EUROPEAN SPALLATION SOURCE

ESS PEB4C Concrete

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IKON 13

September 2017

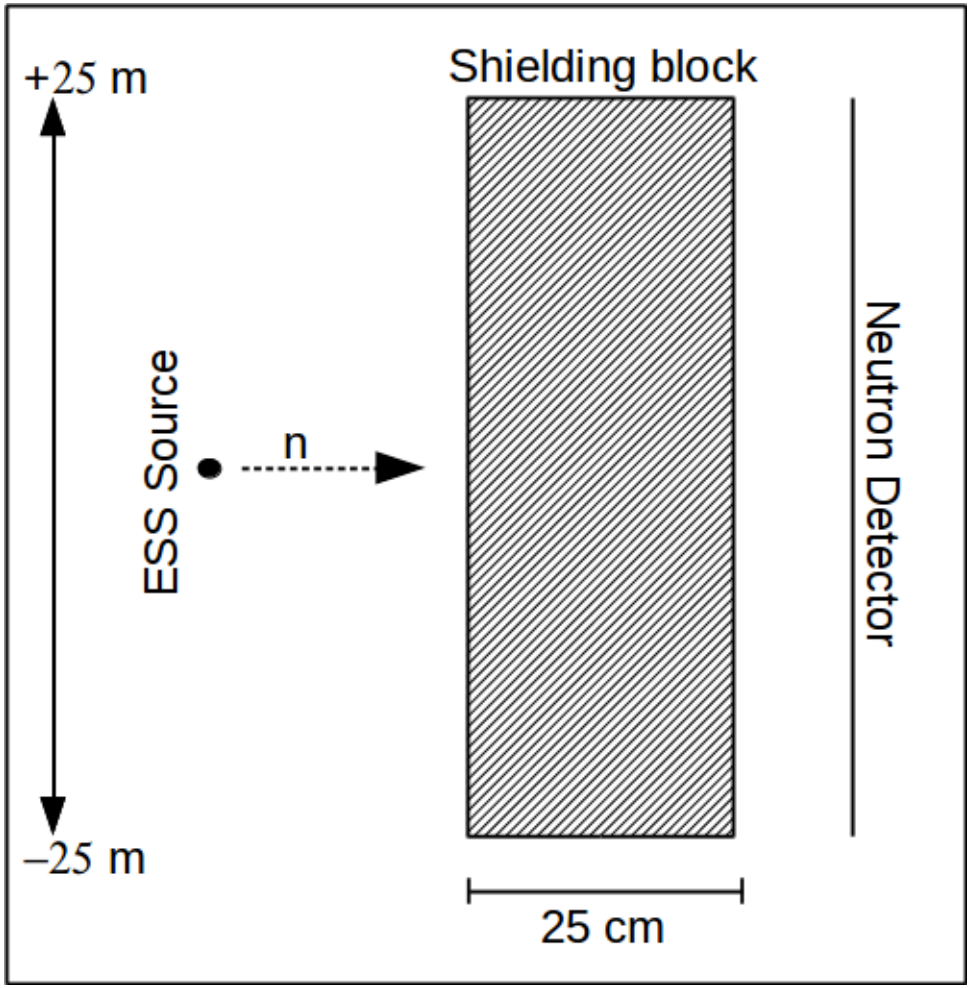
Objectives

- Low cost concrete to replace 1-for-1 “normal” concrete
- Open source – no fees, patents licenses
- Superior performance, particularly 10 keV – 1 MeV
- Chemically stable
- Structurally stable
- Non-toxic
- Fire resistant

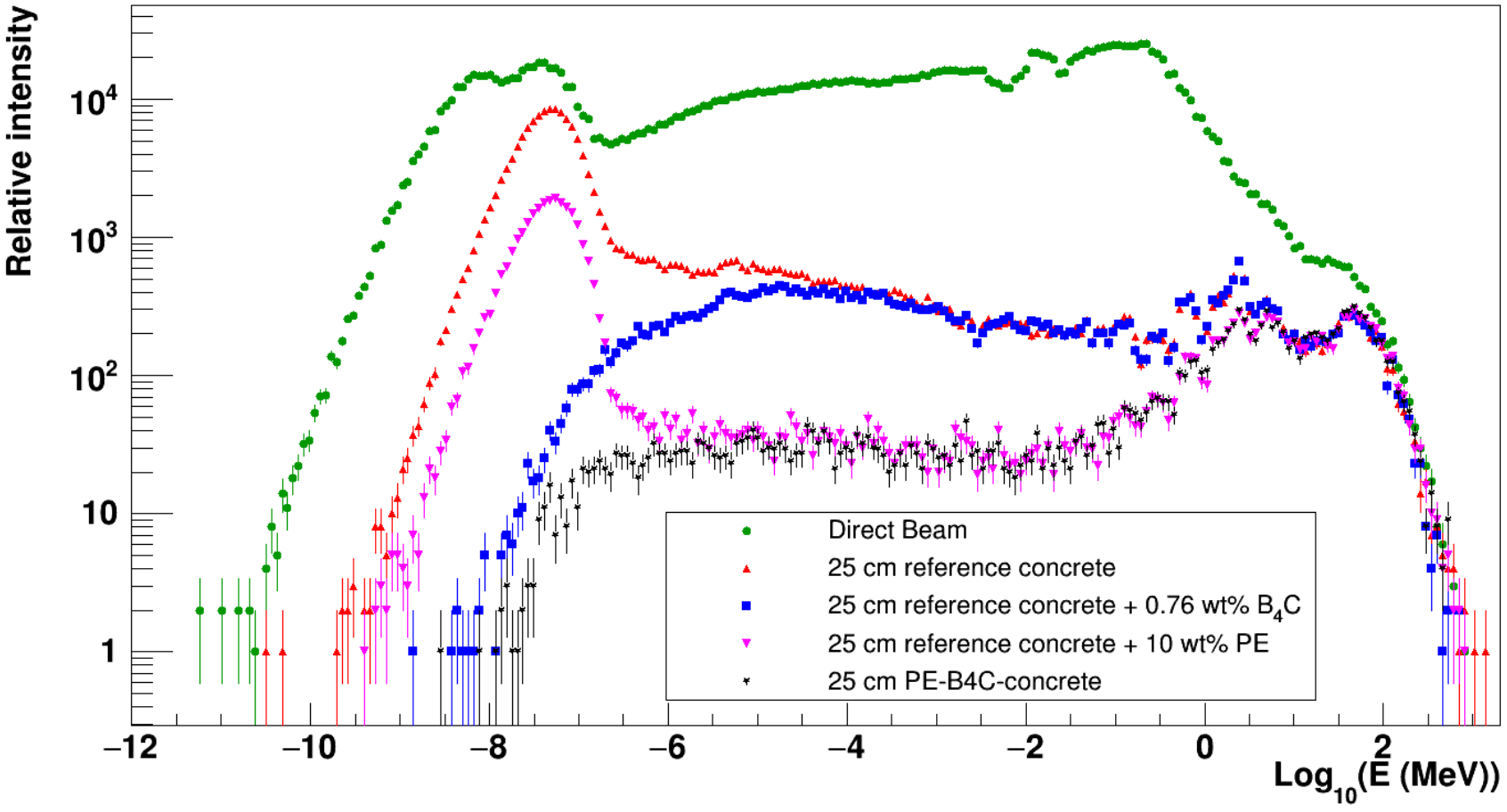
Design of the concrete: Motivation

- Concrete & steel make up two major componenets for bulk shielding at spallation and reactor neutron sources
- Penetration spectra measured at spallation sources exhibit broad peaks between ~keV - ~0.5 MeV (T. Nunomiya, NIMB 179 (2001) 89-102)
- Hydrogen works well in this energy regime. To slow a neutron from a few MeV to 1 eV:
  - Around 20 collisions in hydrogen
  - For comparision it's around 400 in iron
- Can we increase the hydrogen content in concrete?

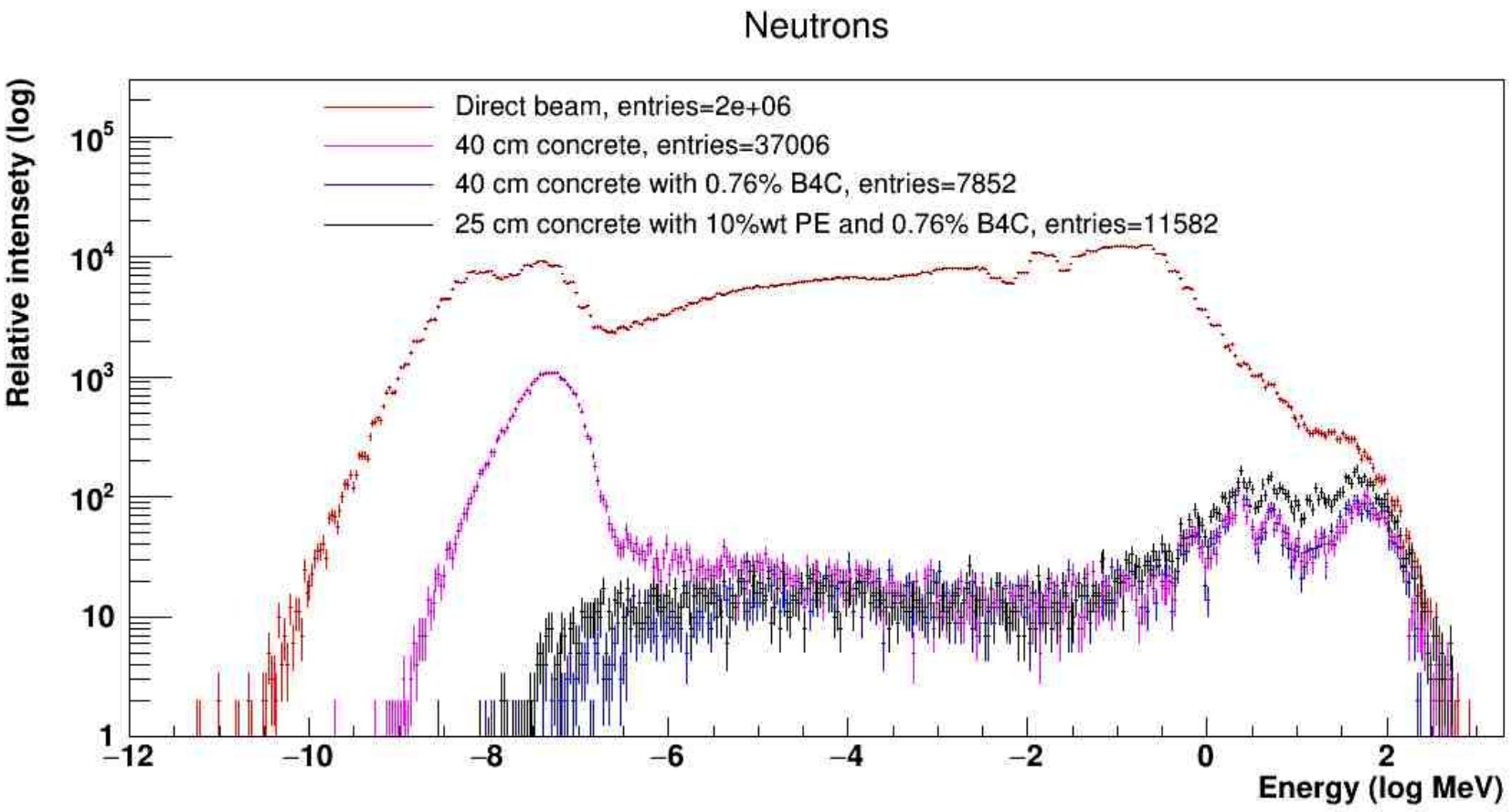
Design of the concrete: Initial Geant4 simulations



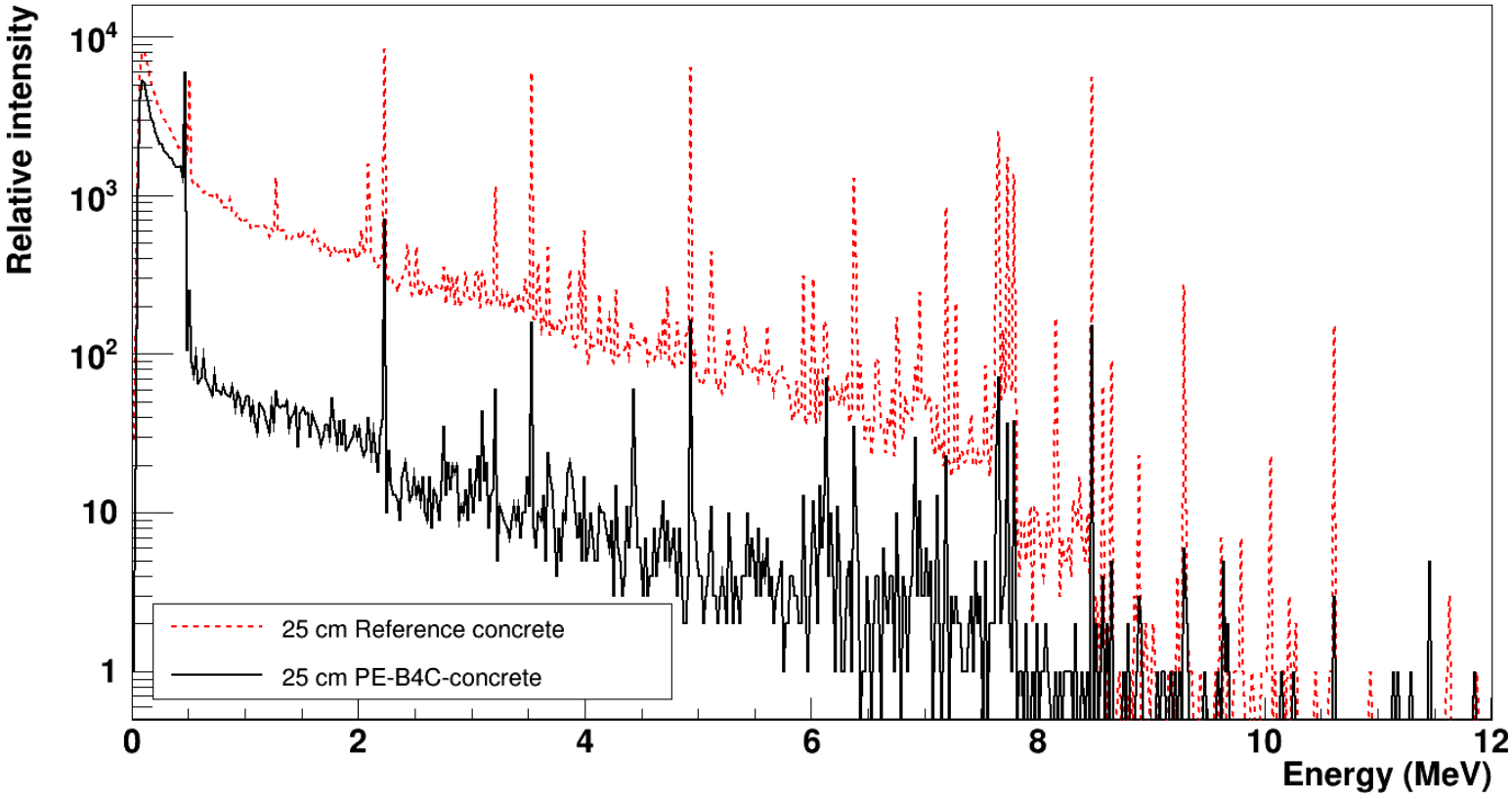
Design of the concrete: Geant4 neutron results



Design of the concrete: Geant4 neutron results



Design of the concrete: Geant4 photon results



Order of magnitude gamma reduction beyond 0.5 keV

Properties of the concrete

Inspired by the previous simulations, we had concrete samples mixed at DTI

Materials	Reference Concrete		PE-B4C-concrete	
	kg	Vol. %	kg	Vol. %
Cement	350.0	11.7	350.0	11.7
Water	155.3	15.5	155.3	15.5
Admixture	0.75	0.1	0.75	0.1
Sand	794.8	30.3	776.4	29.6
Granite 4/8	258.8	9.9		
Granite 8/16	794.8	30.3	508.3	19.4
PE 2.5 mm			100.7	10.4
PE 5.0 mm			102.2	10.5
B_4C			15.1	0.6

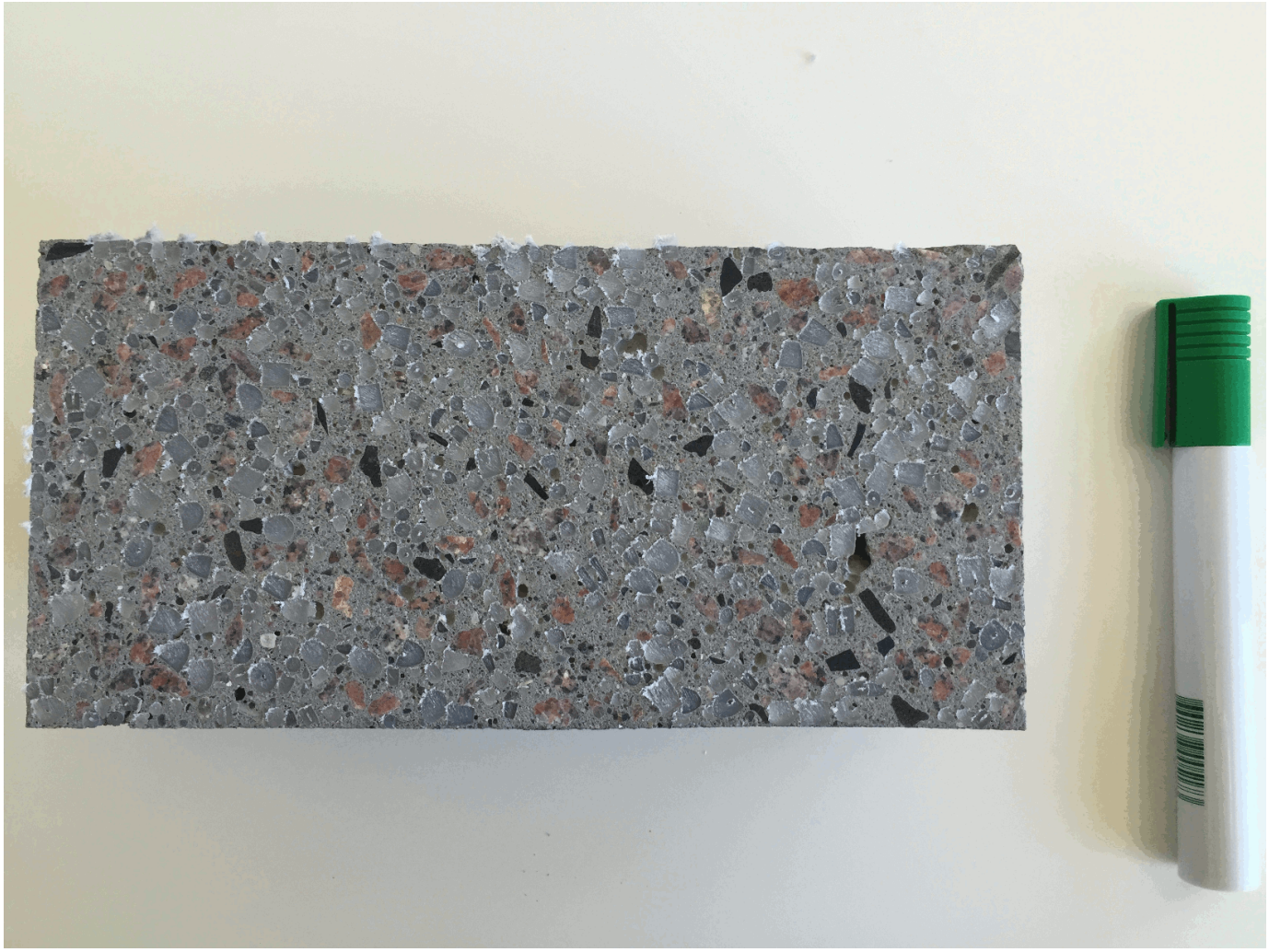
Ingredients for a one meter cubed sample

	Reference Concrete	PE-B4C-concrete
O	51.04%	46.06%
Ca	7.08%	8.05%
Si	32.50%	28.4%
Al	3.68%	2.34%
Fe	1.15%	0.837%
Mg	0.235%	0.195%
Na	1.05%	0.613%
K	2.11%	1.25%
S	0.235%	0.276%
Cl	0.00301%	0.00353%
H	0.782%	2.362%
Ti	0.0903%	0.0517%
P	0.04520%	0.0259%
C		8.93%
B		0.596%
Density	2.34 (g/cm^3)	1.97 (g/cm^3)

Element breakdown

T. Svensson, C. Pade, Neutron Shielding Concrete - Development of mix design and documentation of selected properties, Danish Technological Institute, 2016.

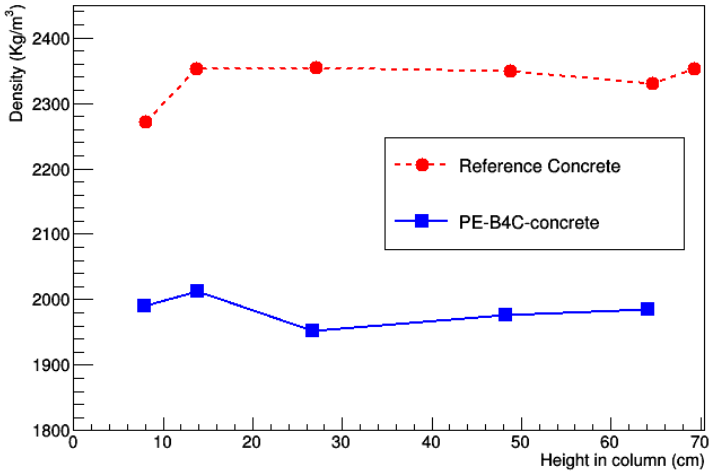
Properties of the concrete



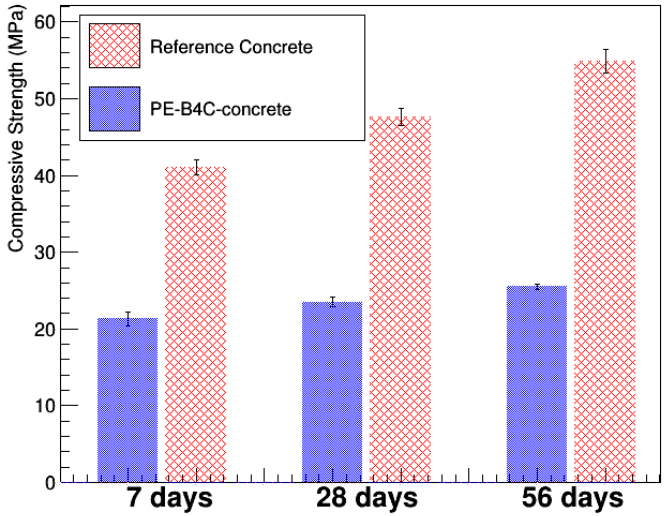
Properties of the concrete

Density and compressive strength

Note regular concrete also needs re-bar for ESS-scale objects; this is not an issue



Density



Compressive strength

T. Svensson, C. Pade, Neutron Shielding Concrete - Development of mix design and documentation of selected properties, Danish Technological Institute, 2016.

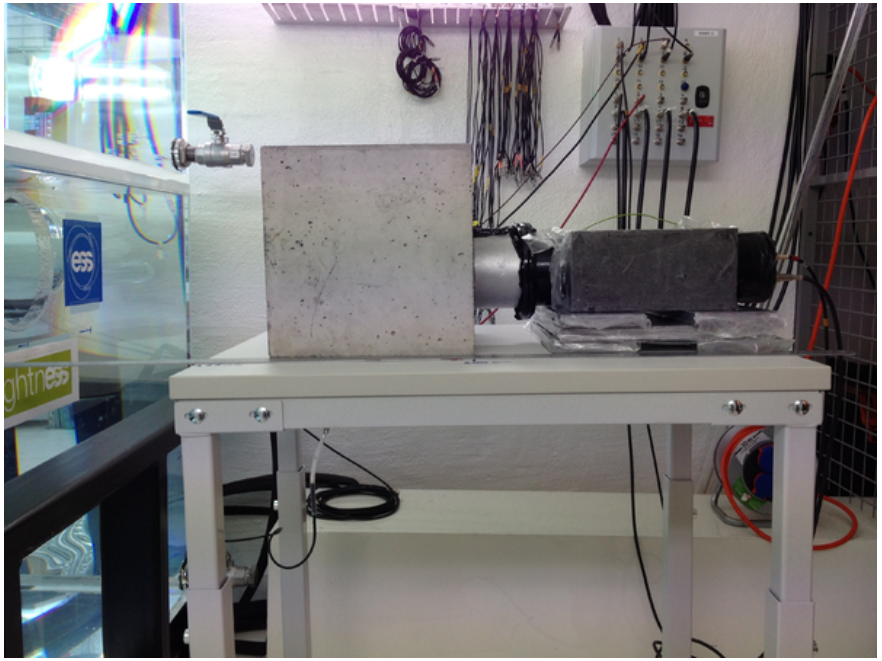
Properties of the concrete – a few other tests

- Fire tests carried out on the concrete, ESS-0096709
  - Normal concrete has an “A” fire rating
  - PE-B4C-concrete as B-s1,d0
    - B: Fire behaviour
    - s1: Smoke production
    - d0: Flaming droplets
- Anchor pull-out tests
  - 12 mm Hilti anchor, HIS-(R)N: load obtained of 64 kN
  - 20 mm Hilti anchor, HIS-(R)N: Only one test and failed
- Contact Carsten Cooper-Jensen for more info

Neutronic testing of the concrete

- Lund University Source Facility
  - MeV neutrons
- IFE ESS test beamline
  - Thermal neutrons
- SNS Vision
  - meV to keV neutrons (analysis in progress, too preliminary)

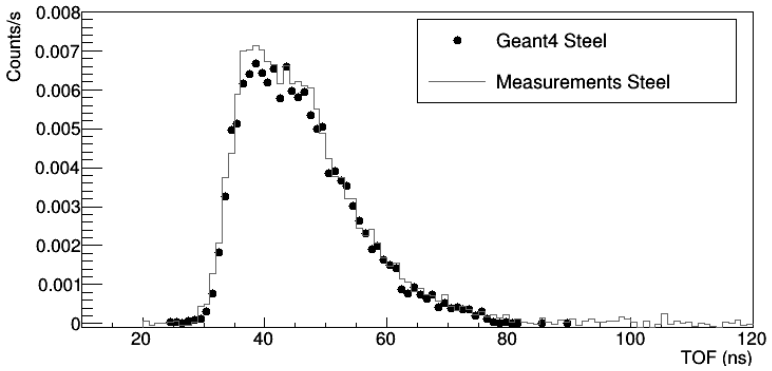
Neutronic testing: LU measurements

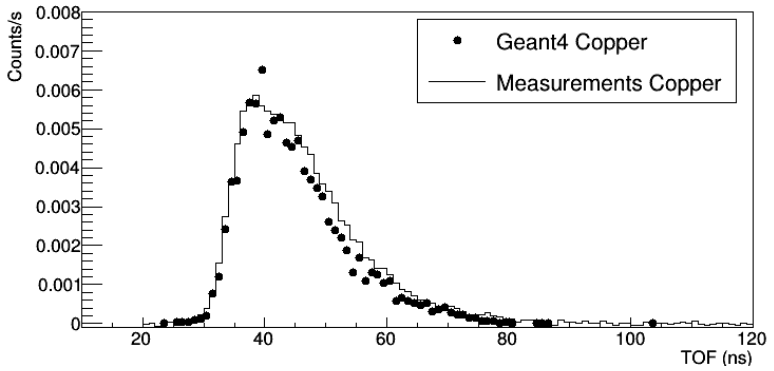


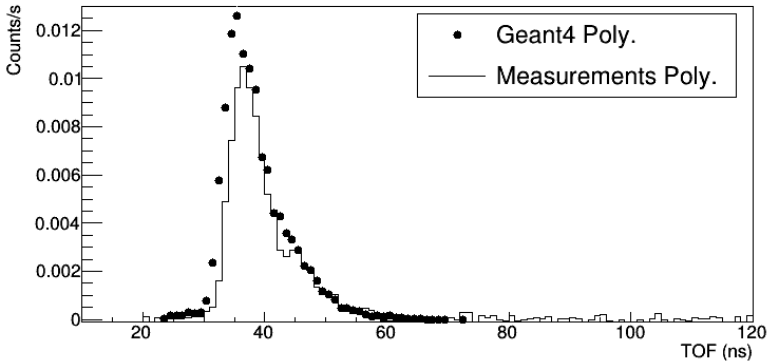
Pictures courtesy of Hanno Perrey

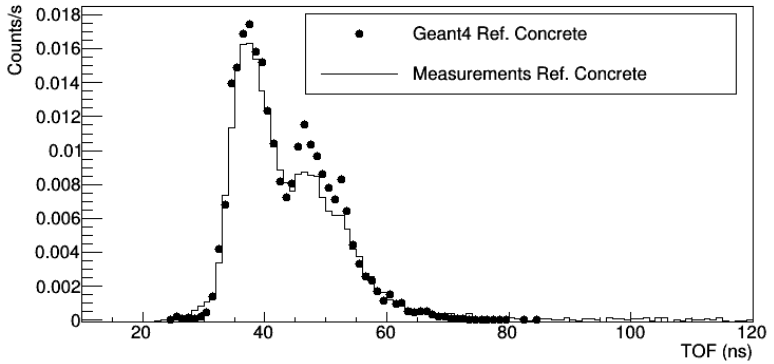
Neutronic testing: LU measurements

Benchmark measurements









Thanks to many others who contributed to this work

IFE: Isabel Jansa Llamas, Saima Sultana Kazi, Rodion Kolevatov

LU: Kevin Fissum, Hanno Perrey, Emil Rofors, Julius Scherzinger

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