mta EK CENTRE FOR ENERGY RESEARCH HUNGARIAN ACADEMY OF SCIENCES

DTU

SINE 2020

ACTIVATION PROPERTIES OF NEUTRON SHIELDING MATERIALS

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Introduction

- European Spallation Source ESS ERIC, Lund, Sweden
  - Brightest neutron source

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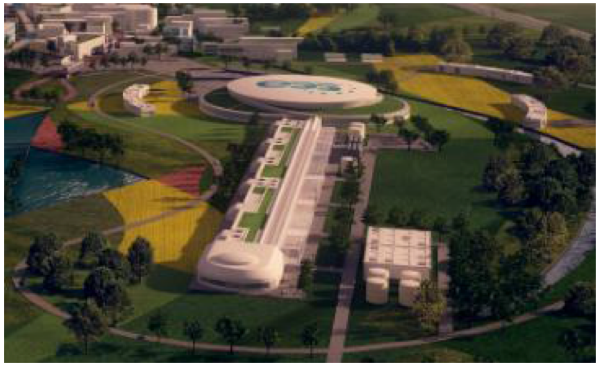
  - Massive shielding volume
    - Space & budget issues

    ↓

  - New shielding material:
    - PE-B4C concrete



waste management

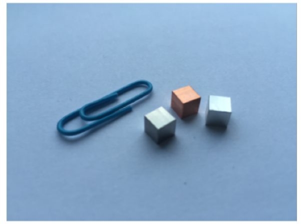
maintenance

Study of activation properties, irradiation experiment & simulation

γ-emitting isotopes only!

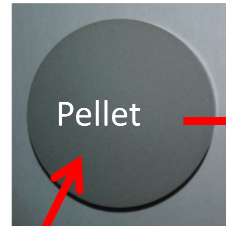
Composition study for MCNP + Cinder90 simulation

Samples and analysis



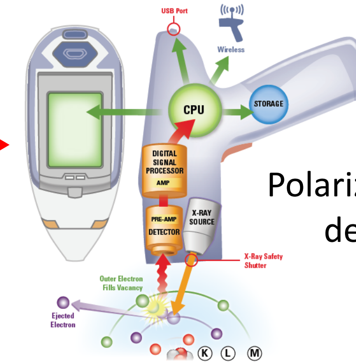
- Metal samples
  - 5x5x5 mm^3 cubes
  - Al, Cu, stainless steel
  - NAA, XRF, validation

- Concrete samples (grain):
  - Reference concrete
  - PE-B4C concrete (developed from reference)
  - Skanska concrete

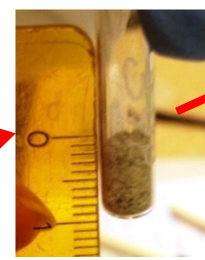


Composition

XRF @ IAEA Seibersdorf



Polarizing XRF device



PGAA @BRR

Composition

HPGe detector

NAA @BRR

Activation & Composition

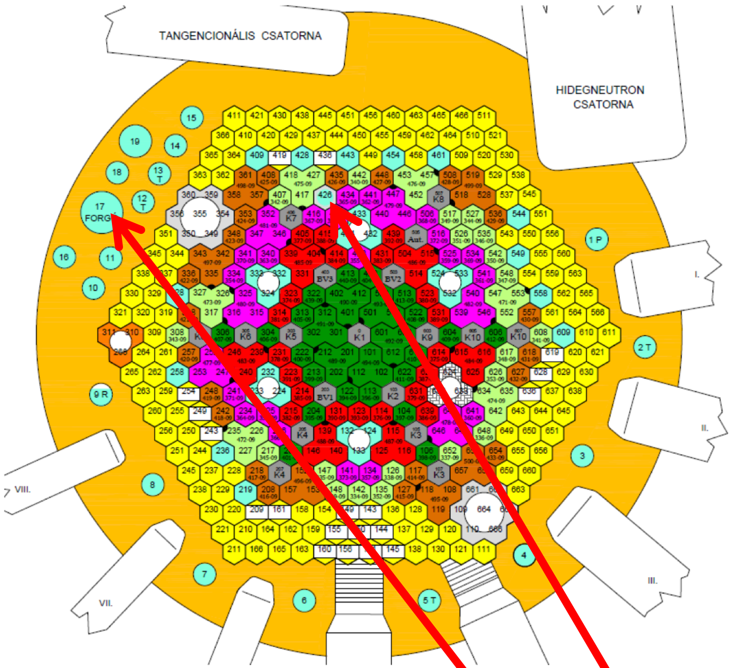
BRR – Budapest Research Reactor

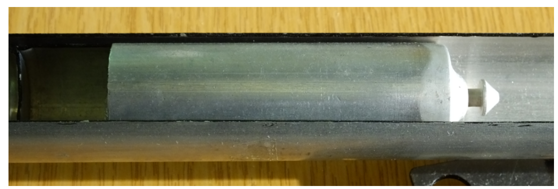
- VVR-type research reactor
  - light water-cooled and moderated tank type reactor with a beryllium reflector
  - low enriched uranium fuel (LEU: 19.9% ^{235}U)
- nominal thermal power: 10 MW
- maximal thermal flux: 2.1×10^{14} n/cm^{2}s
- Reactor „campaign”: 10 effective days
  + break for weekend

~ 160 operational days/year, flexible timetable

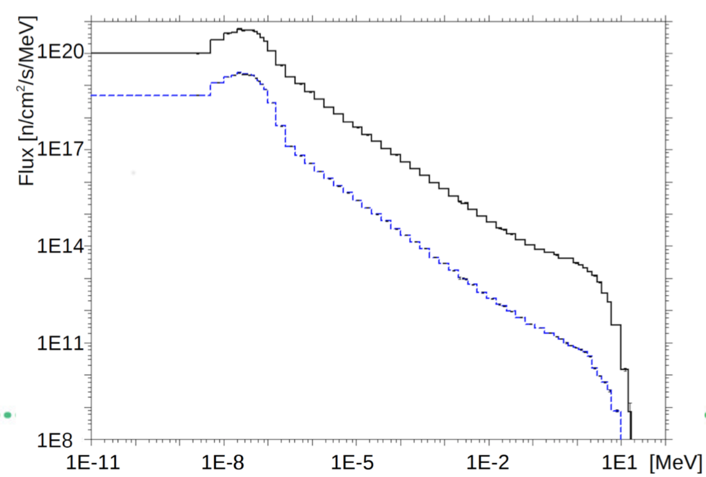
Neutron irradiation of concrete samples – Measurement and simulation

MCNP



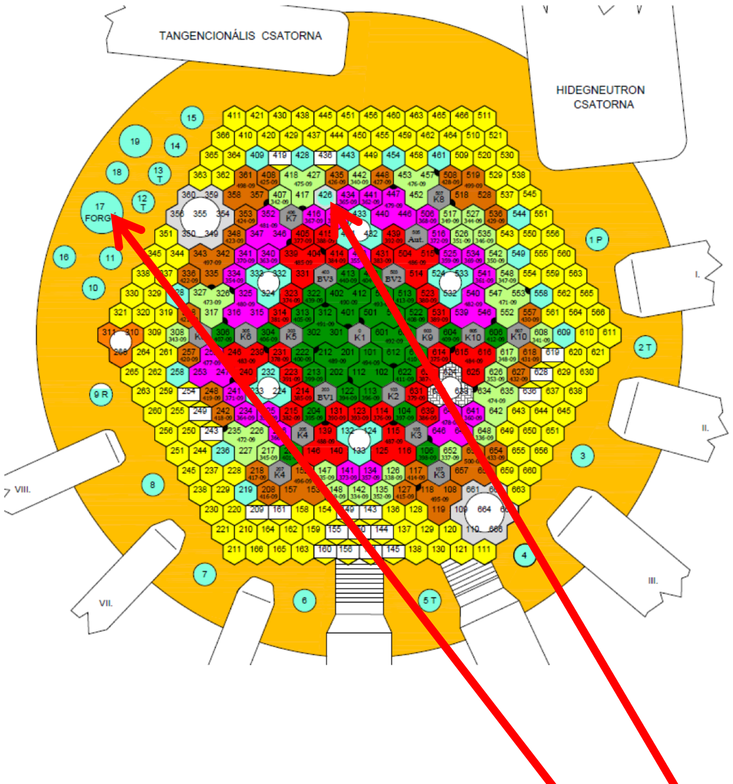


Channel	Thermal	Fast
Thermal flux [1/(cm2*s)]	2.00E+13	5.00E+13
Epithermal flux [1/(cm2*s)]	4.30E+11	3.80E+12
Fast flux [1/(cm2*s)]	1.30E+12	4.70E+13



Neutron irradiation of concrete samples – Measurement and simulation

Measurement



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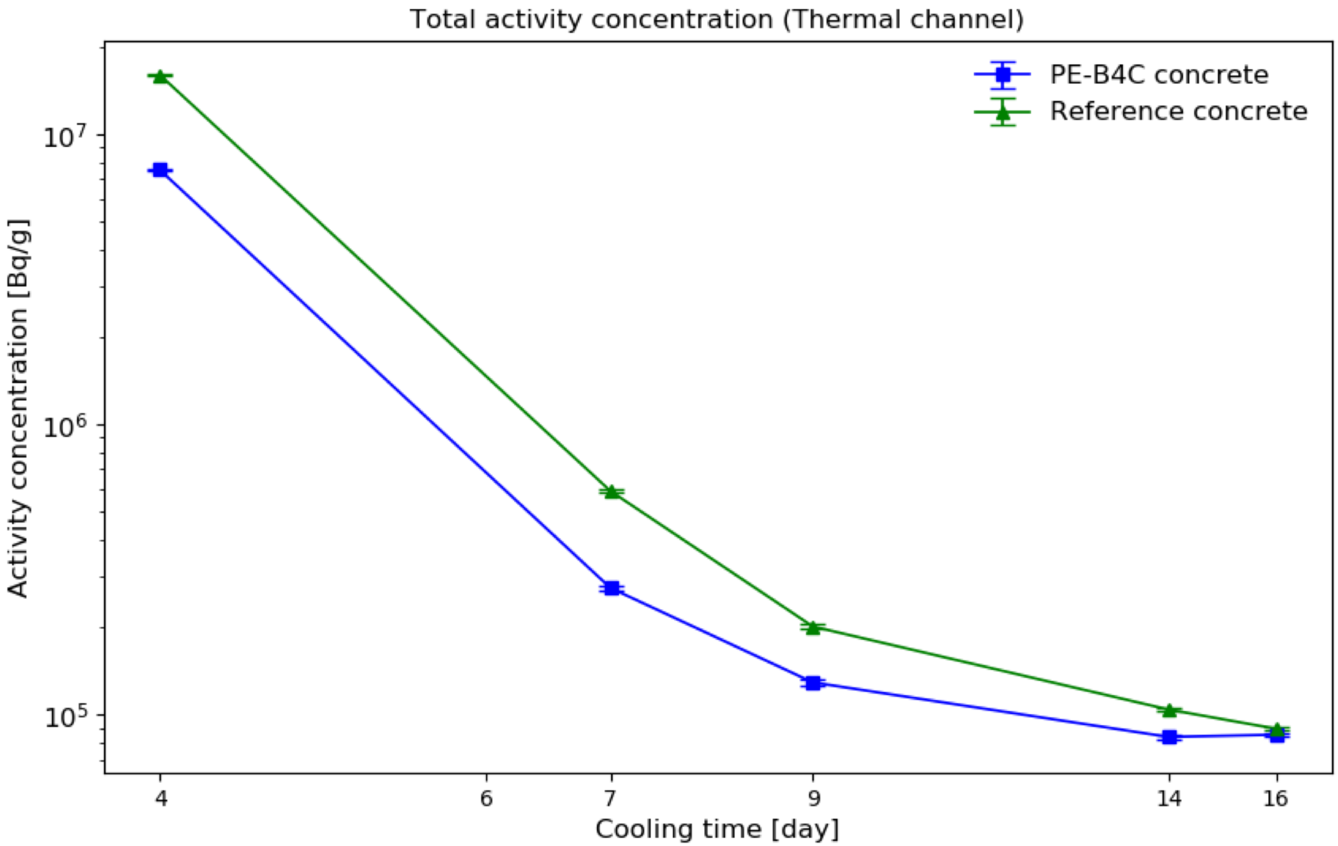
- Irradiation:
  - 2h in 'Thermal channel'
  - 2h in 'Fast channel'
- Gamma spectroscopy:
  - HPGe detector
  - low background measurement chamber
- Cooling time: > 4 days
- Follow-up time: 18 days
- Measurement time: 10 – 110 mins
- Deadtime: 20 – 2 %

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

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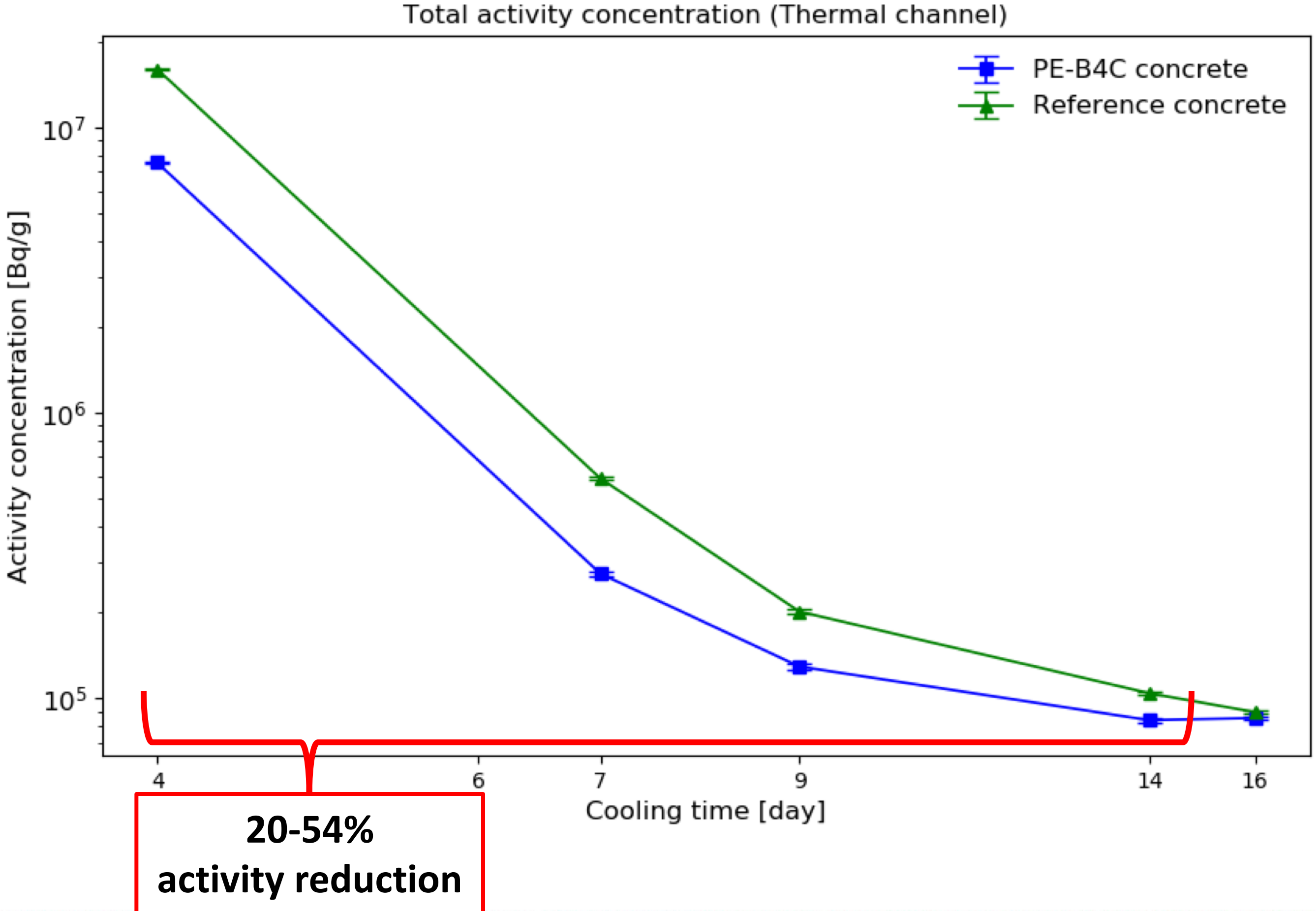

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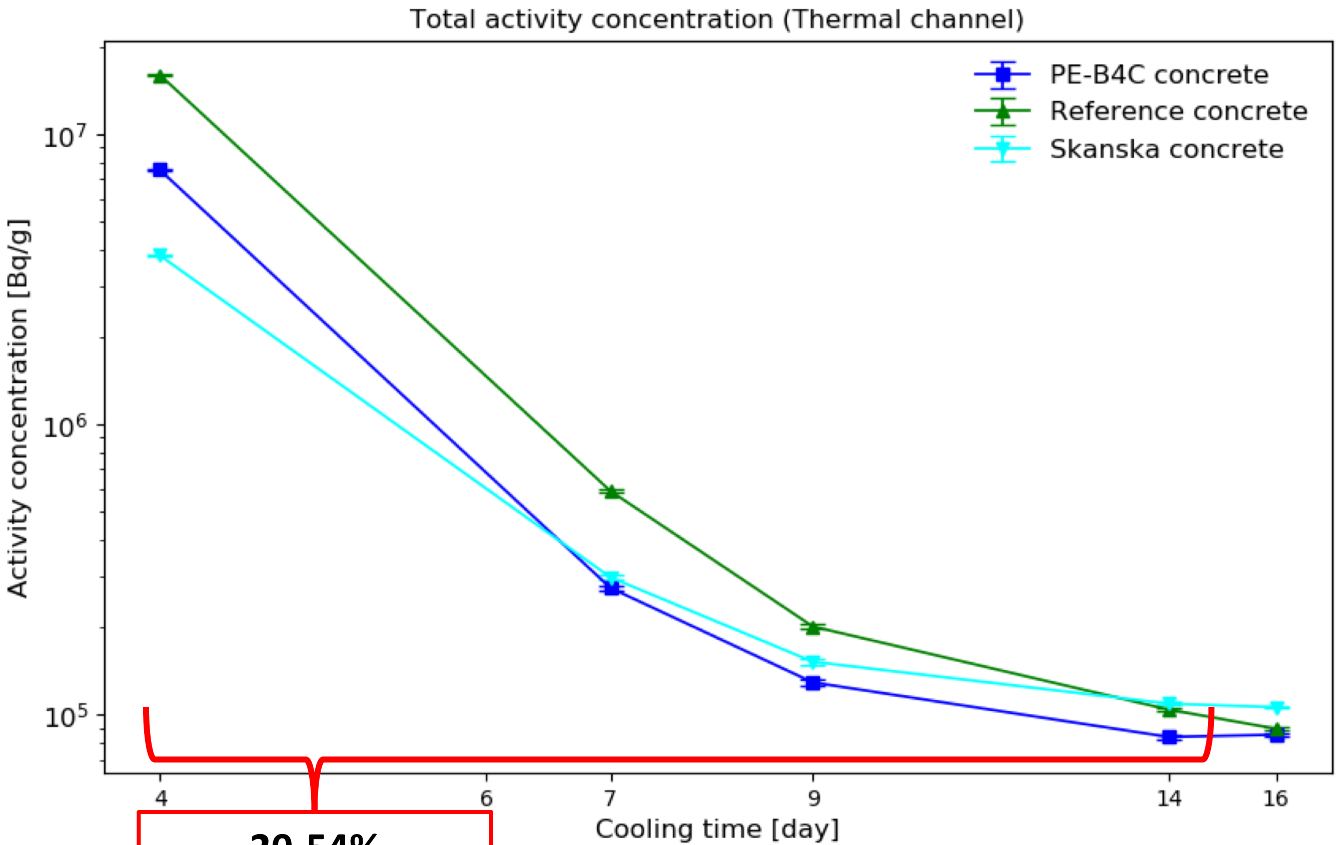

20-54% activity reduction

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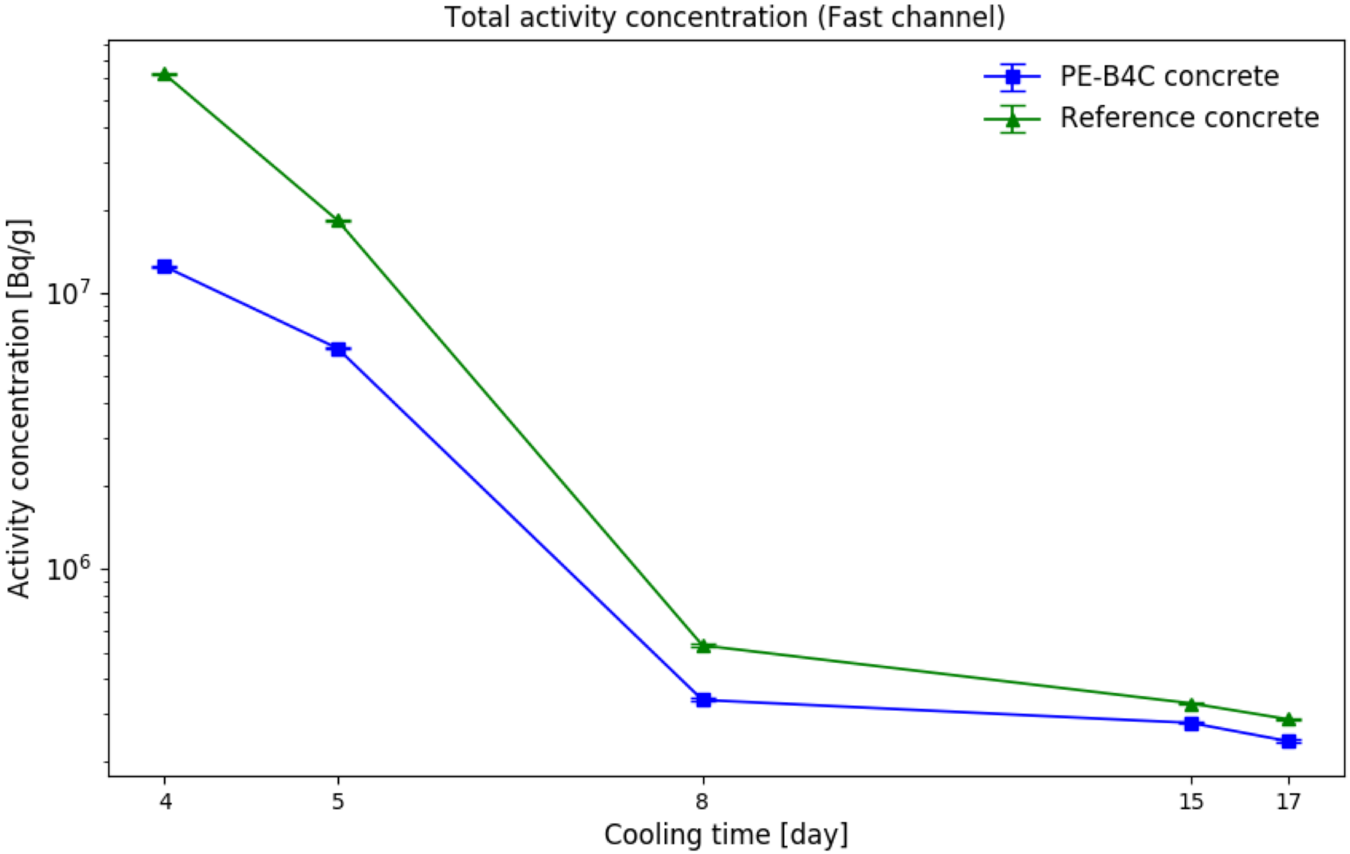
↓

- Key difference for maintenance

Decay of measured activity concentration – ‘fast’ channel

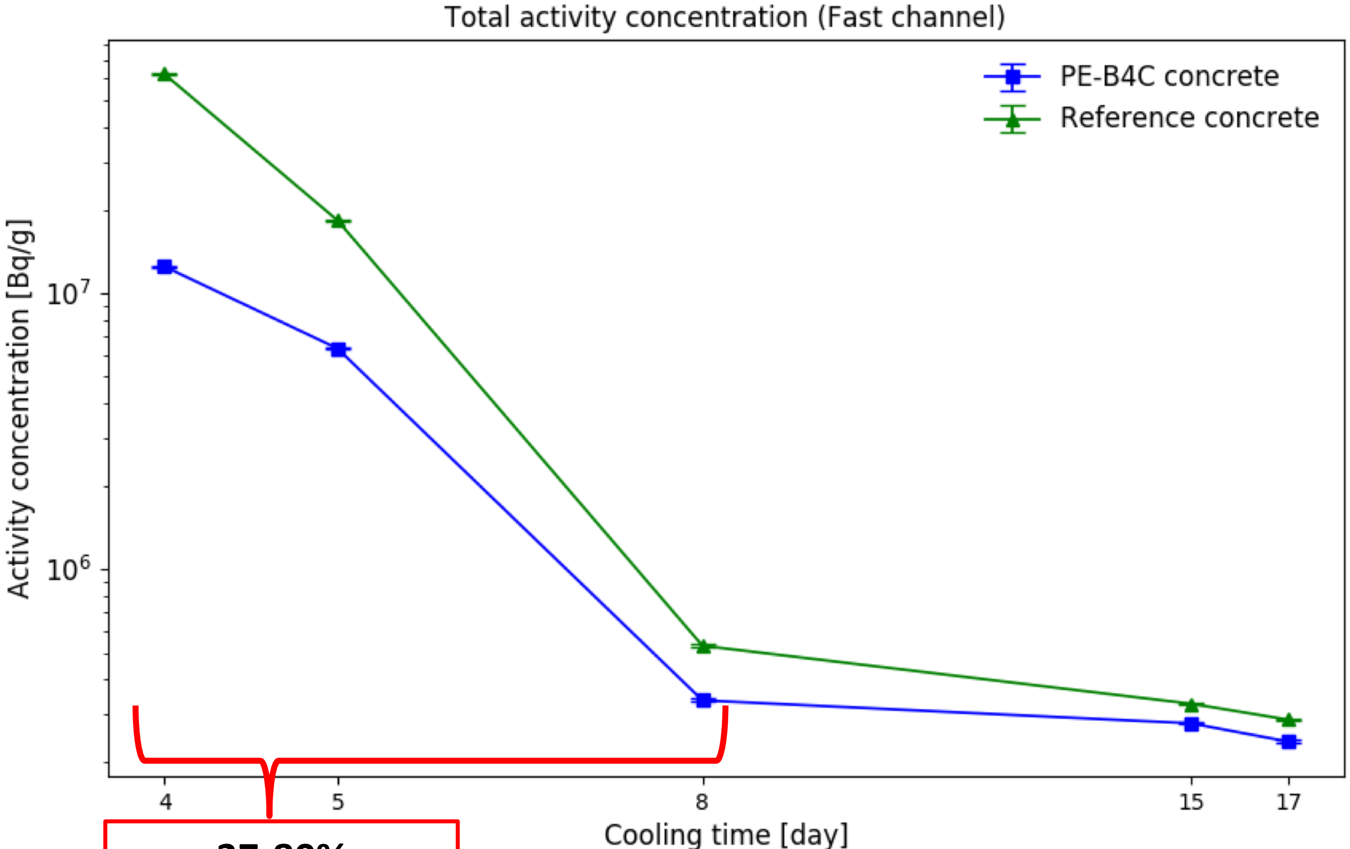
Measurement



- 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

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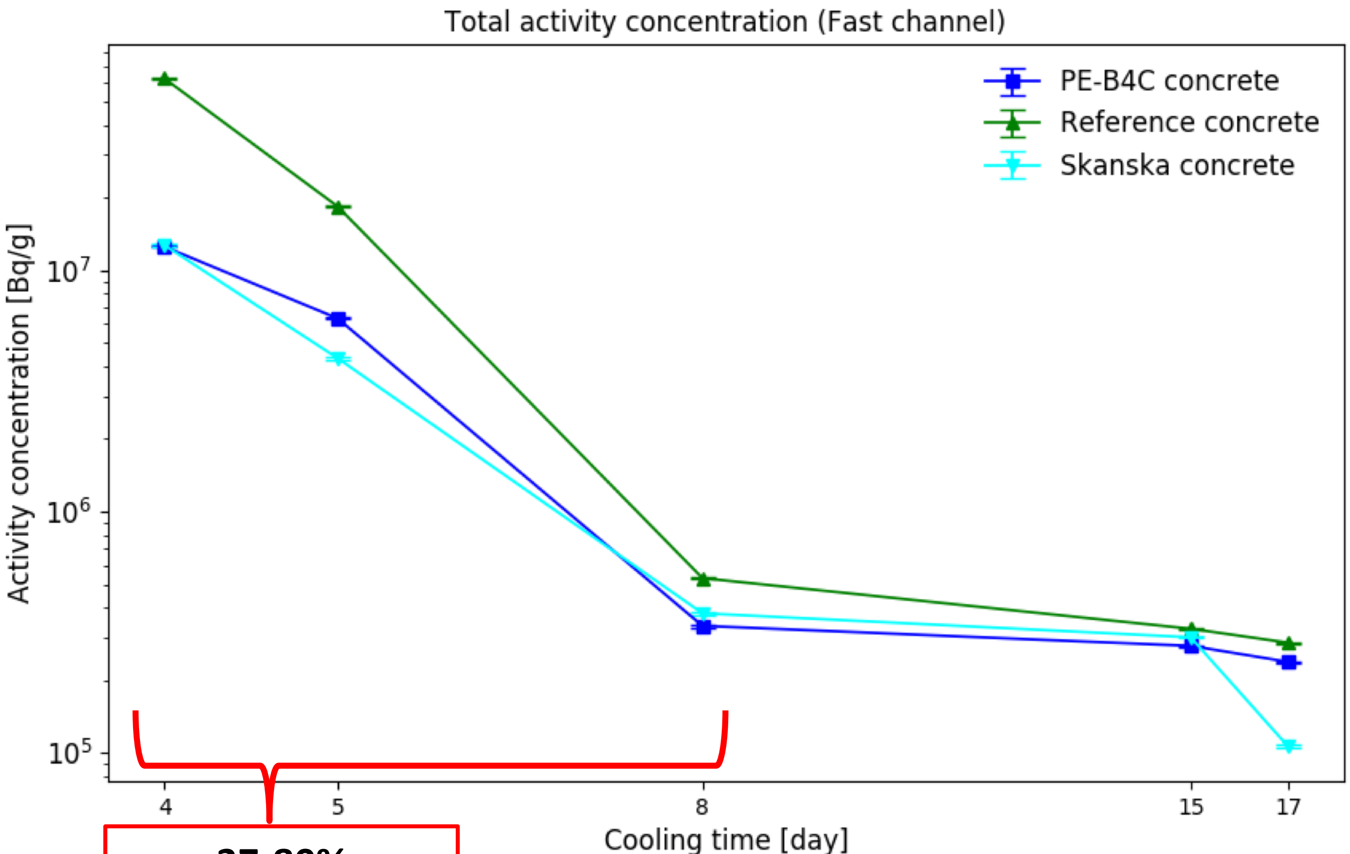

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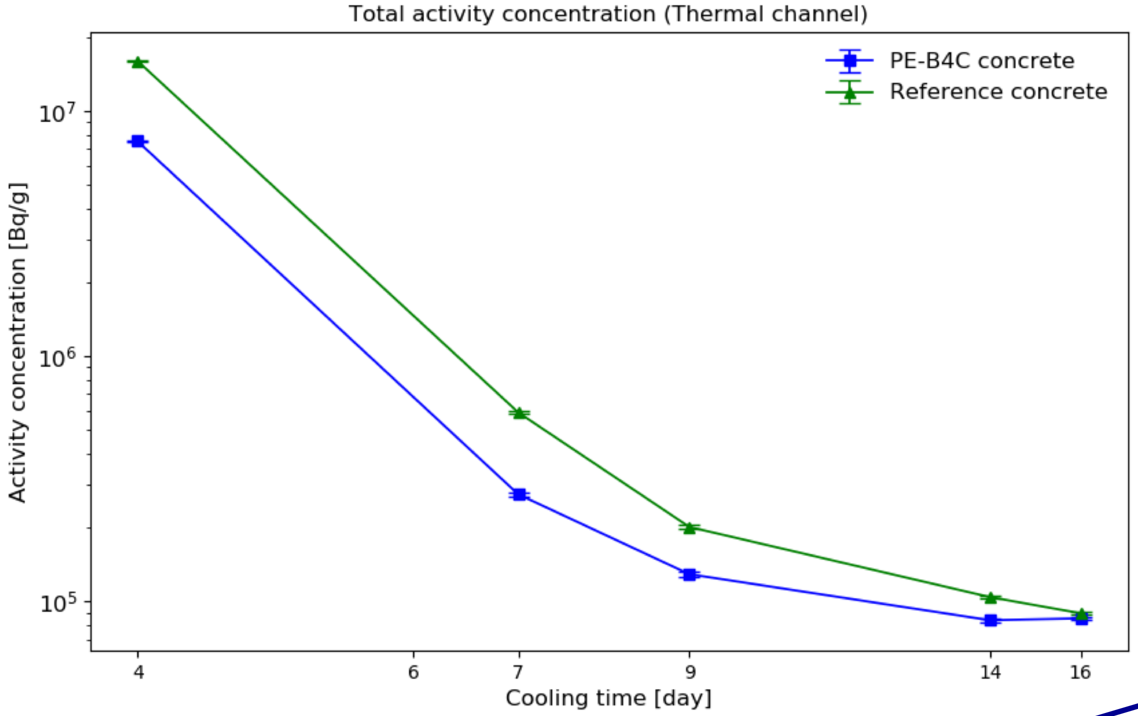

Cinder issues due to pure β-emitters

- 15 γ-emitting 'key nuclides' found, giving >85% 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

	[w%]						
Element	**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					

	[ppmw] (understanding as simple mass ratios)						
Element	**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	295.225		
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

Measured and nominal composition of PE-B4C concrete

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Si	28.60	21.50	0.710	27.04	0.003		
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P	260						

Recommended MCNP material cards

PE-B4C CONCRETE [1.97 g/cm^3]

```
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
```

REFERENCE CONCRETE [2.33 g/cm^3]

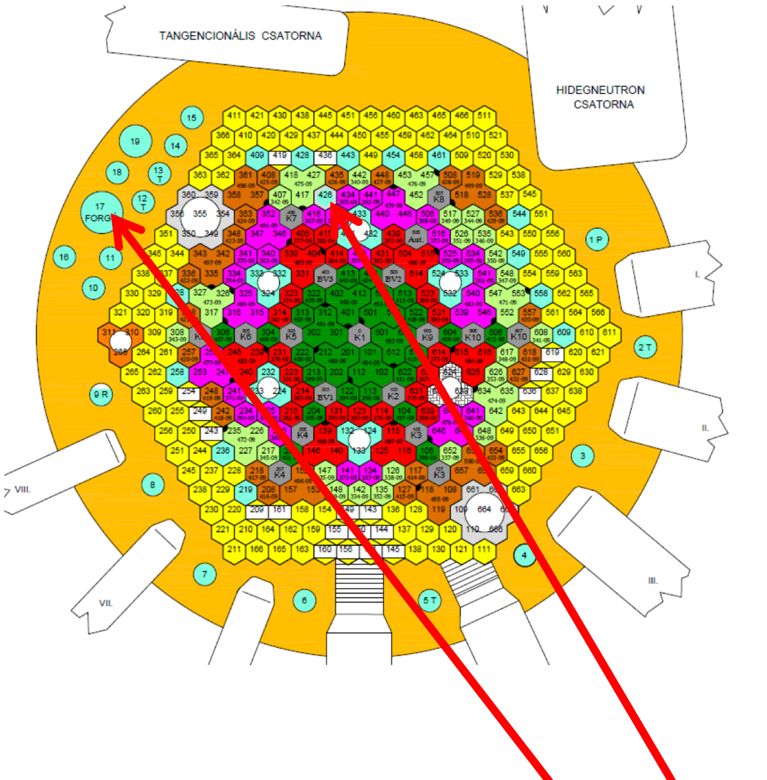
```
M31   1001  -7.23E-01
     13000  -3.70E+00
     14000  -3.27E+01
     16000  -2.36E-01
     19000  -2.12E+00
     20000  -7.12E+00
     17000  -3.02E-03
     12000  -2.37E-01
      8016  -4.94E+01
     22000  -1.76E-01
     11000  -1.99E+00
     26000  -1.55E+00
     74000  -5.96E-02
     57000  -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
```

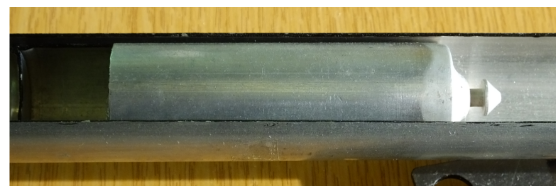
- Mixed composition from nominal composition and the results of all three analytical methods (XRF, PGAA, NAA)
- Recommended for MCNP activity simulation

↓

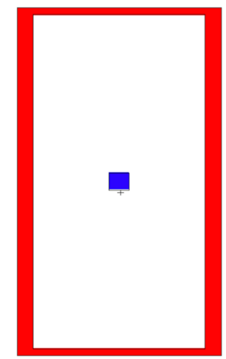
'Supermix'

Neutron irradiation of concrete samples – Measurement and simulation





MCNP



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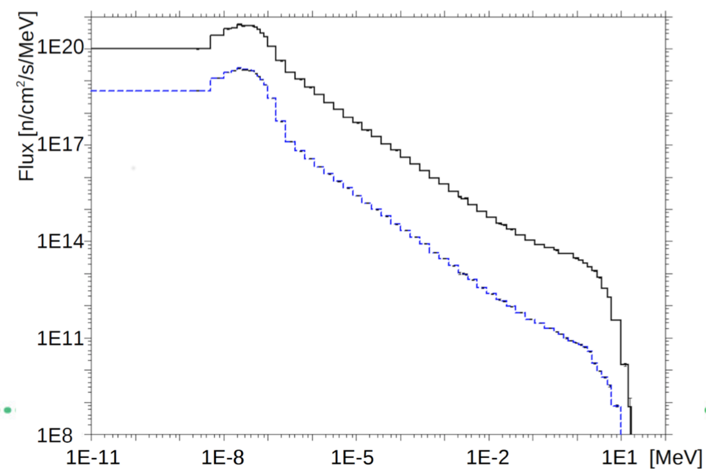
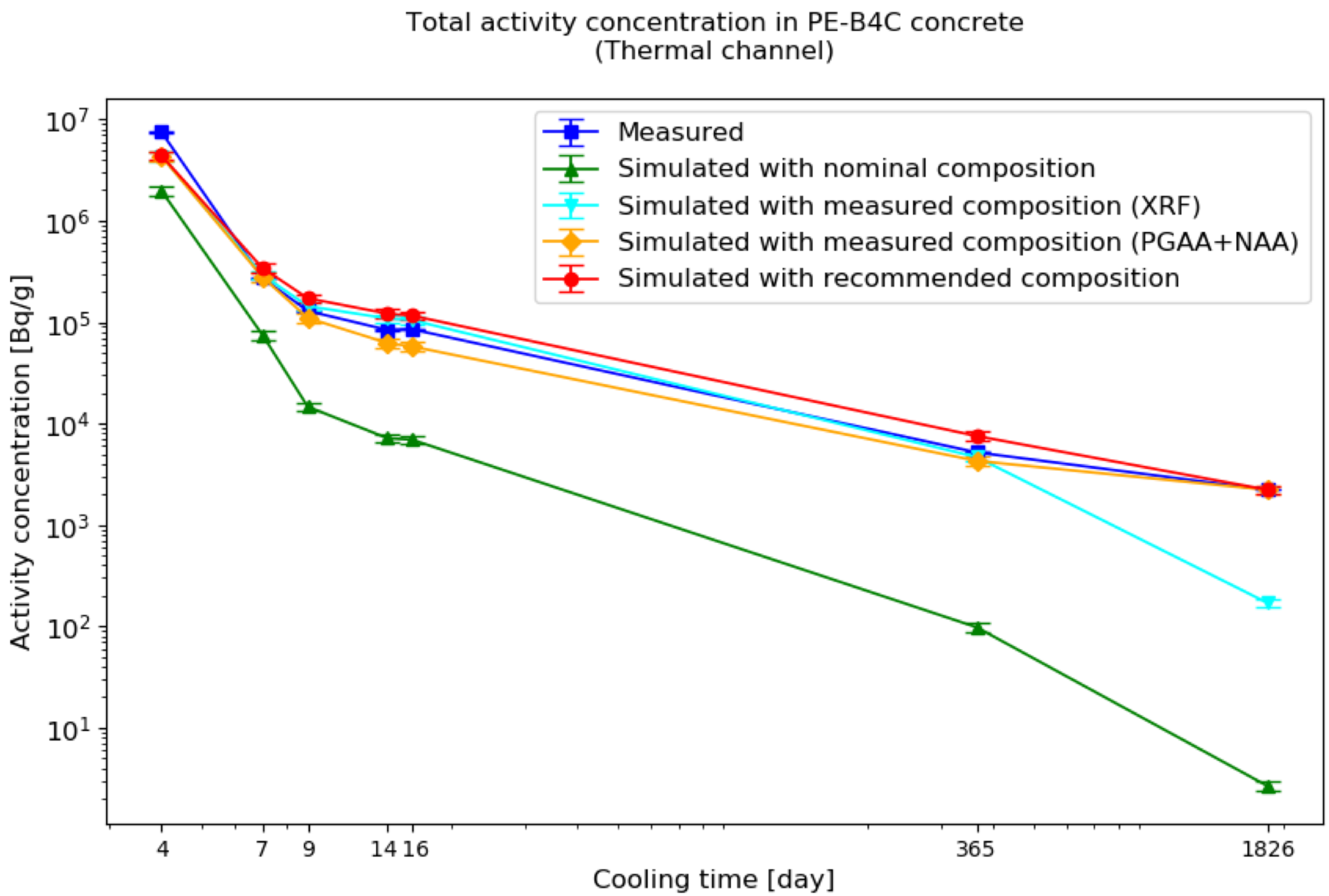


Decay of measured and simulated activity concentration – PE-B4C concrete, ‘thermal’ channel

MCNP

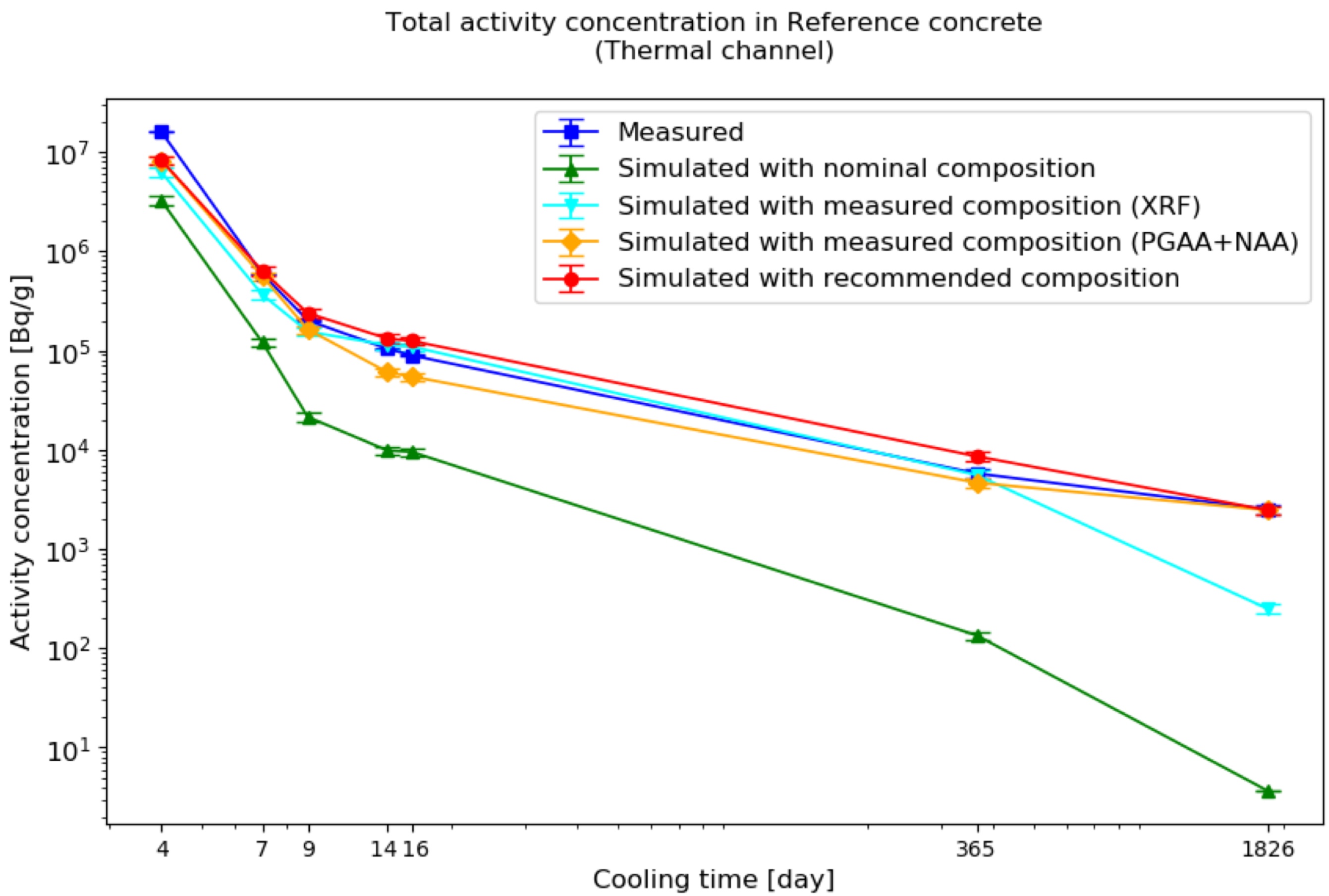


Realistic and conservative activation simulation ✓

Future plans: sensitivity study for measured input data

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

MCNP

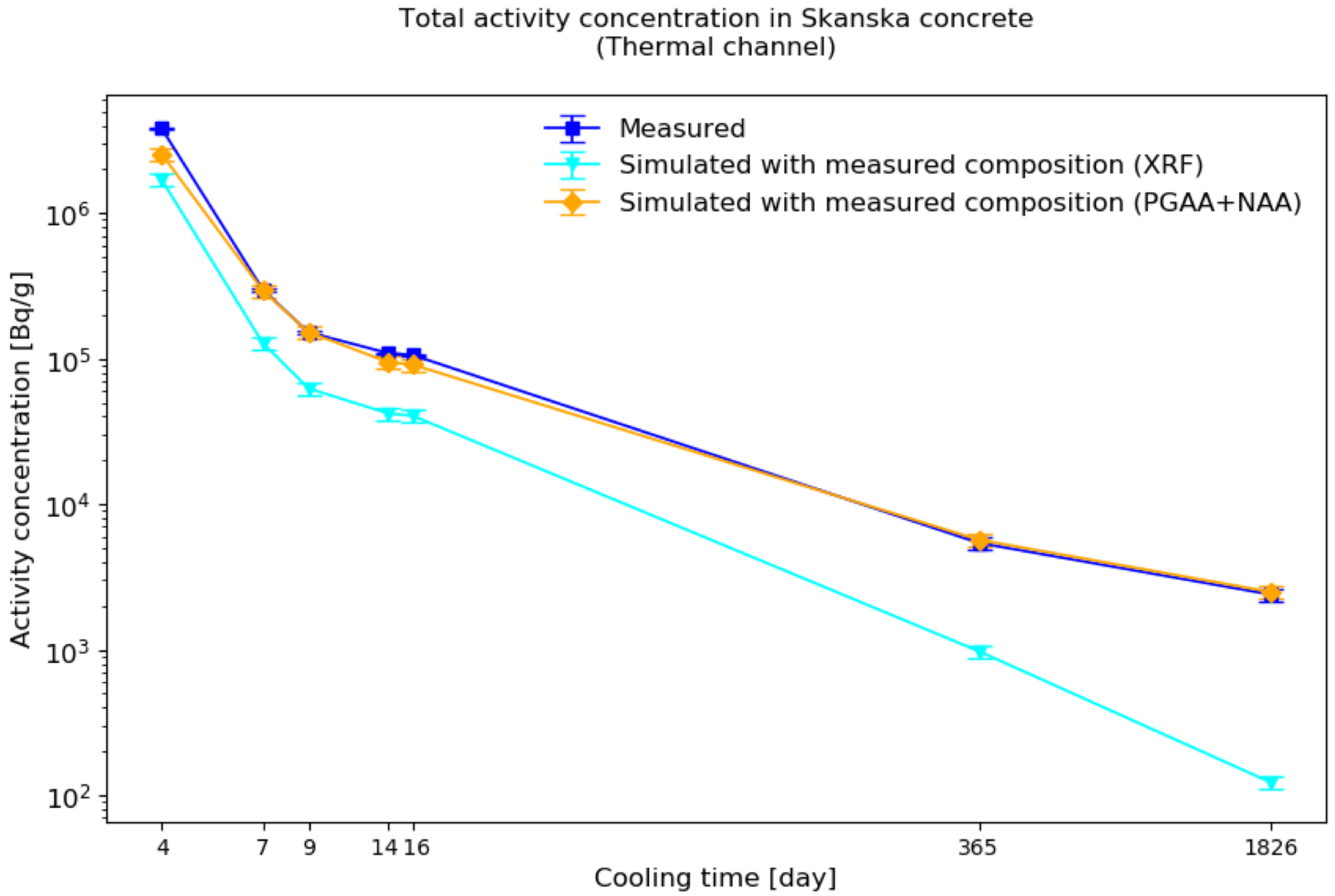


Realistic and conservative activation simulation

Future plans: sensitivity study for measured input data

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

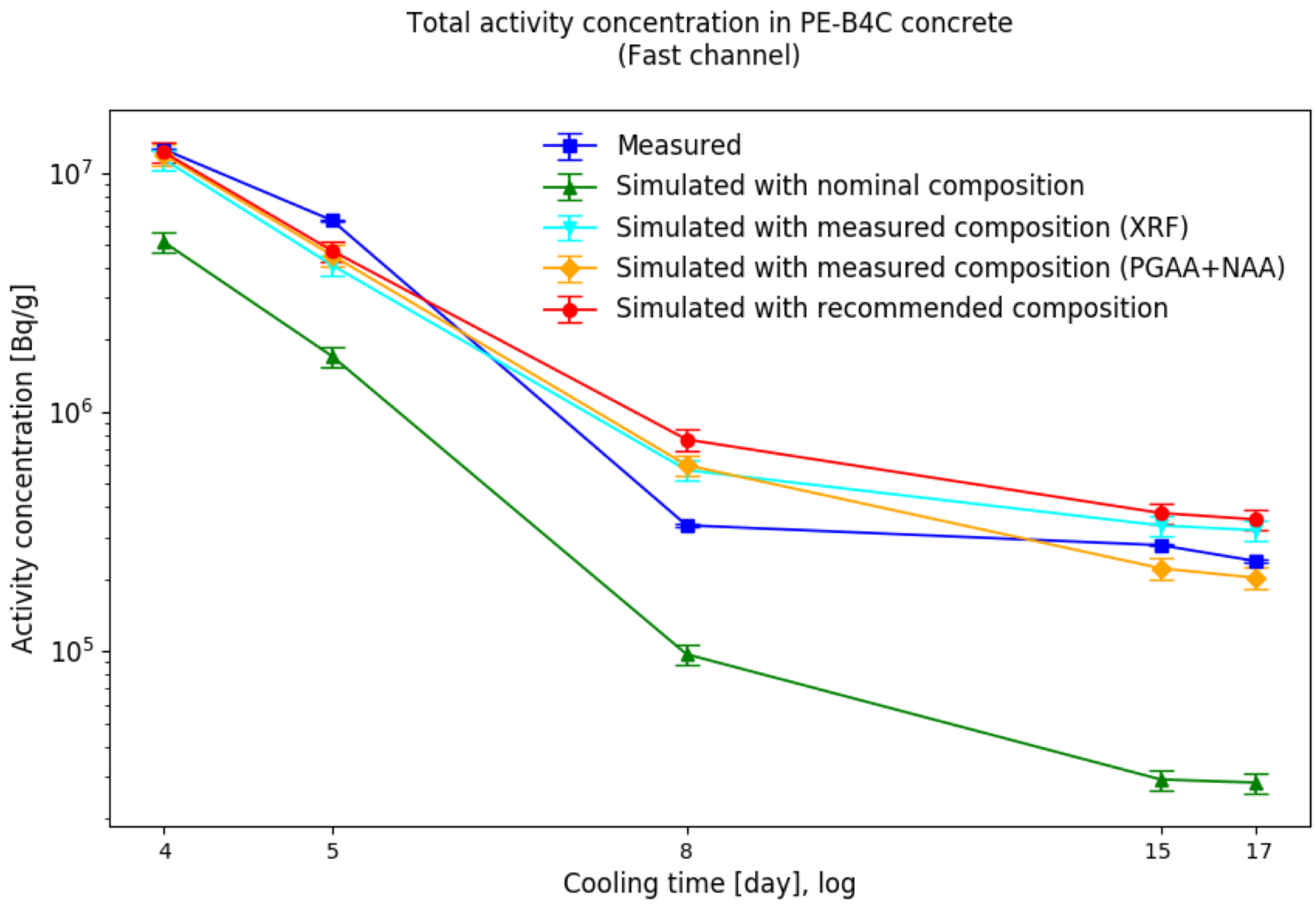
MCNP



Future plans: sensitivity study for measured input data

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

MCNP



Realistic and conservative activation simulation

Future plans: sensitivity study for measured input data

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

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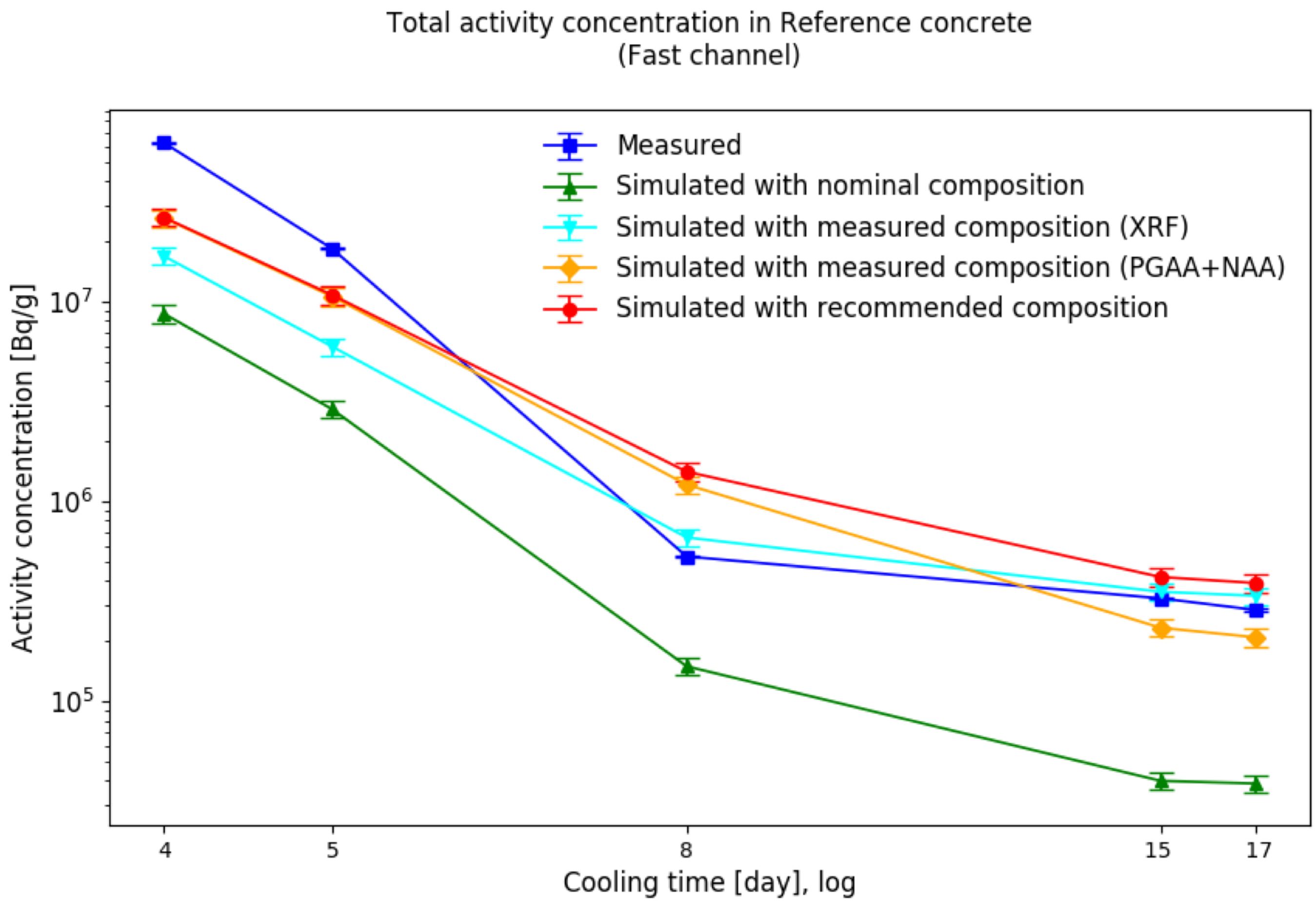

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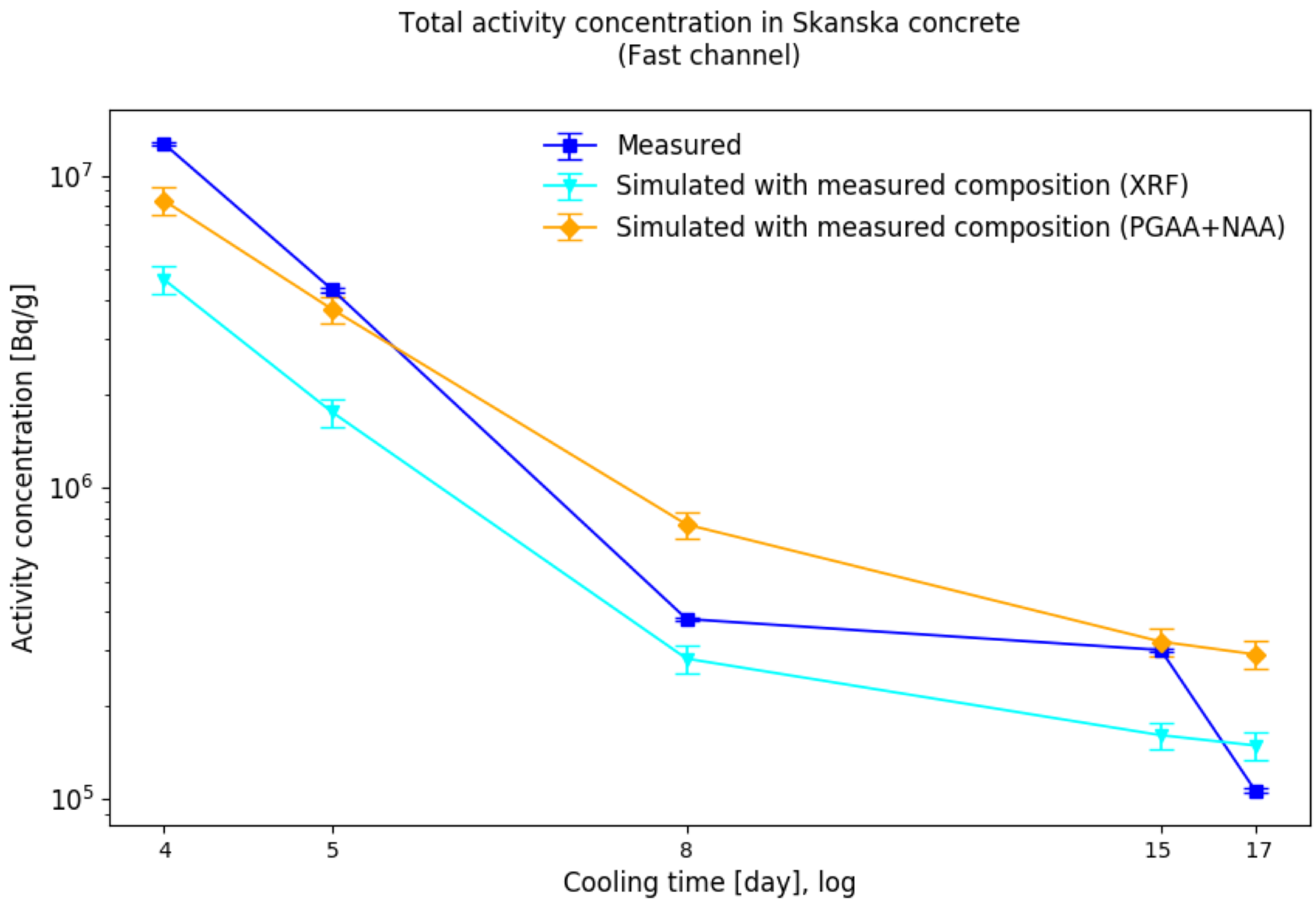
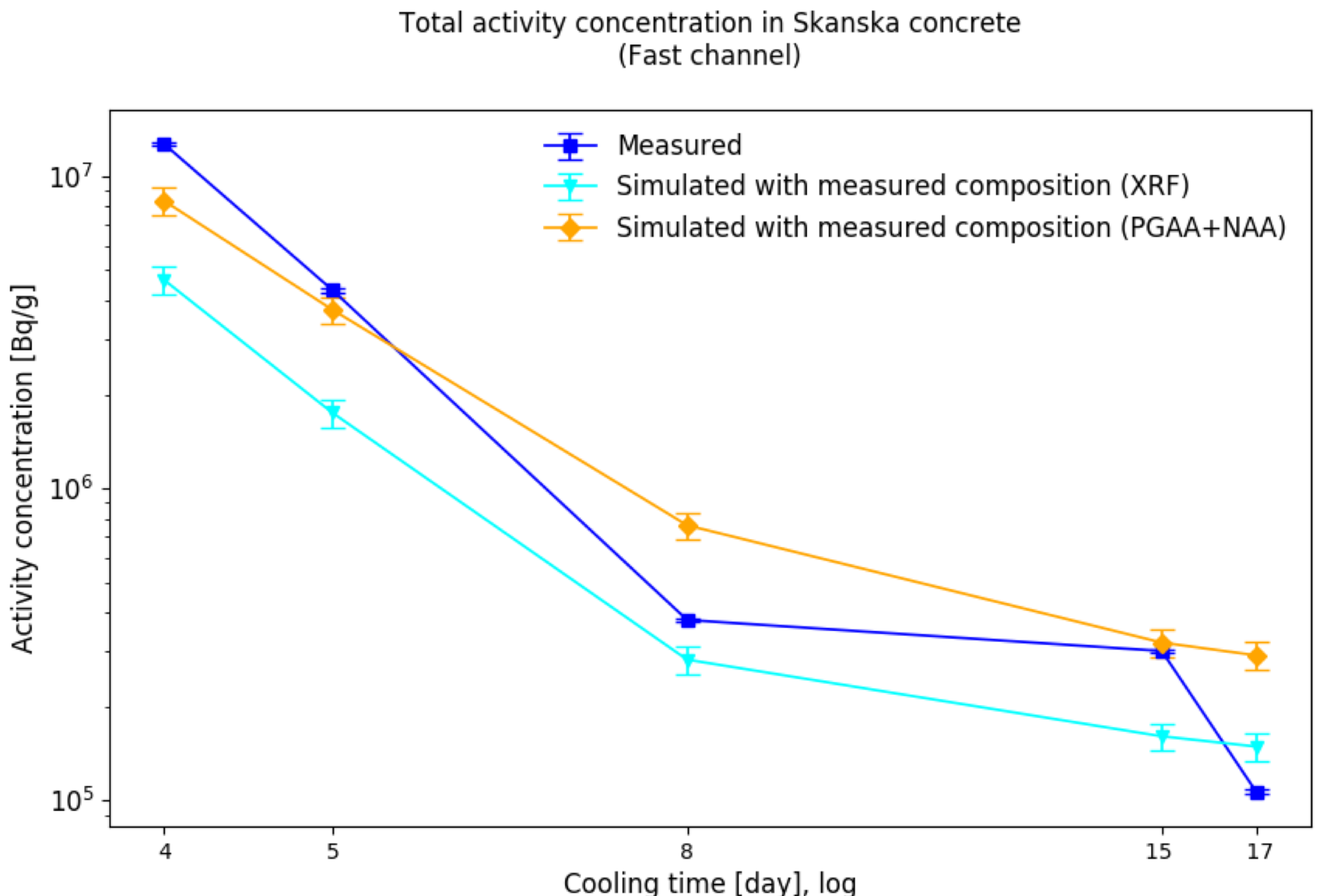


Future plans: sensitivity study for measured input data

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

MCNP



Future plans: sensitivity study for measured input data

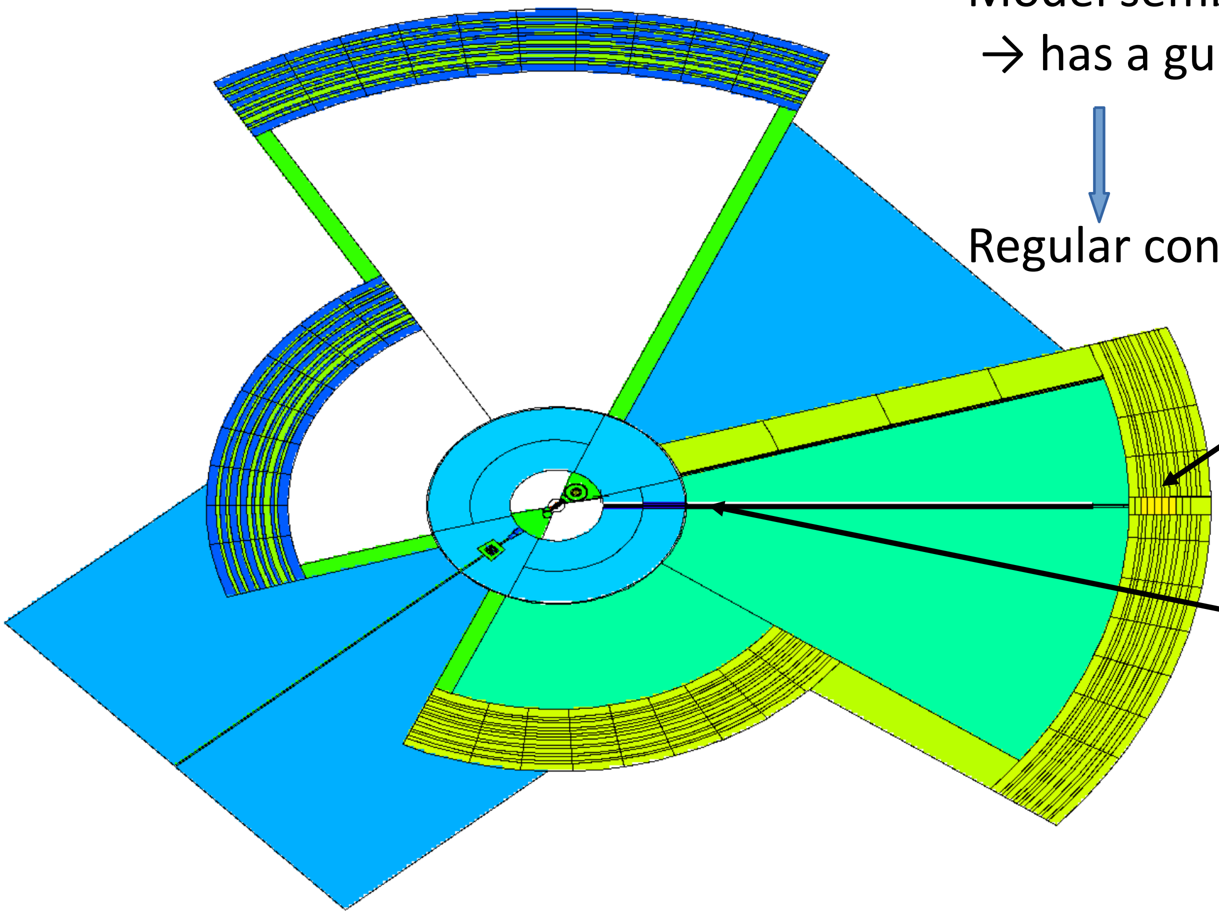
Recommended material cards applied to ESS bunker
→ ‘Supermix’

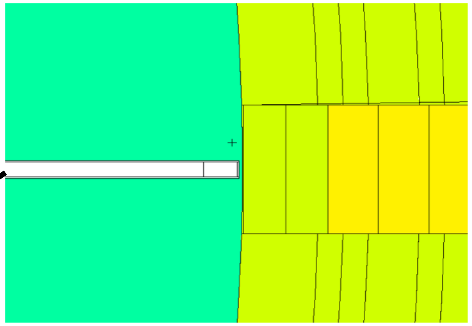
Comblayer model – VOR beamline

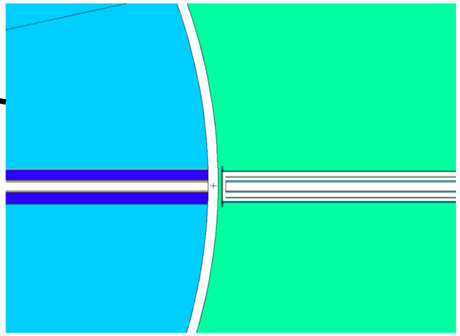
MCNP

Model semirealistic only.
→ has a guide, but no bunker penetration

Regular concrete







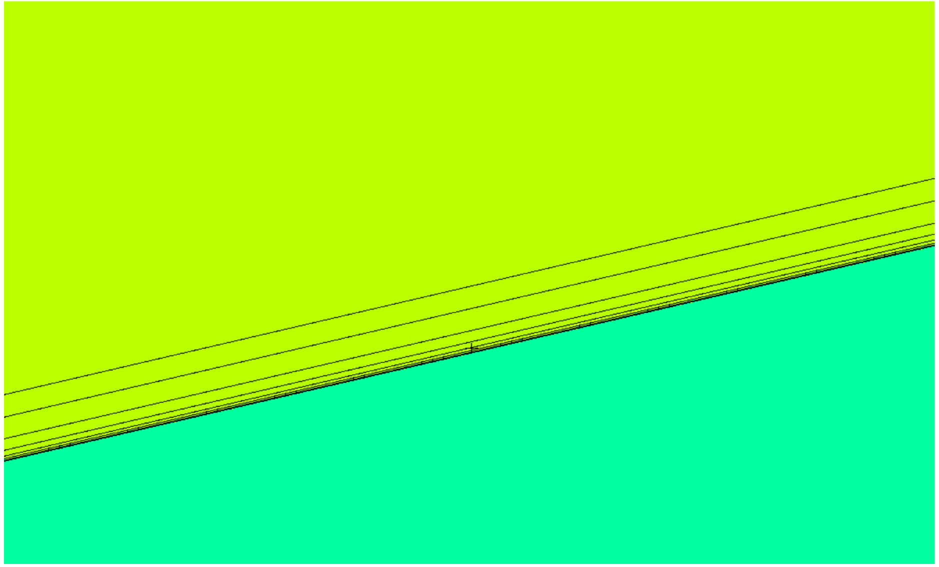
Simulation procedure

1) MCNP transport simulation. Source: protons on target
=> energy binned flux + spallation induced isotope production rates.
Results are normalized: per proton
2) Characterize irradiation and cooling scenarios
3) Cinder Activation calculation + gamma script => Gamma source(s)
4) MCNP gamma transport calculation.
5) Conversion gamma flux to dose rate

The above steps are carried out for each material:
→Supermix (recommended composition from measurement)
→ESS ref: old, dating to initiation of studies
→ESS ref: used in bunker modeling

Simulation procedure

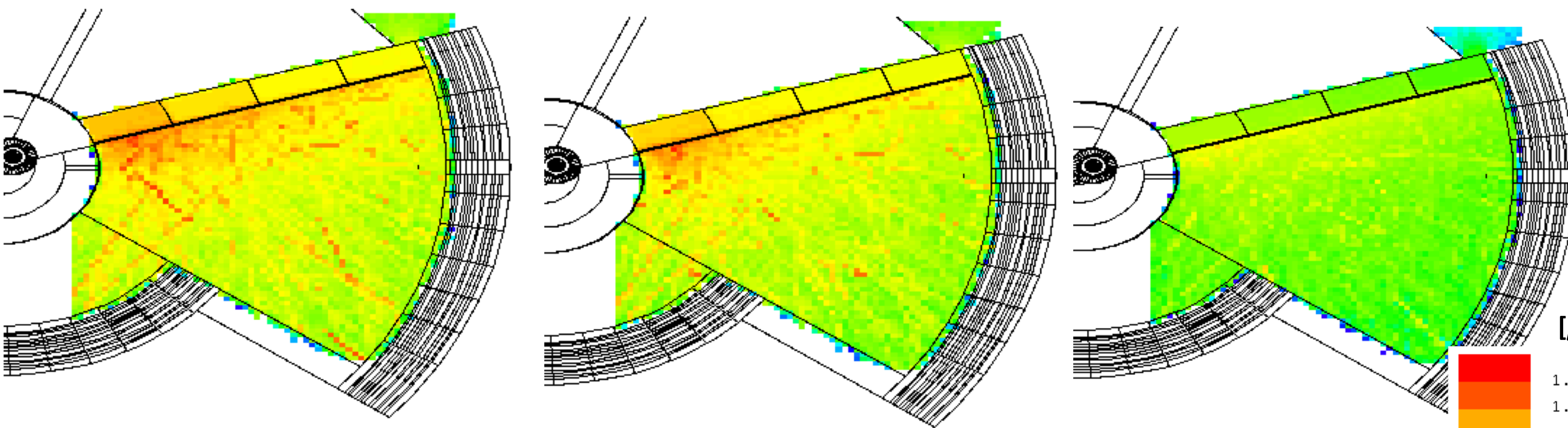
→To ensure accurate results, self shielding is important to consider.
→In practice this means that the parts of the concrete facing the inside of the inside of the bunker is much more important for the dose in the bunker, than concrete behind it => cell divide

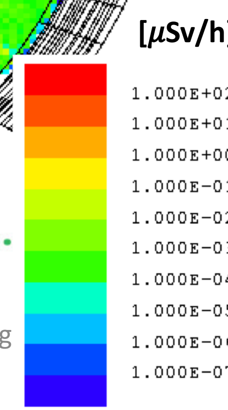


Results

Assuming 10 years of ESS average operation (5MW x 0.616), followed by 6 months of 5MW followed by 3 days of cooling.

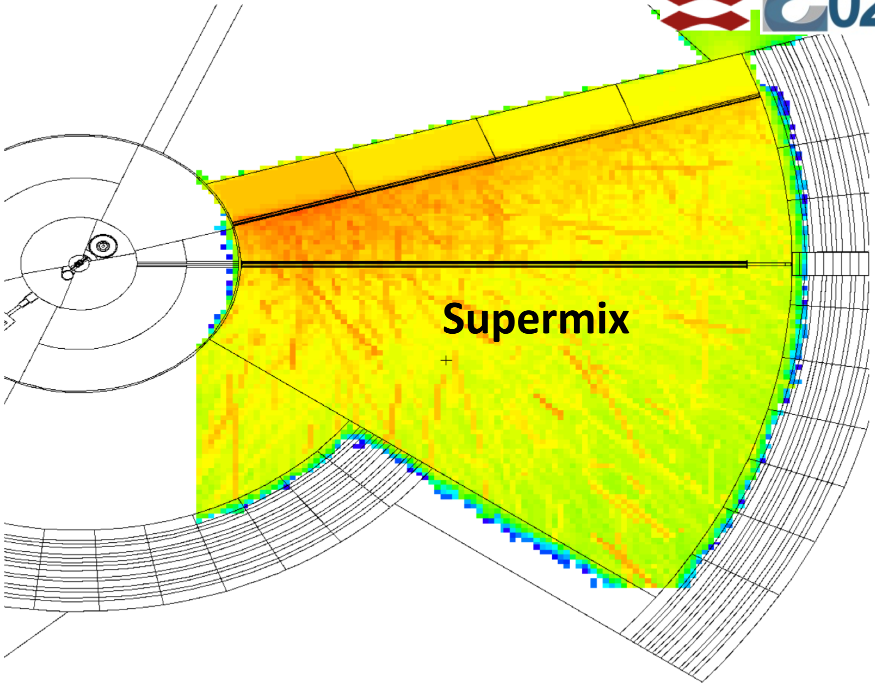
Supermix | ESS ref (old) | ESS ref (used in bunker)

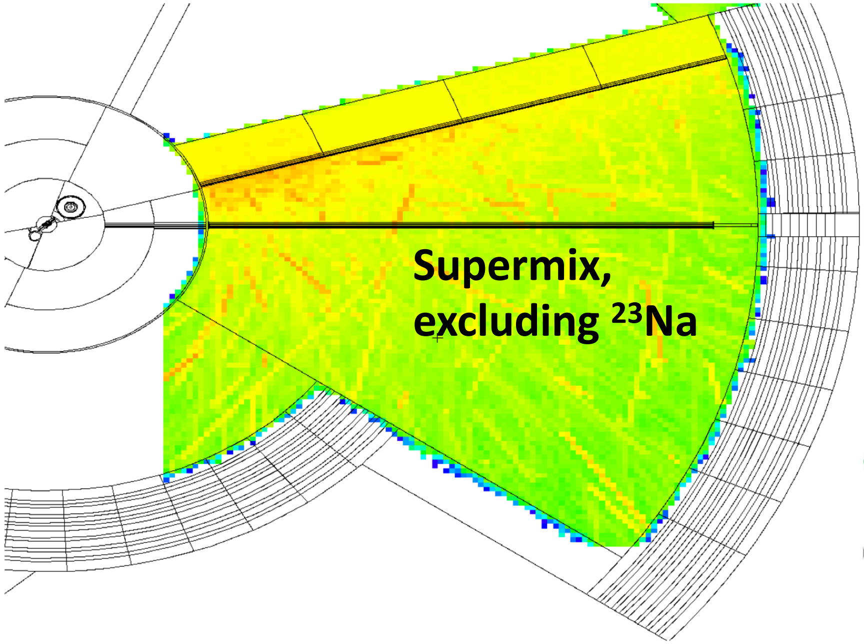




Results

- In addition to a new gamma source, Cinder lists the activity of all isotopes
- From that list ^{24}Na seems to be the main source of dose.
- T½ = 15h
- Eγ =1.4MeV





Summary

Activity measurements:

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

↓

- 20-80% lower activity-concentration from 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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