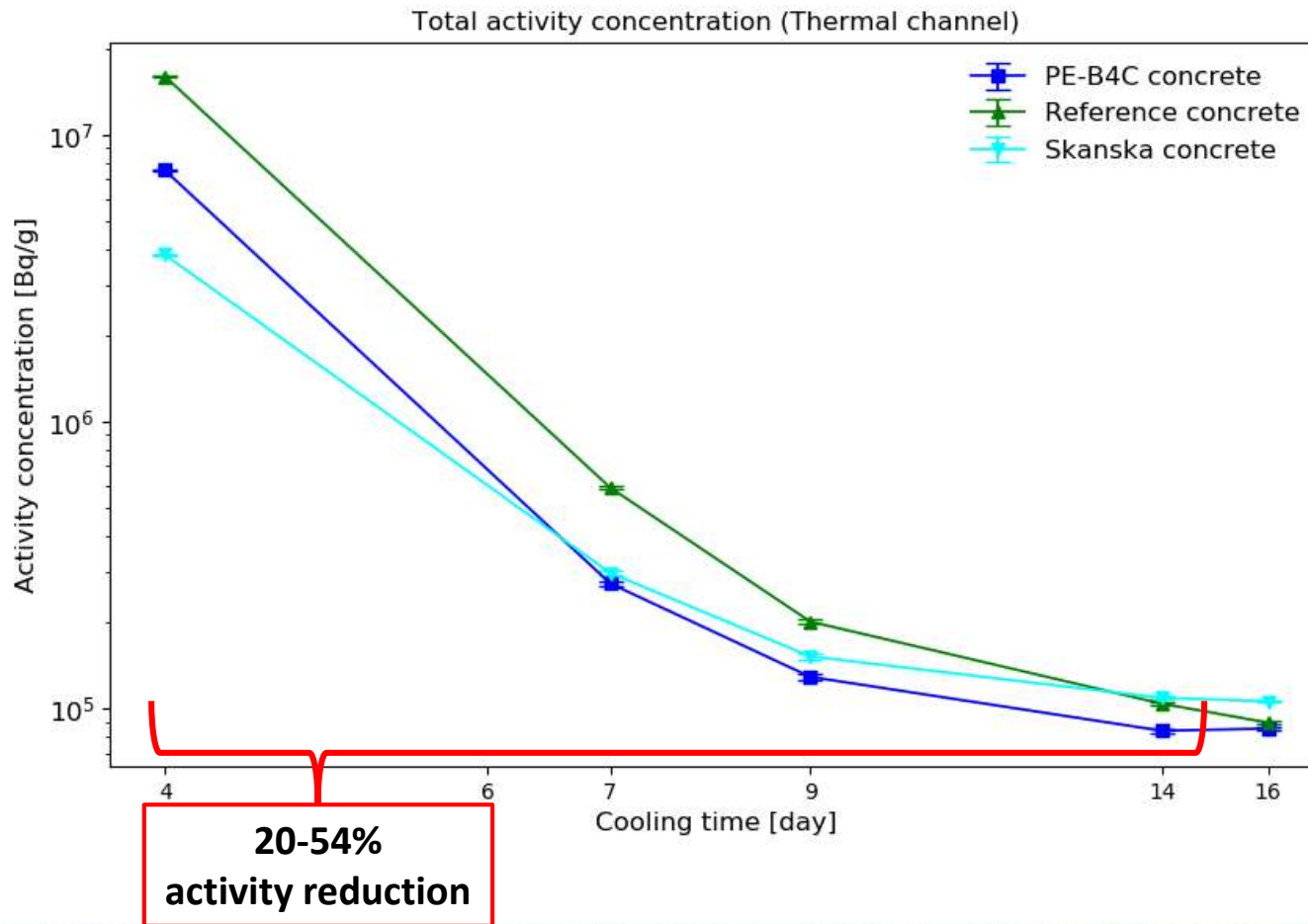


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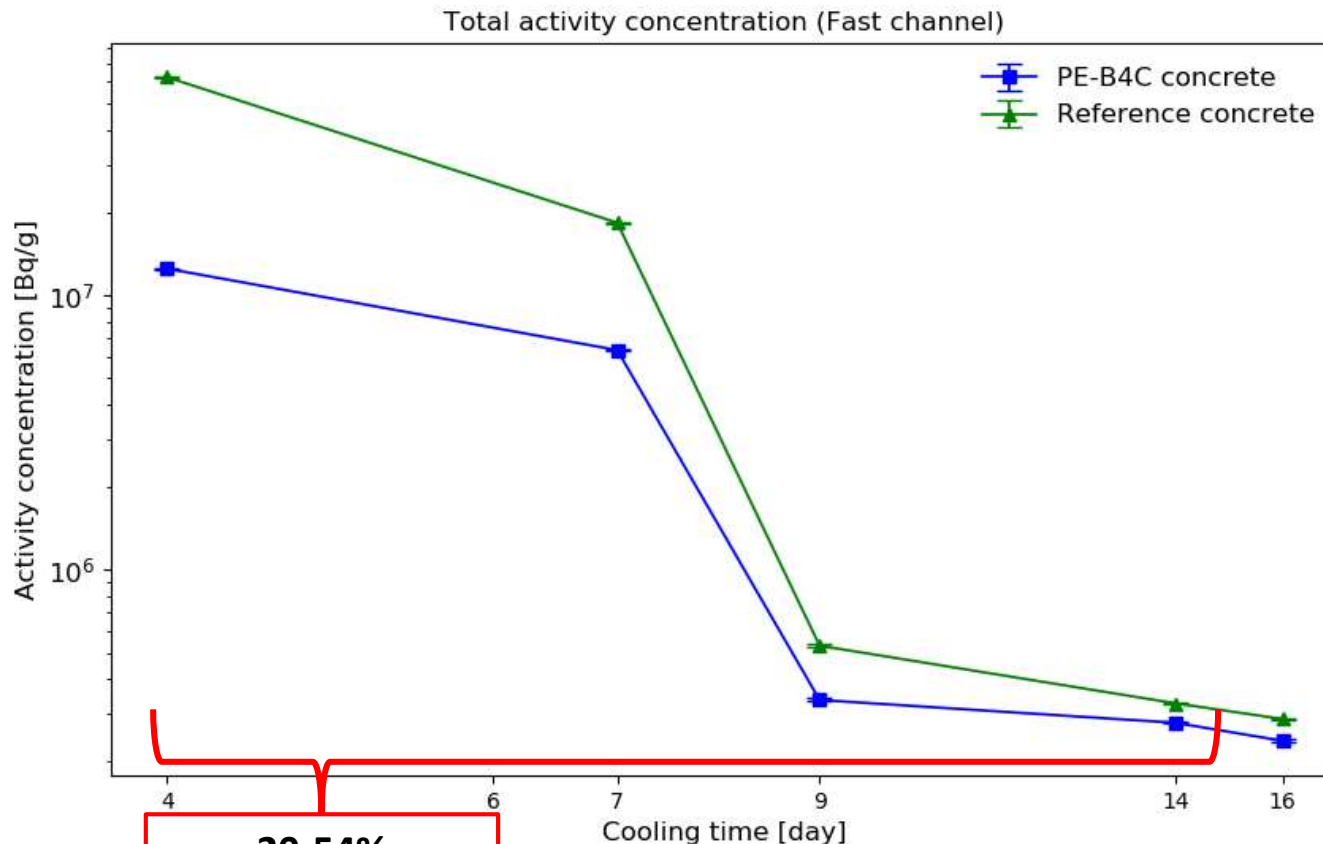
Decay of measured activity concentration – ‘thermal’ channel



- Significantly lower neutron-induced activity in PE-B4C concrete ✓
- ~50% lower during the **1st week** of cooling
- Key difference for maintenance

Decay of measured activity concentration – ‘fast’ channel

Measurement

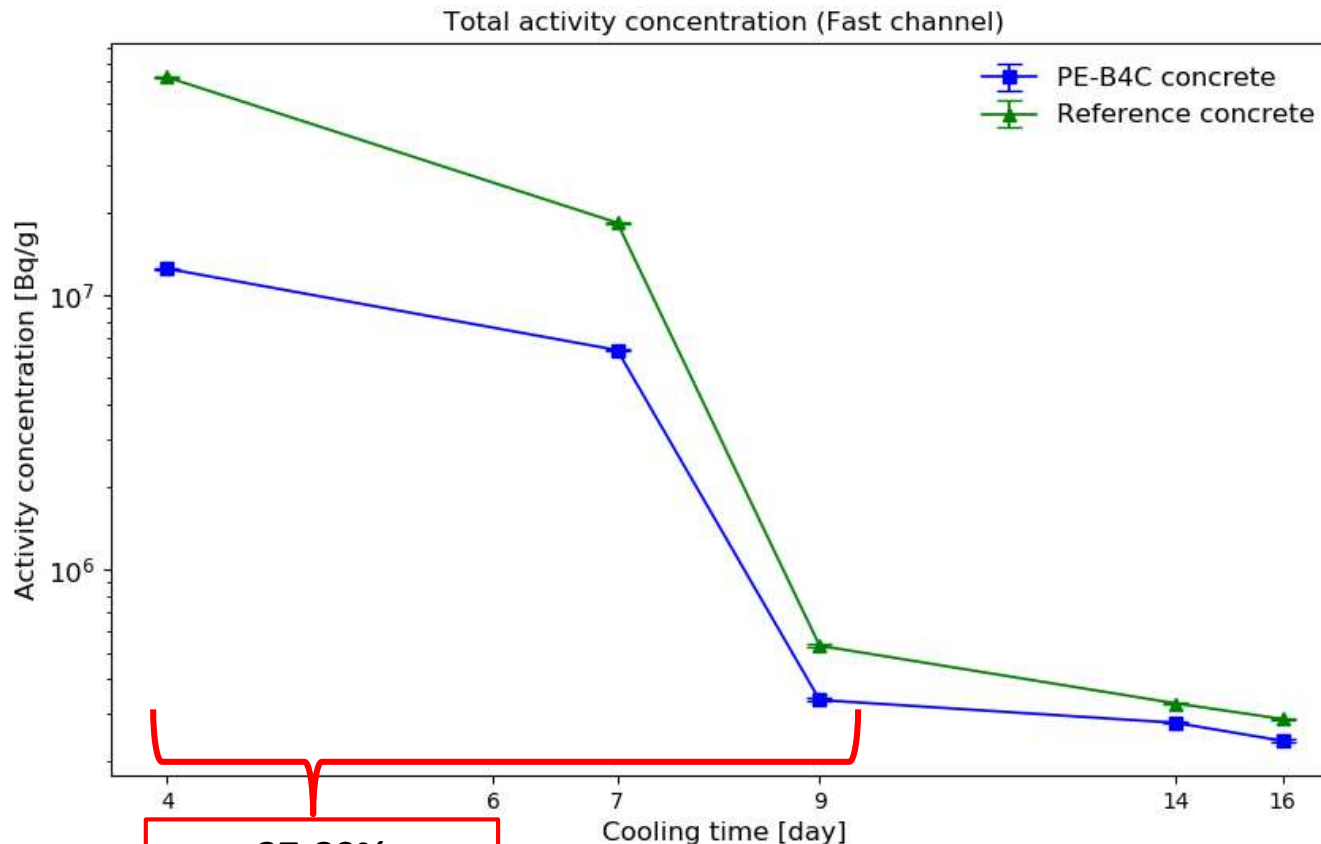


20-54%
activity reduction

- Significantly lower neutron-induced activity in PE-B4C concrete ✓
- >66% lower during the **1st week** of cooling
- Key difference for maintenance

Decay of measured activity concentration – ‘fast’ channel

Measurement

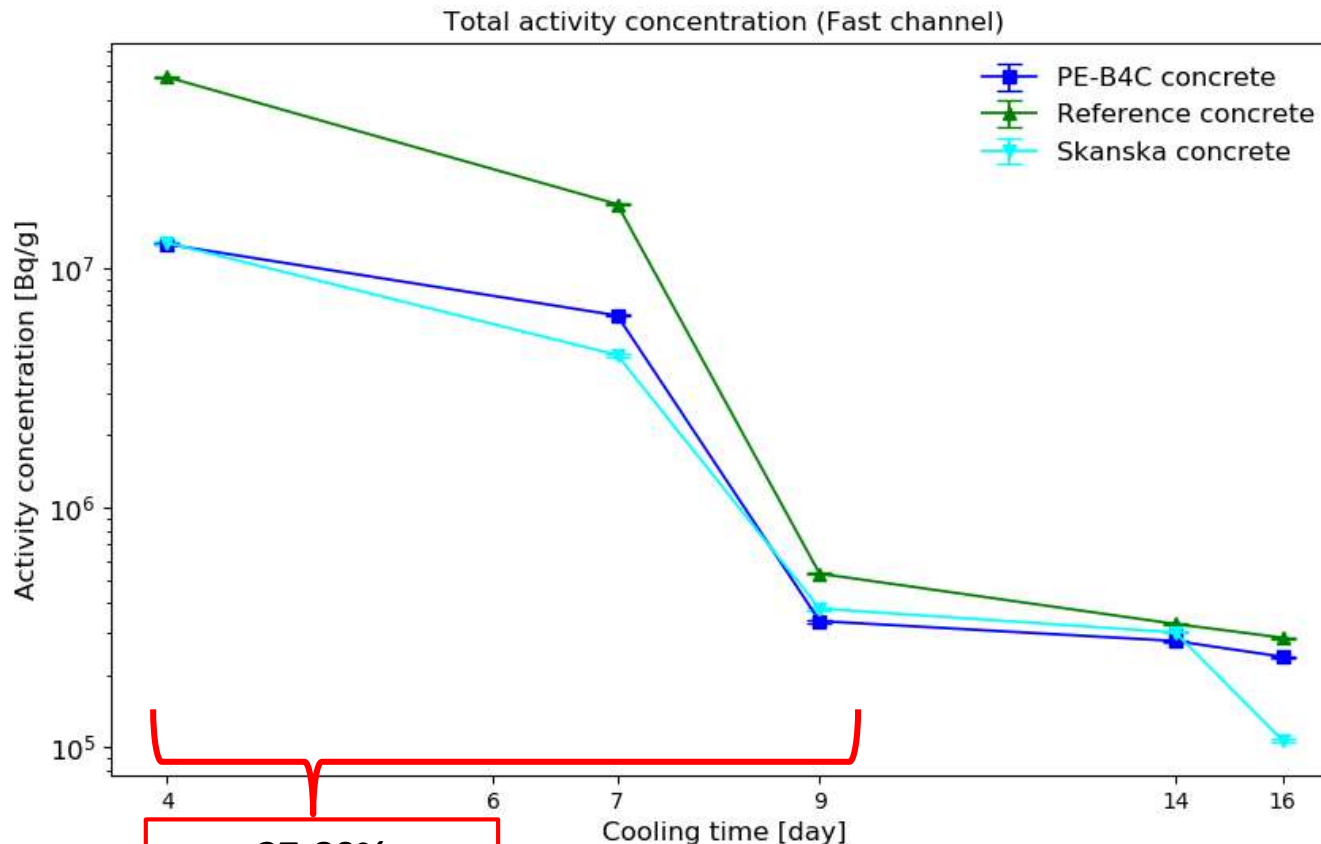


37-80%
activity reduction

- Significantly lower neutron-induced activity in PE-B4C concrete ✓
- >66% lower during the **1st week** of cooling
- ↓
- Key difference for maintenance

Decay of measured activity concentration – ‘fast’ channel

Measurement

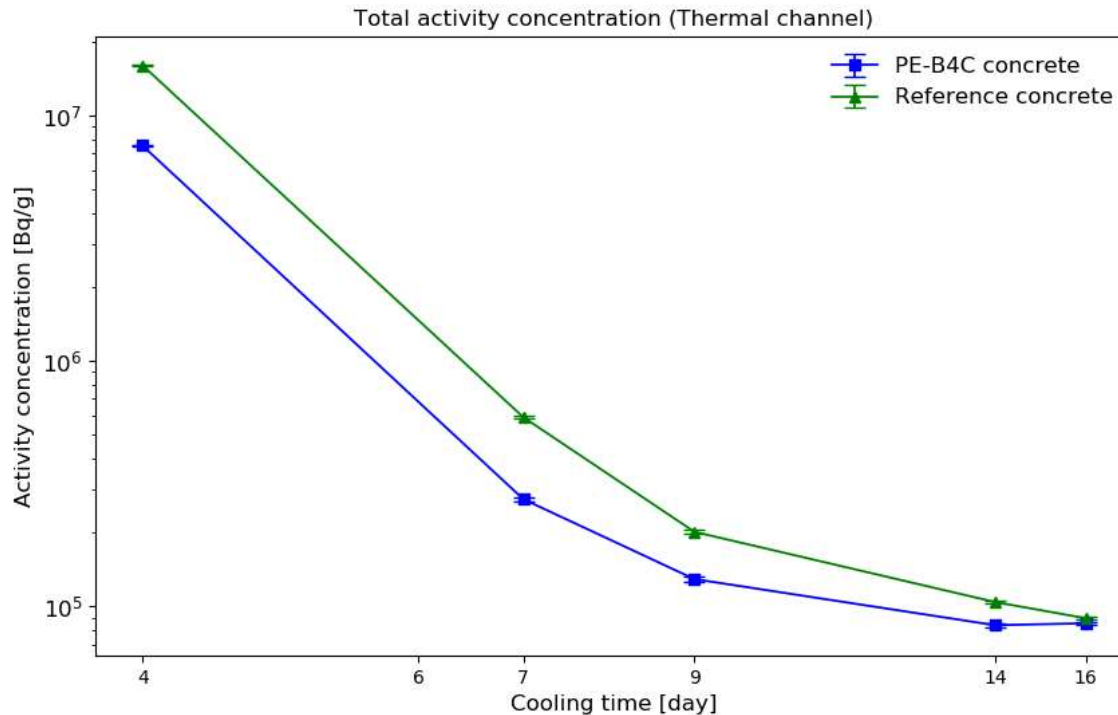


37-80%
activity reduction

- Significantly lower neutron-induced activity in PE-B4C concrete ✓
- >66% lower during the **1st week** of cooling
- Key difference for maintenance

Decay of measured activity concentration – ‘thermal’ channel

Measurement



Cinder issues due to pure β -emitters

- 15 γ -emitting ‘key nuclides’ found, giving ~90% of total activity concentration for a 4 day – 5 year cooling time:

Na-24	Fe-59
W-187	Sc-46
La-140	Zn-65
Sm-153	Mn-54
Yb-175	Cs-134
Rb-86	Co-60
Pa-233	Eu-152
Cr-51	

- Effective comparison of activity simulation

Measured and nominal composition of PE-B4C concrete

Element	[w%]						
	Nominal	PGAA	Unc.	XRF	Unc.	NAA	Unc.
H	2.31	1.26	0.040				
C	8.99	5.46	0.648				
Na	0.62	1.11	0.047	1.29	0.197	1.21	0.044
Al	2.35	3.44	0.127	5.51	0.036		
Si	28.60	21.50	0.710	27.04	0.003		
S	0.28	0.23	0.013	0.24	0.015		
K	1.26	1.39	0.051	1.95	0.001		
Ca	8.10	6.50	0.252	8.54	0.000		
Ti	0.05	0.10	0.0002	0.16	0.001		
Mn				0.02	0.001		
Fe	0.84	1.12	0.018	1.47	0.001	1.59	0.073
O	45.80	56.35					

Element	[ppmw] (understanding as simple mass ratios)						
	Nominal	PGAA	Unc.	XRF	Unc.	NAA	Unc.
B	6000	2000.0	40.000				
Cl	36	156.0	4.212	130.00	10.000		
V		77.0	4.620	57.62	7.114		
Sm		1.5	0.090			1.57	0.065
Gd		1.6	0.160				
Mg	1960			982.57	295.22	5	
Sc				11.76	3.406	3.45	0.126
Cr				82.18	1.348	94.30	3.727
Co						5.78	0.248
Ni				11.68	0.781		
Cu				43.53	0.633		
Zn				100.06	0.864	107.70	6.261
Ga				7.84	0.428		
Ge				4.87	0.283		
As				2.92	0.143		
Rb				59.36	0.388	68.50	4.866
Sr				311.67	1.244		
Y				11.55	0.198		
Zr				91.43	0.394		
Nb				5.36	0.135		
Mo				3.03	0.130		
In				1.70	0.194		
Sn				2.81	0.047		
Sb				1.59	0.229	1.43	0.128
Cs				2.58	0.301	1.98	0.130
Ba				508.51	1.124	514.20	25.450
La				19.97	0.277	12.97	0.514
Ce				41.16	0.535	31.35	1.324
Pr				4.84	0.458		
Nd				19.55	0.220	14.15	1.414
W						75.46	3.084
Pb				18.31	0.869		
Th				3.85	0.301	4.30	0.186
U				2.70	0.367		
Eu						0.59	0.026
Hf						2.70	0.124
Tb						0.30	0.035
Yb						1.03	0.095
Pa	260						

- Comparison of all nominal and measured (XRF, PGAA, NAA) concrete compositions
- 15 'key isotopes' and their mother elements



- MCNP material cards

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Yb						1.03
Pa	260					0.095

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- 15 'key isotopes' and their mother elements



- MCNP material cards

Recommended MCNP material cards

PE-B4C CONCRETE [1.97 g/cm³]

```

M31  1001 -2.31E+00
      6000 -8.99E+00
      13000 -2.35E+00
      14000 -2.86E+01
      16000 -2.78E-01
      19000 -1.26E+00
      20000 -8.10E+00
      5000 -6.00E-01
      17000 -3.55E-03
      12000 -1.96E-01
      8016 -4.43E+01
      22000 -1.59E-01
      11000 -1.21E+00
      26000 -1.59E+00
      74000 -7.55E-03
      57000 -1.30E-03
      62000 -1.57E-04
      70000 -1.03E-04
      37000 -6.85E-03
      90000 -4.30E-04
      24000 -9.43E-03
      21000 -3.45E-04
      30000 -1.08E-02
      55000 -1.98E-04
      27000 -5.78E-04
      63000 -5.85E-05
  
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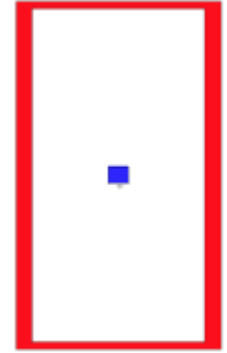
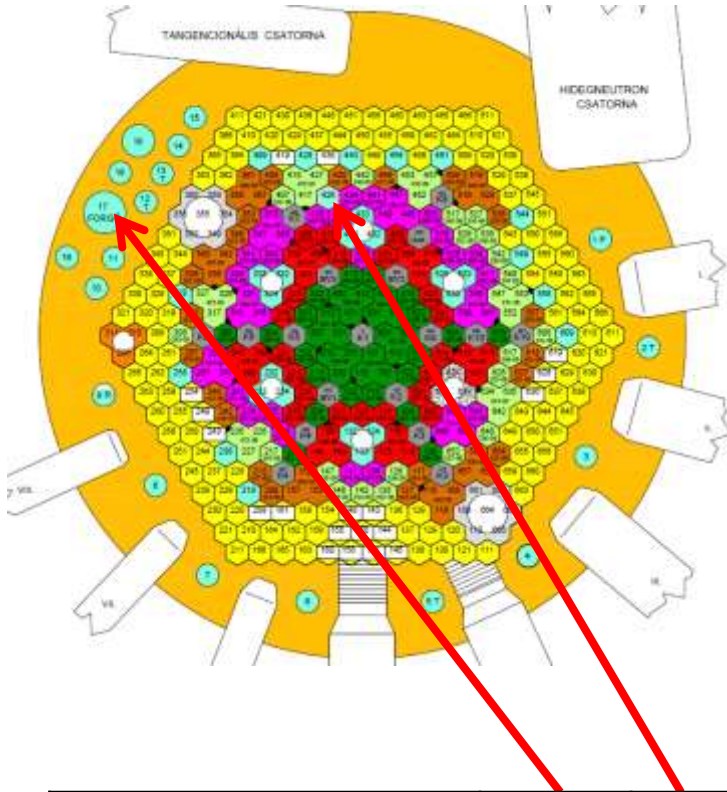
REFERENCE CONCRETE [2.33 g/cm³]

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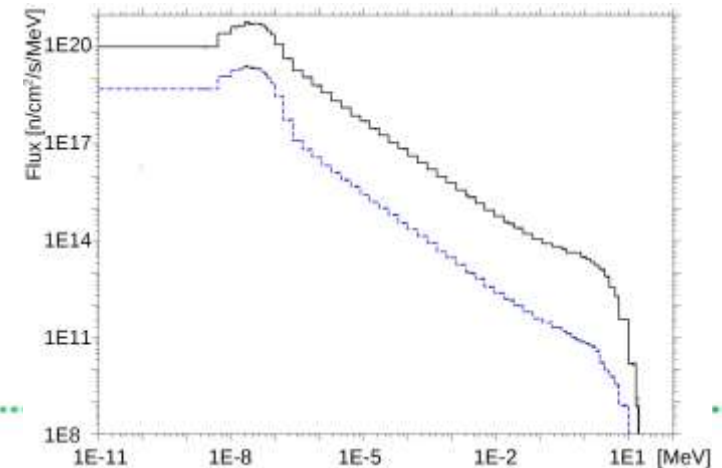
M31  1001 -7.23E-01
      13000 -3.70E+00
      14000 -3.27E+01
      16000 -2.36E-01
      19000 -2.12E+00
      20000 -7.12E+00
      17000 -3.02E-03
      12000 -2.37E-01
      8016 -4.94E+01
      22000 -1.76E-01
      11000 -1.99E+00
      26000 -1.55E+00
      74000 -5.96E-02
      57000 -2.14E-03
      62000 -2.38E-04
      37000 -8.62E-03
      90000 -7.62E-04
      24000 -6.57E-03
      21000 -3.97E-04
      30000 -1.07E-02
      55000 -2.59E-04
      27000 -5.52E-04
      63000 -7.00E-05
  
```

- Mixed composition from nominal composition and the results of all three analytical methods (XRF, PGAA, NAA)
- Recommended for MCNP activity simulation

Neutron irradiation of concrete samples – Measurement and simulation

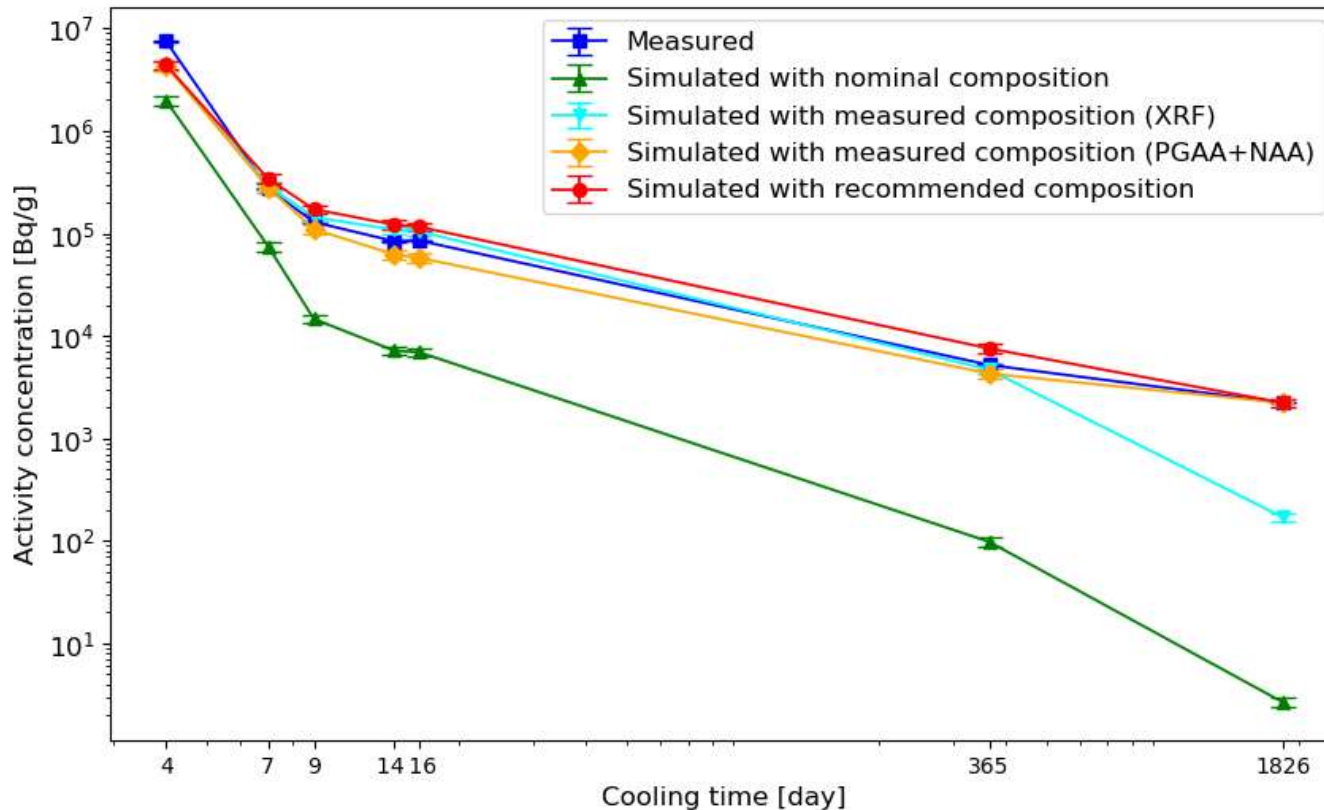


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Decay of measured and simulated activity concentration – PE-B4C concrete, ‘thermal’ channel

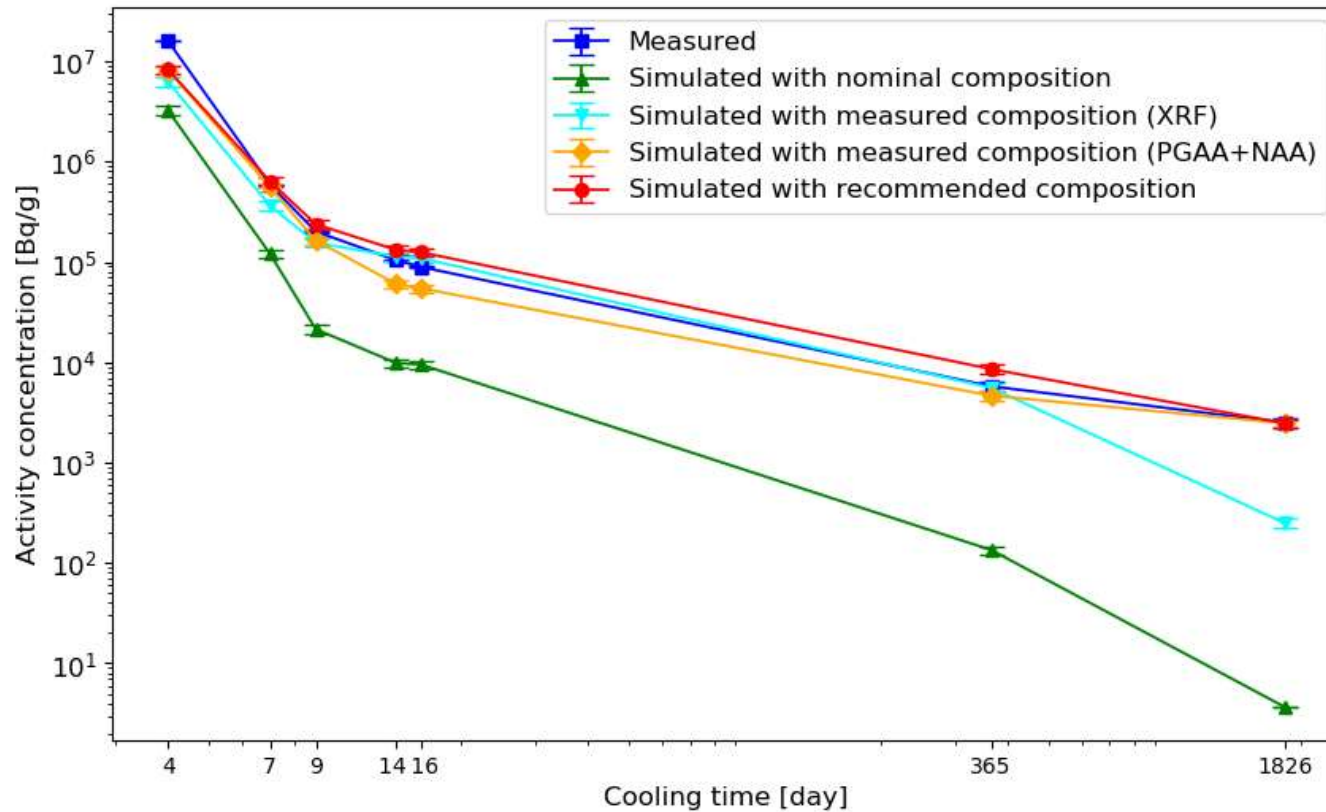
Total activity concentration in PE-B4C concrete
(Thermal channel)



Realistic and conservative activation simulation ✓

Decay of measured and simulated activity concentration – reference concrete, ‘thermal’ channel

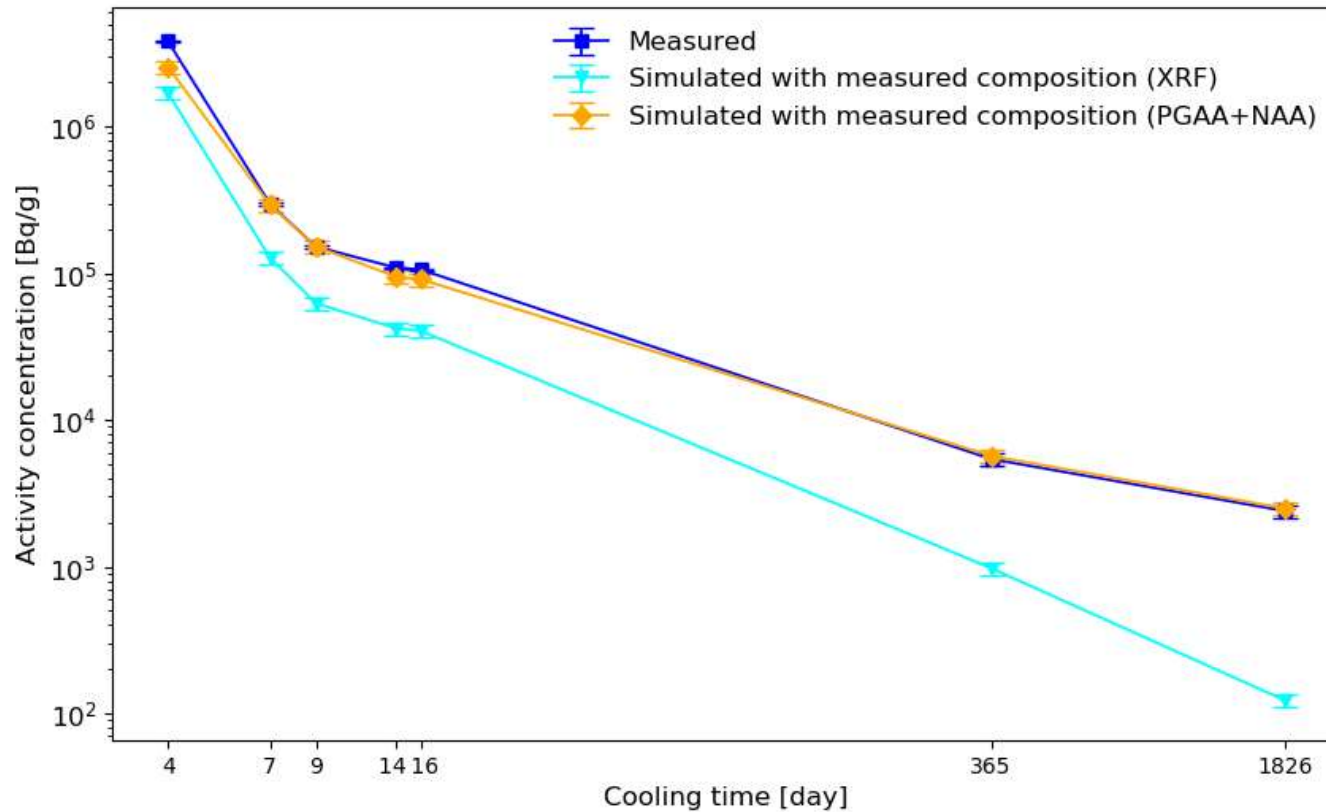
Total activity concentration in Reference concrete
(Thermal channel)



Realistic and conservative activation simulation ✓

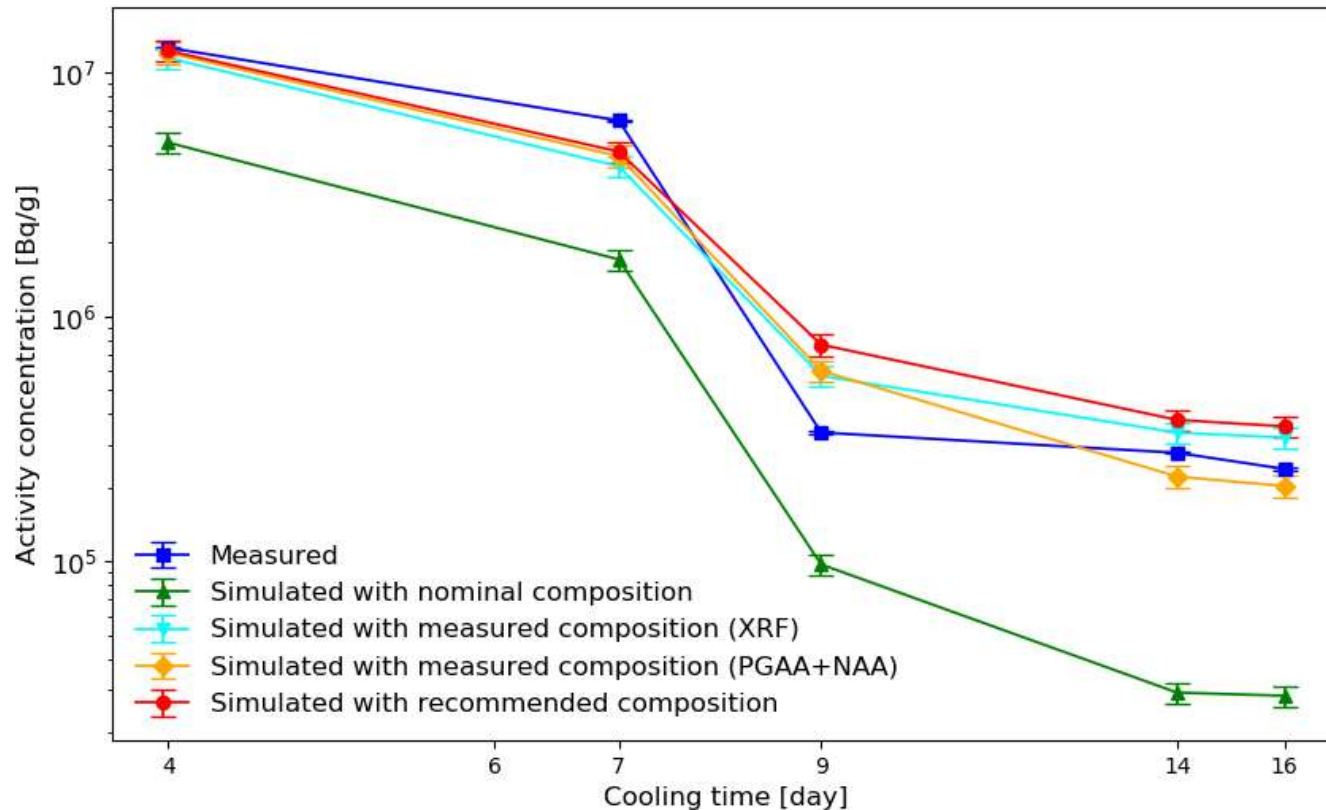
Decay of measured and simulated activity concentration – Skanska concrete, ‘thermal’ channel

Total activity concentration in Skanska concrete
(Thermal channel)



Decay of measured and simulated activity concentration – PE-B4C concrete, ‘fast’ channel

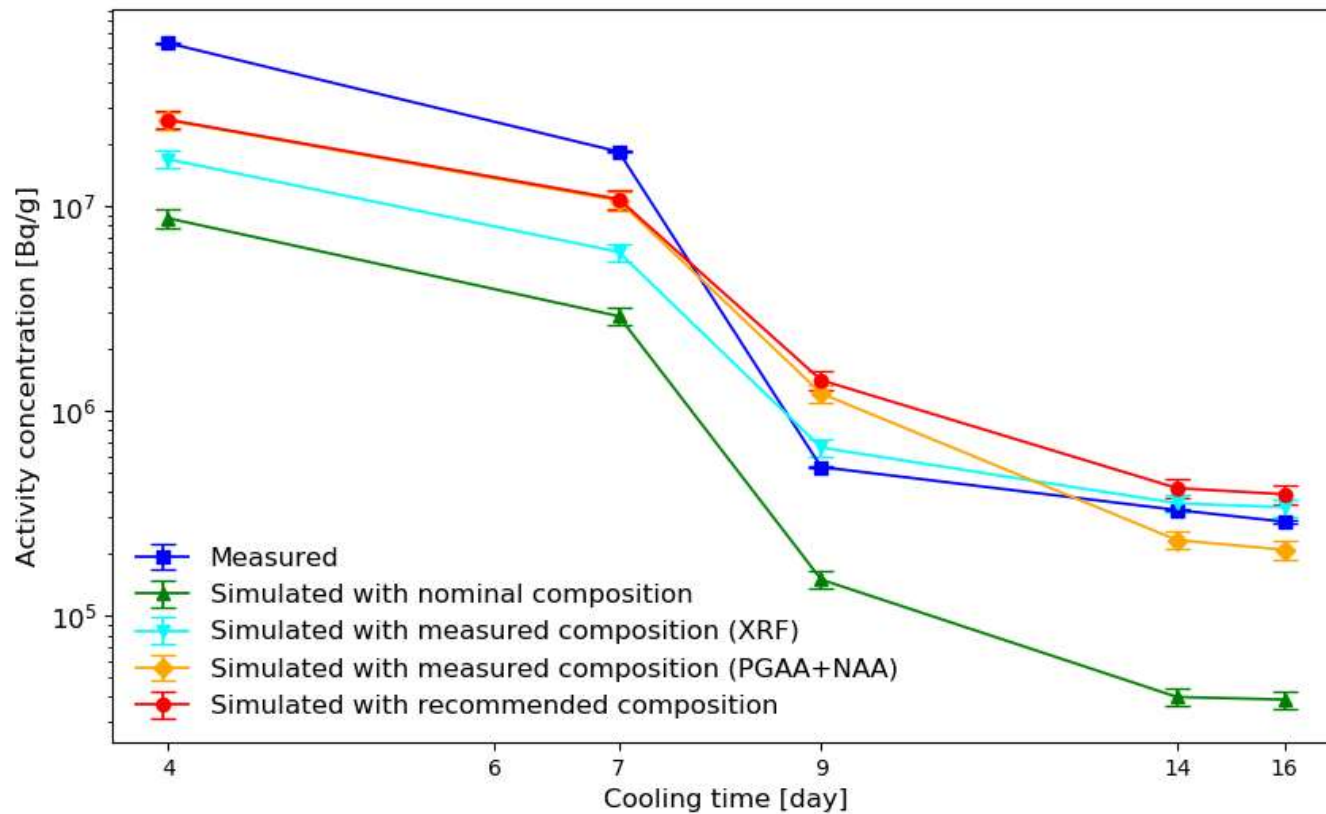
Total activity concentration in PE-B4C concrete
(Fast channel)



Realistic and conservative activation simulation ✓

Decay of measured and simulated activity concentration – reference concrete, ‘fast’ channel

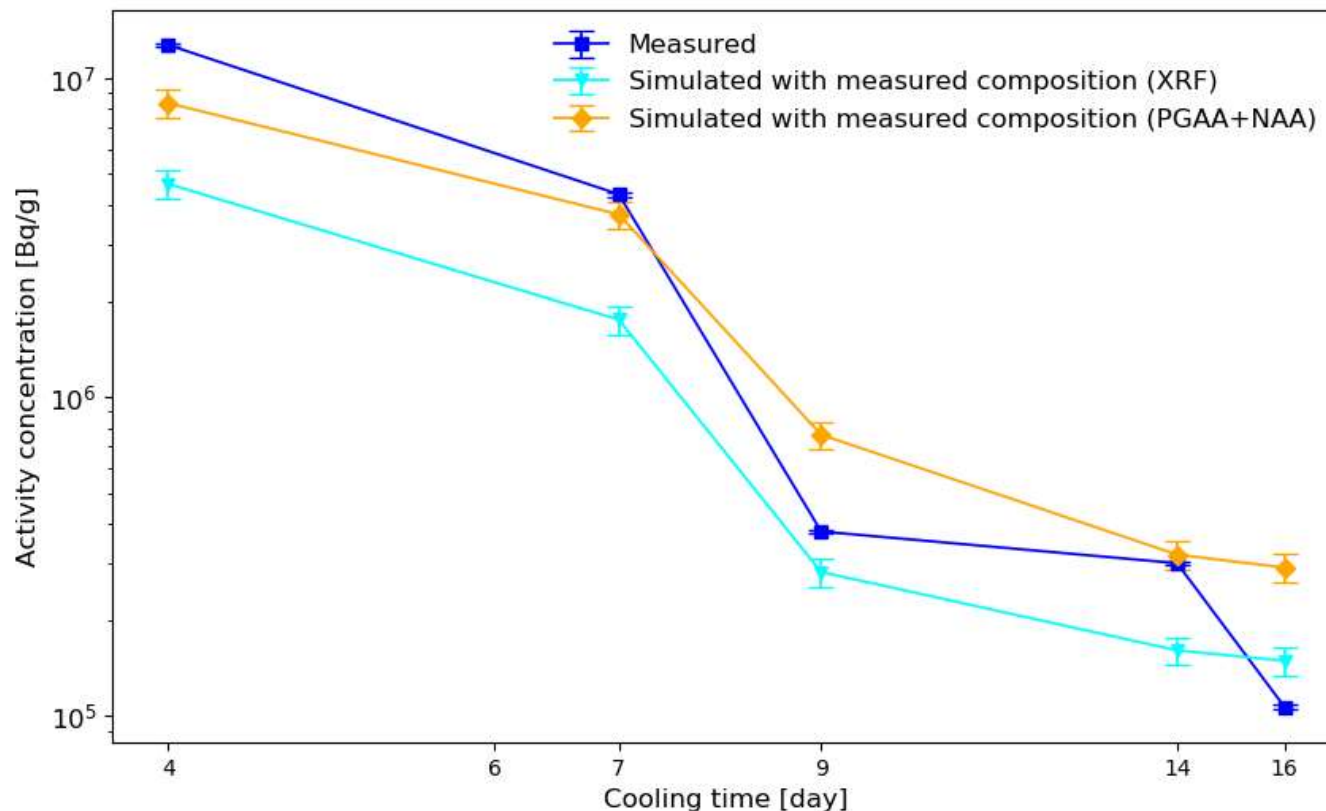
Total activity concentration in Reference concrete
(Fast channel)



Realistic
activation simulation

Decay of measured and simulated activity concentration – Skanska concrete, ‘fast’ channel

Total activity concentration in Skanska concrete
(Fast channel)



Summary

Activity measurements:

- Neutron activation properties of PE-B4C, 'Reference', and Skanska concrete measured and compared



- 20-80% lower activity-concentration in PE-B4C concrete through 2 weeks cooling time

The methodology is ready to adapt for other shielding materials

Measurements & simulations:

- Simulation with nominal composition found to underestimate the activity-production



- Concrete compositions determined with different analytical methods: XRF, PGAA and NAA



- Measurement-based realistic material cards produced for PE-B4C and 'Reference' concrete



Thank you for your attention!
Questions?



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