Fusion Neutronics Meeting 2025, 7th-10th April, 2025
Facultad de Educación of UNED, Madrid

EUROfusion

Neutronic benchmark and validation experiments at the Frascati Neutron Generator

N. Fonnesu

ENEA, Nuclear Department, Frascati, Rome

nicola.fonnesu@enea.it

ENEA ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Introduction

Frascati Neutron Generator (FNG)

- Electrostatic accelerator-driven neutron source
- D^+ ions (**10 µA-1.25 mA**) are accelerated up to ~ **300 keV onto a tritiated target** where neutron are produced by means of nuclear fusion reactions
- Neutron yield rate range= **10^8 - 1.5×10^{11} n/s**
- Max n flux ~ **5×10^9 $cm^{-2}s^{-1}$ @ 14 MeV**, ~ 5×10^7 $cm^{-2}s^{-1}$ @2.5 MeV
- Maximum fluence **~ 10^{14} cm^{-2} @ 14 MeV** (25 hours @ full power, limit due to target depletion)

2025 Fusion-relevant experiments at FNG

In line with its role in Fusion, three main experiments devoted to **benchmark and validation** (of some computational methods, codes and nuclear data) and electronics testing are **foreseen at FNG in 2025,** focused on:

- **Activated corrosion products (ACPs)** *→ S. Noce presentation*
- **Shielding properties of concrete**
- GENeuSIS assembly *→ R. Villari, M. Damiano presentations*

ACP loop at FNG

- **Corrosion, erosion and release** phenomena play an important role in mobilizing activated materials in fusion machines.
- **ACPs are a concern in terms of occupational radiation exposure (ORE).**
- The reference code for the ACPs assessment in ITER framework is **OSCAR-Fusion** developed by CEA.
- Experimental validation of ACP codes are mainly in Fission, **validation experiments are needed in Fusion**.
- **Design experiments at the Frascati Neutron Generator (FNG) under ITER relevant conditions** to validate the OSCAR-Fusion code and methodology for ITER assessment of radiation field due to ACP.

Aim is reproducing **thermo-hydraulic** (water temperature, velocity, Reynolds number), **chemical** (pH, oxygen content) and **neutronic conditions** relevant for ITER in a water circuit at a smaller scale by exploiting hydraulic similarity as much as possible considering laboratory and safety constraints.

OSCAR models which can be explored at FNG

- **Deposition** (Particles)
- **Dissolution-Precipitation** (Ions and particles)
- **Fluid-dynamics transport & purification** (Ions and particles)

Corrosion/Erosion -> Experiment at RINA labs. on **Cu samples in autoclave in reducing environment** (240°C, 45 bar, O_2 < 10 ppb)

ACP loop at FNG - Final Layout

LiOH/KOH:
$pH_T = 7$

Filtering branch:
- 1- µm Polypropylene
- mixed bed resins

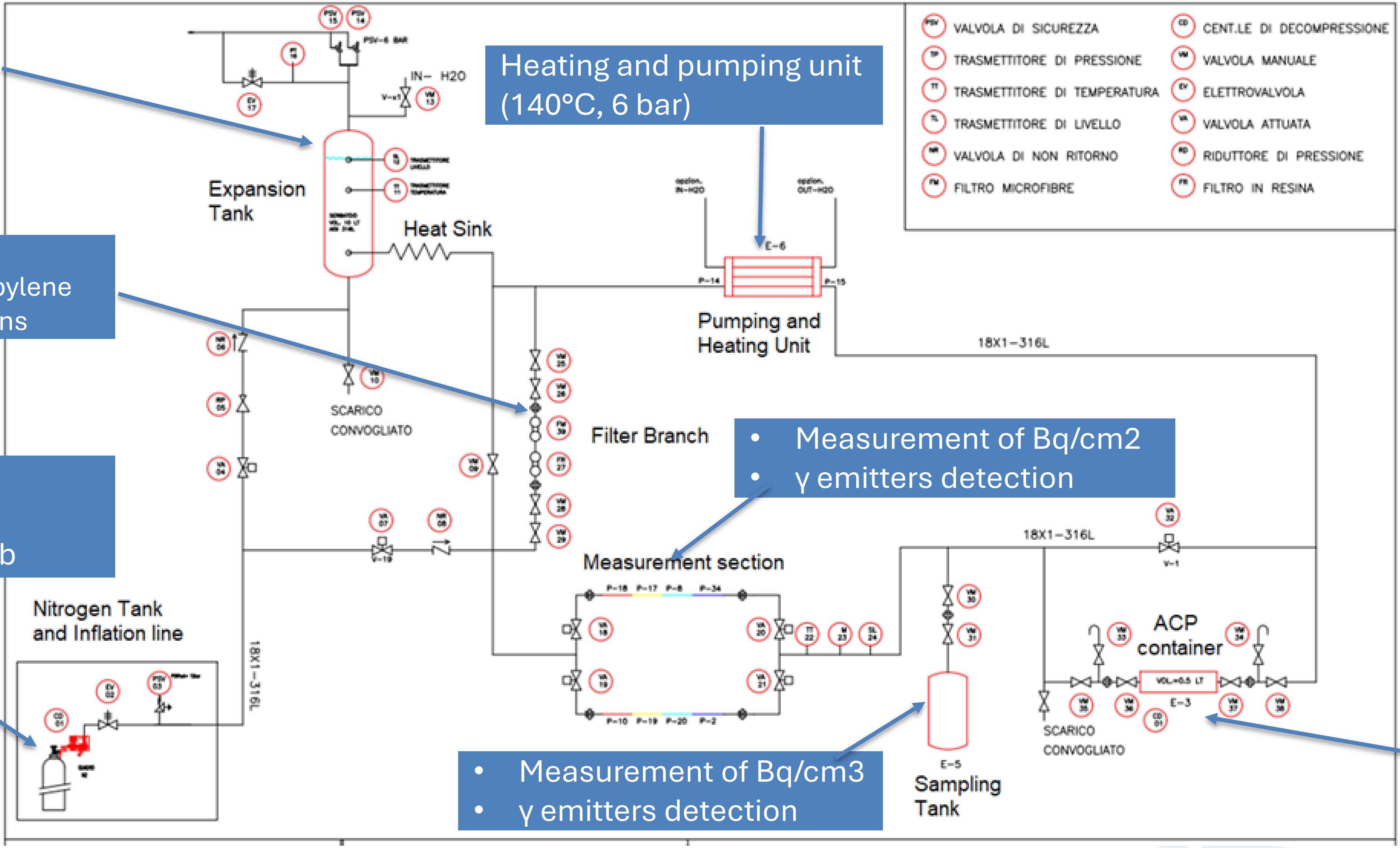
N2 line to:
-pressurize (6 bar)
- Keep O2 @ 10 ppb

Heating and pumping unit (140°C, 6 bar)

- Measurement of Bq/cm2
- γ emitters detection

- Measurement of Bq/cm3
- γ emitters detection

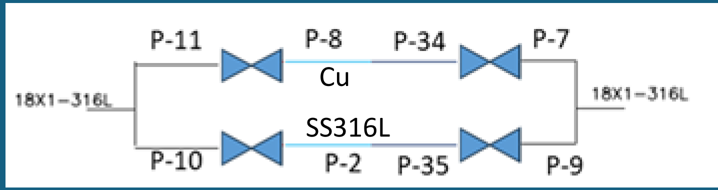
Injection point (solid particles, ions)

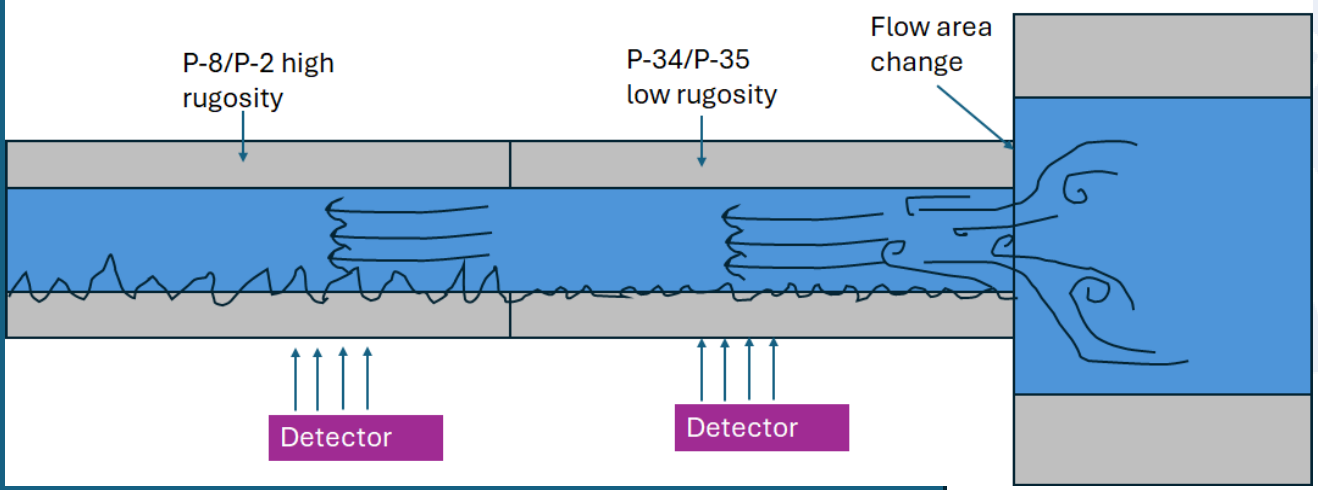


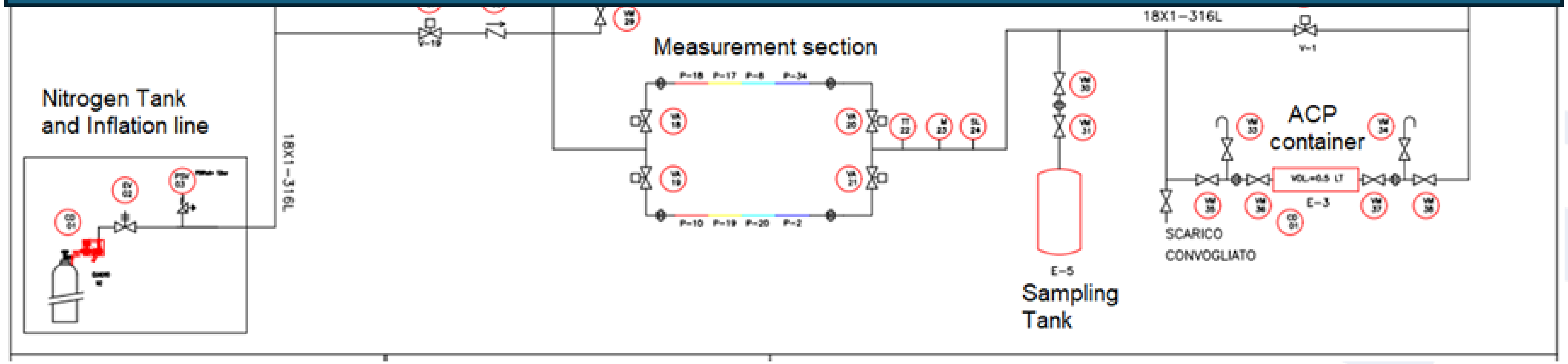
ACP loop at FNG - Final Layout

Study of pipe deposit formation depending on:

- Material impact: one SS316L line and one Cu line
- Rugosity: 0.5 and 10-µm pipes in the same line
- Fluid-dynamics: effect of turbulence due to flow area change





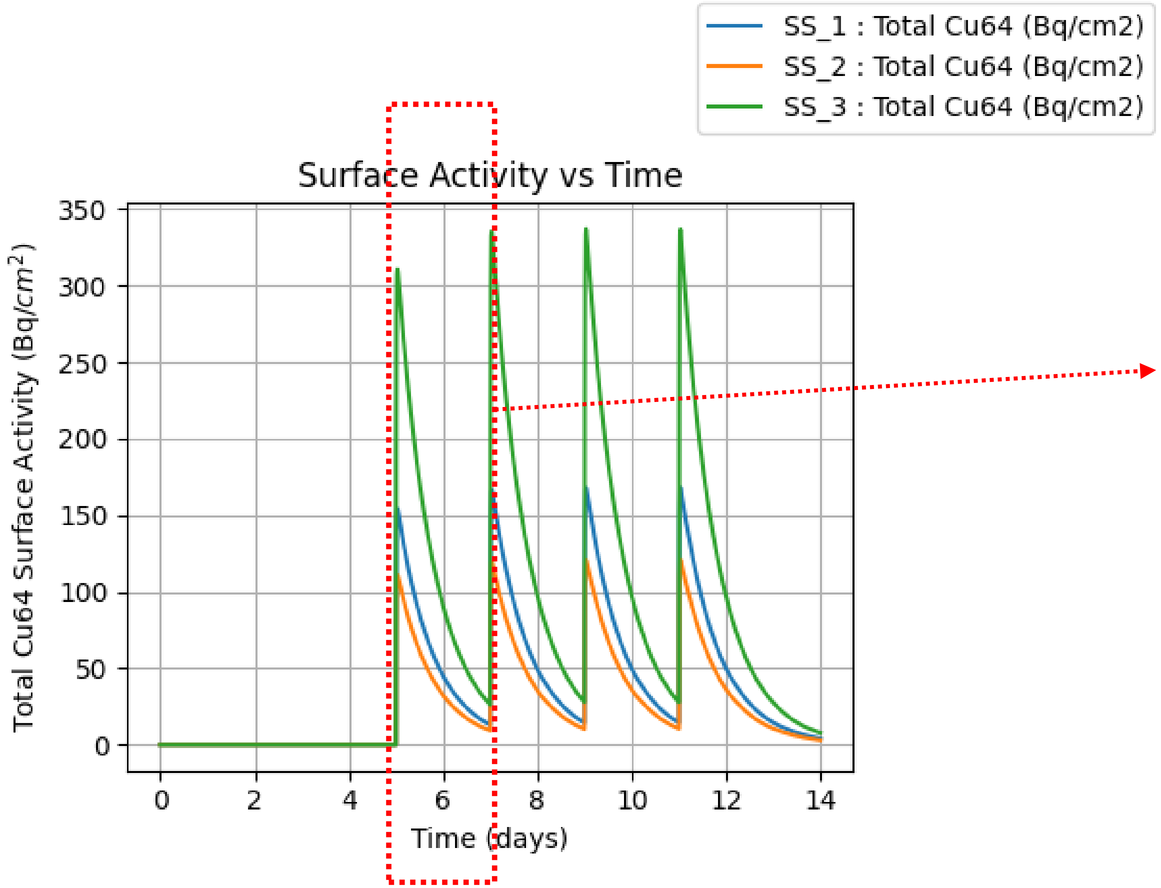


Comparison of water conditions ACP loop at FNG vs. ITER IBED

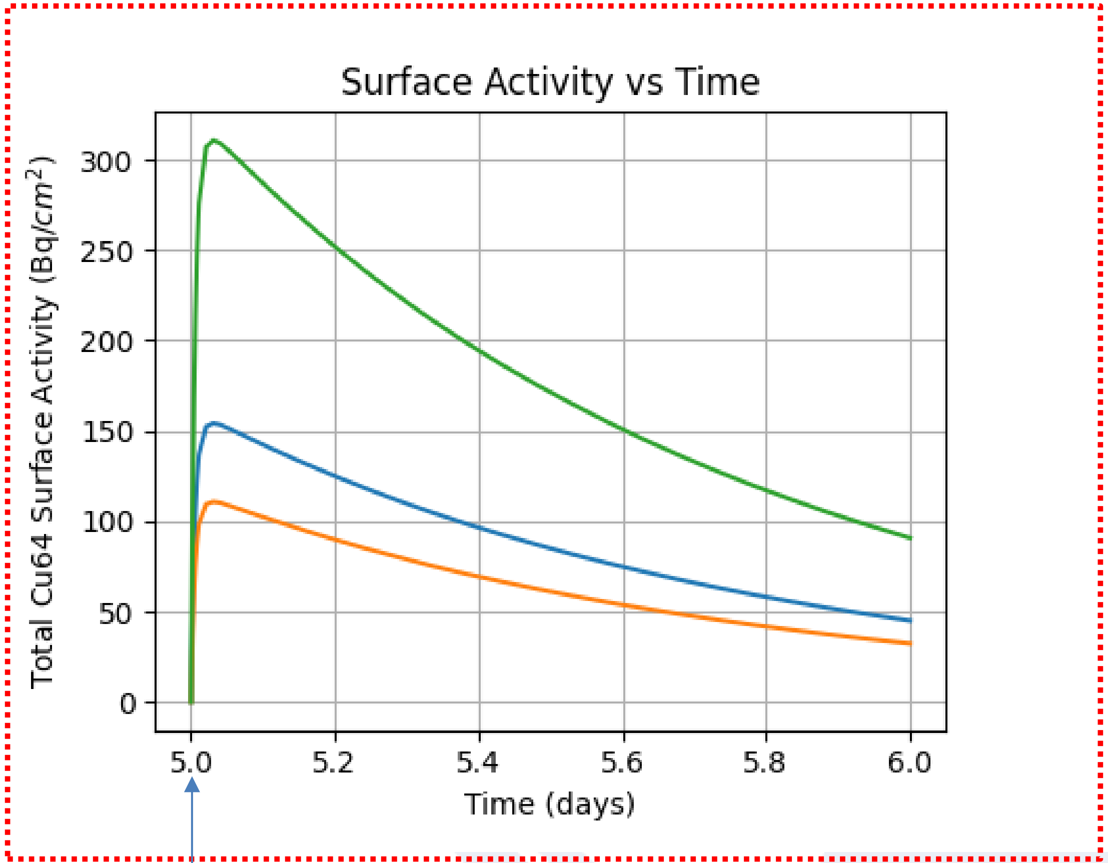
The relevancy for ITER case is confirmed by comparison with typical water conditions expected in the ITER IBED PHTS **during plasma operation** of the tokamak, i.e., **water temperature** =150°C, **velocity** 10 m/s, **Reynolds number** 10^6-10^7, **water pH_T** =7 and the capability of reproducing **low O_2 content in water** (10 ppb) up to natural concentration.

Parameter	ACP loop	ITER IBED PHTS during plasma operation
Water type	Demineralized water	Demineralized water
Nominal Temperature and Pressure	140°C, 6 bar	150°C, 40 bar
Maximum Volumetric Flow Rate	80 l/min	
Nominal Volumetric Flow Rate	60 l/min	
Maximum water speed	15 m/s	
Linear length of the loop	20 m	
Water volume	20 l	
Water velocity range	3-13 m/s	10 m/s
Reynolds number range	5×10^4 – 5×10^5	10^6 - 10^7
Oxygen content into the water	10 ppb – natural concentration	10 ppb
pH_T of water	7	7

Expected activity at the meas. section, 1g of Cu dust, 1 um

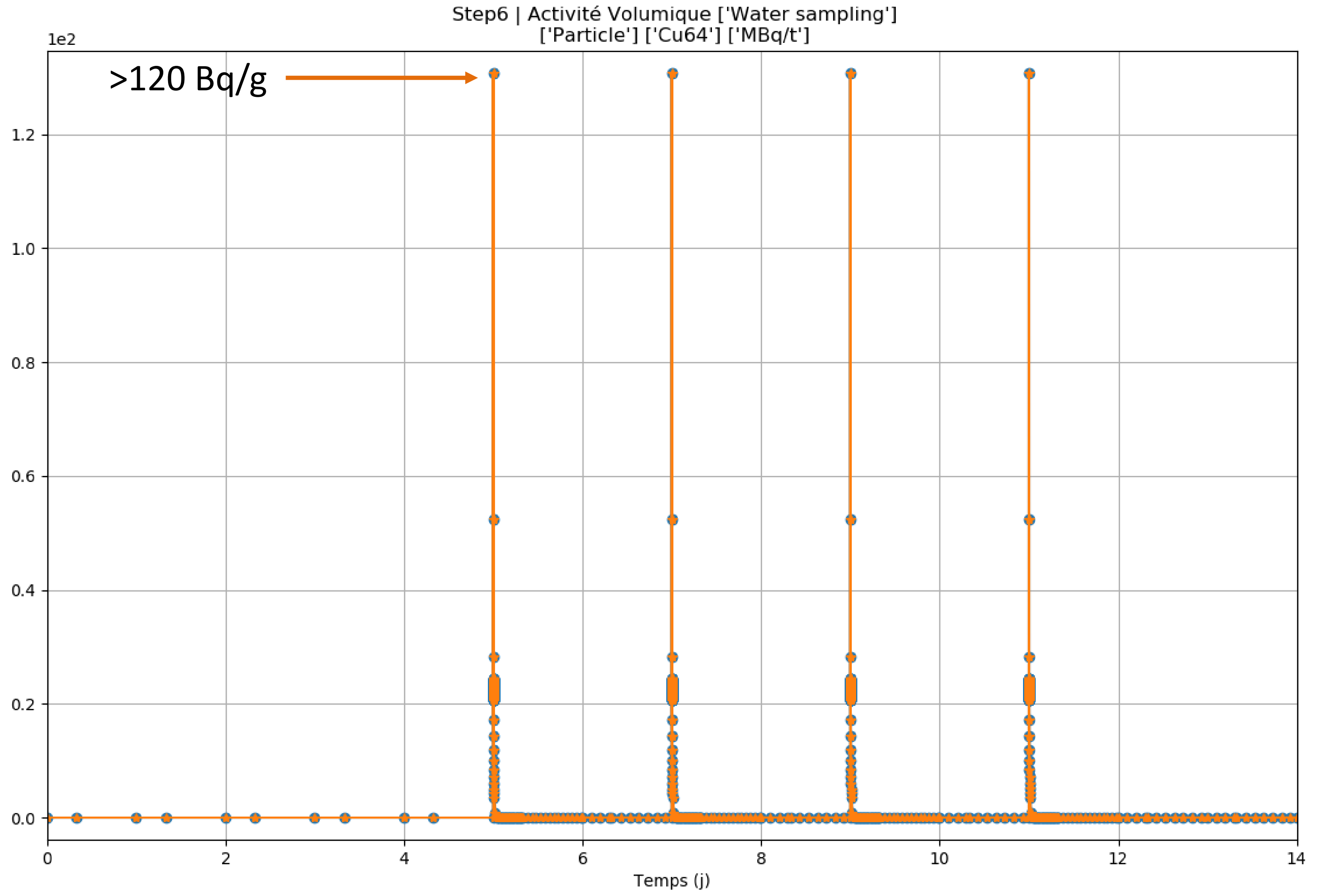


Surface activity to be measured with HPGe portable spectrometers



Injection of ACPs into the loop

Expected activity at the meas. section, 1g of Cu dust, 1 um

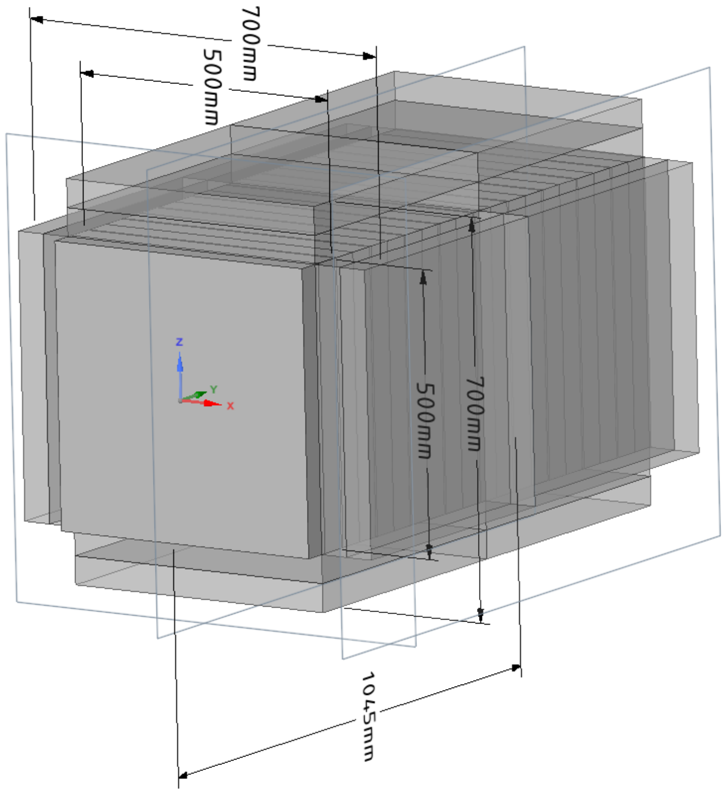


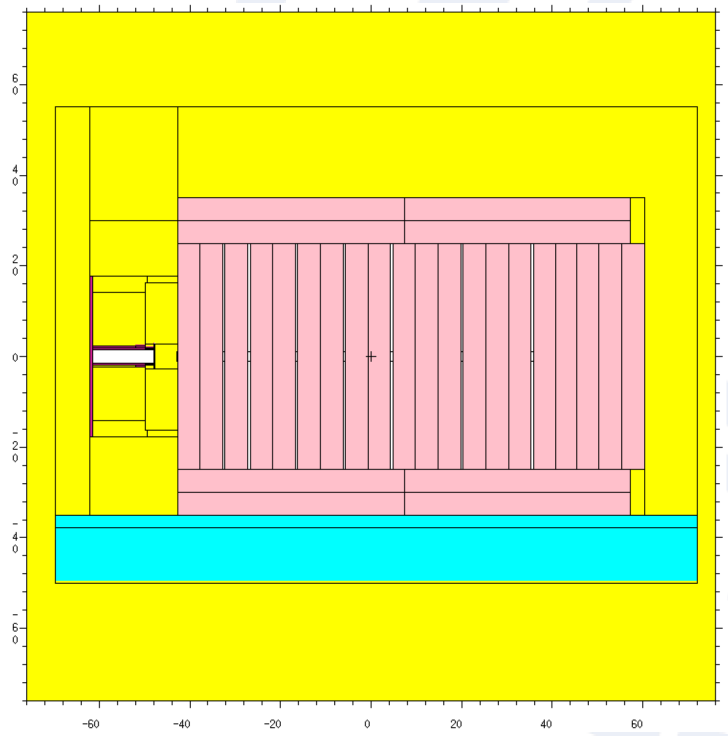
Activity concentration in sampled water to be measured at the well-type HPGe of the lab.

Concrete shielding benchmark experiment

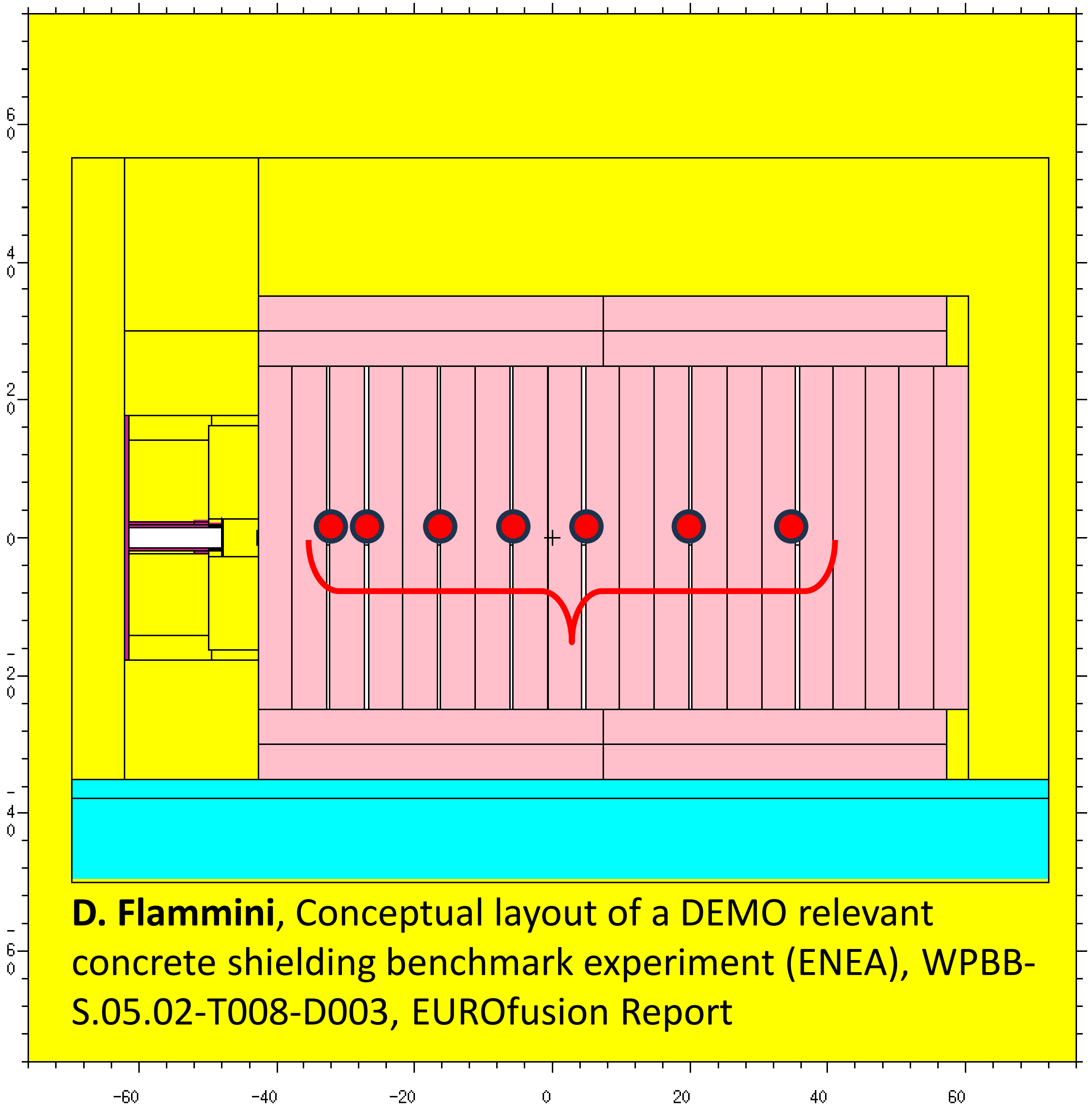
To improve accuracy in modeling radiation transport for shielding design, some experimental campaigns with ordinary and heavy concrete are planned at FNG, within EUROfusion WP BB.

The **DEMO-relevant ordinary concrete shielding benchmark experiment** is foreseen in 2025, with a mock-up consisting of **thirty-six 50x50x5 cm³ slabs** of ordinary concrete, its feasibility being demonstrated by a thorough MCNP pre-analysis with JEFF 3.3 and IRDFF 2 data libraries, respectively for transport and dosimetry.



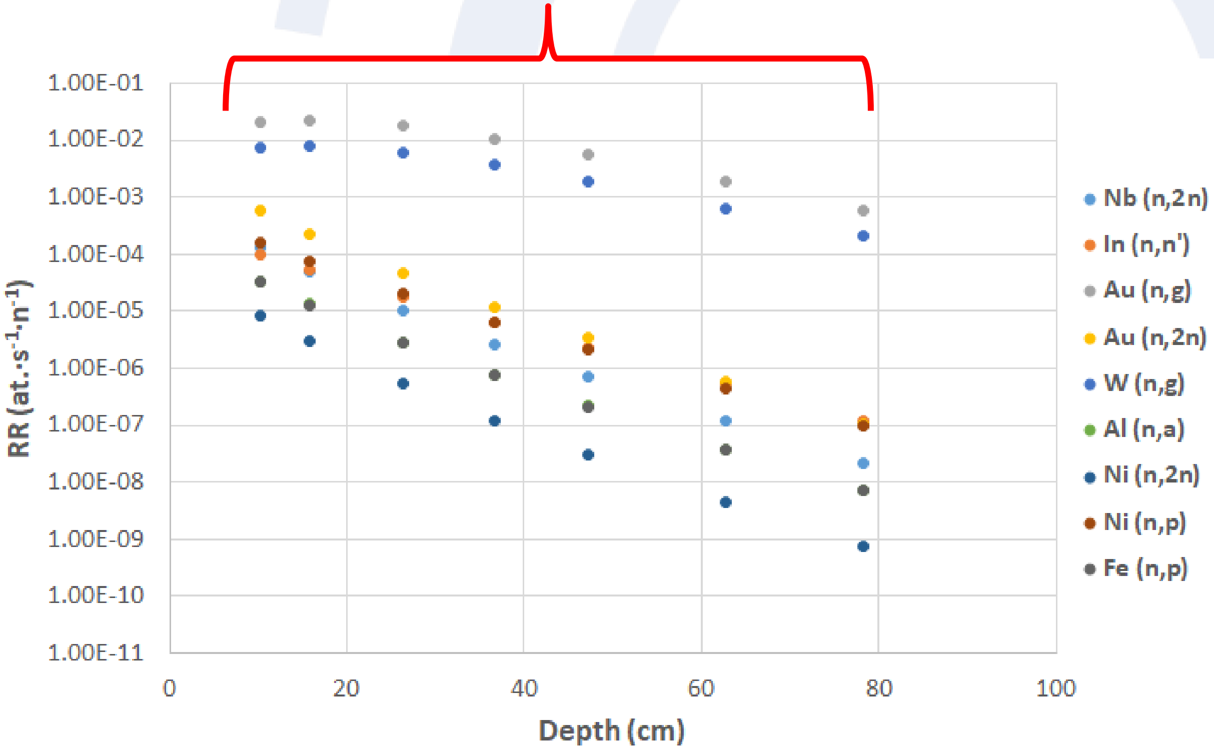


Concrete shielding benchmark experiment



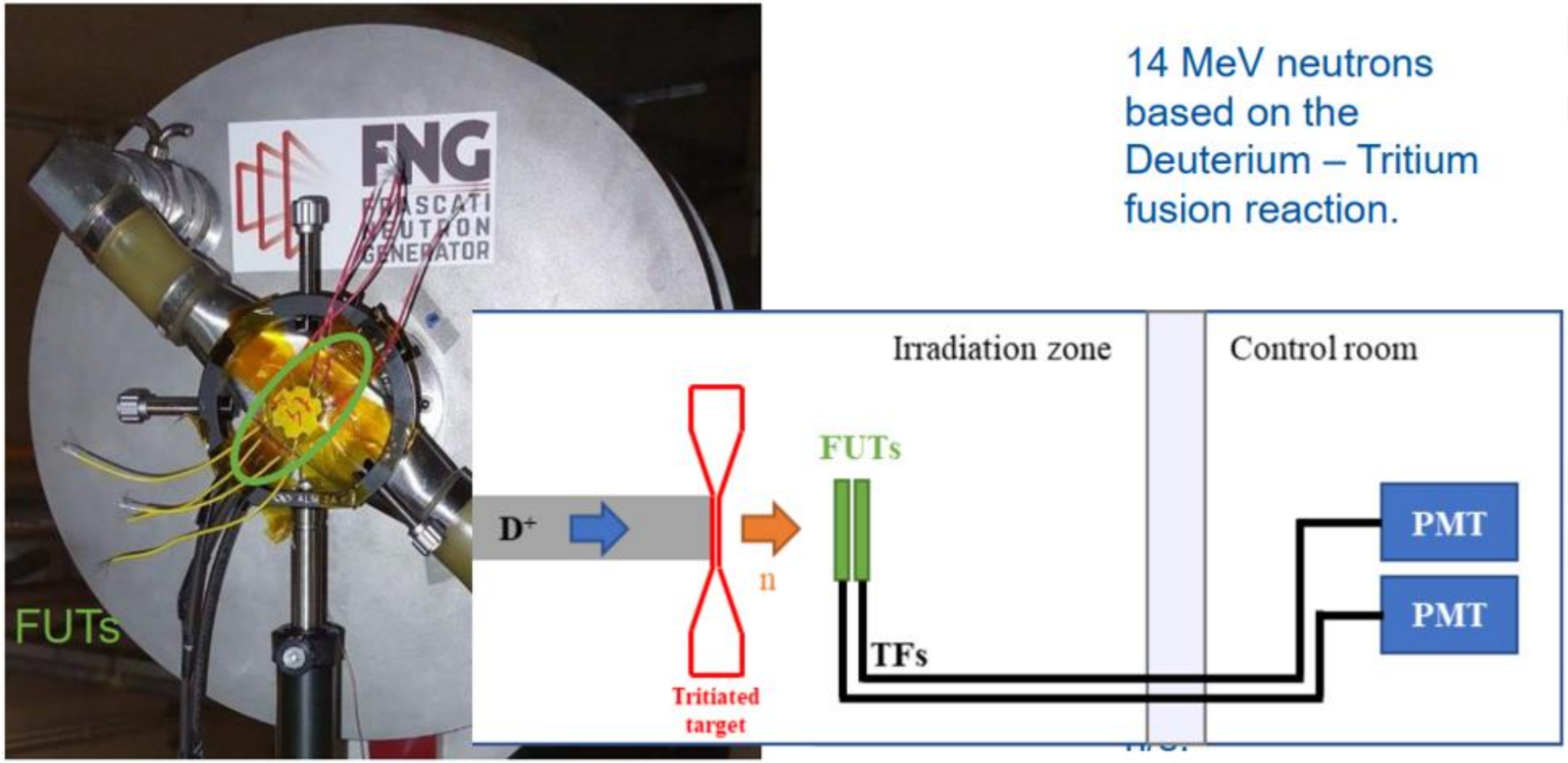
D. Flammini, Conceptual layout of a DEMO relevant concrete shielding benchmark experiment (ENEA), WPBB-S.05.02-T008-D003, EUROfusion Report

The pre-analyses defined the experimental configuration for to have both **measurable activated foils** and low **background (< 10%)** due to scattered neutrons, so that the experimental response of the detectors is a measure of the neutron transport inside the concrete mock-up and it is not influenced in a significant way by the surrounding environment.



Silica-based optical fibers for 14 MeV neutron beam monitoring

Ce-doped optical fibers, based on the radiation-induced luminescence (RIL) phenomenon
RIL response calibrated to the neutron flux, via a linear fit between the facility monitors and the optical fiber response.

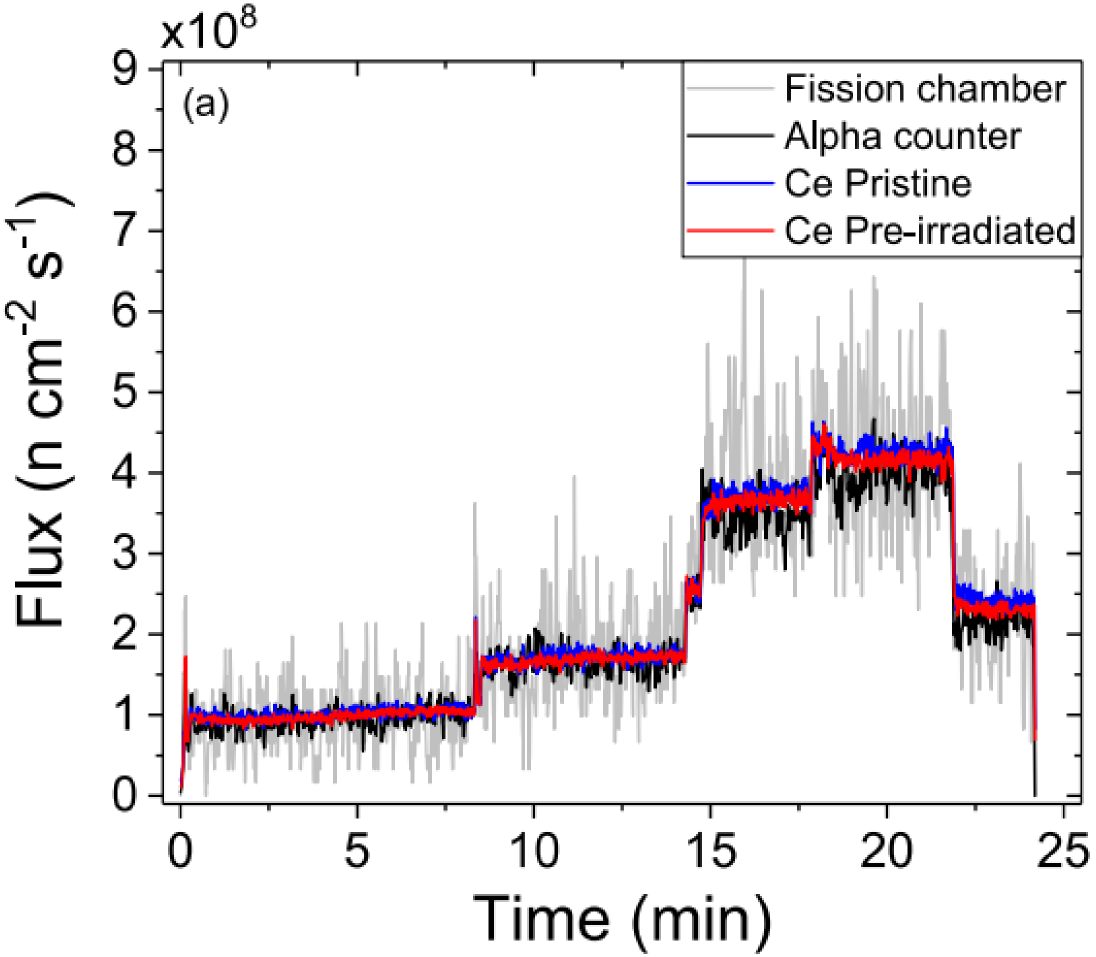


14 MeV neutrons based on the Deuterium – Tritium fusion reaction.

Luca Weninger et al., Potential of radioluminescent silica-based optical fibers for 14 MeV neutron beam monitoring, Results in Optics 19 (2025) 100807

Silica-based optical fibers for 14 MeV neutron beam monitoring

Ce-doped optical fibers, based on the radiation-induced luminescence (RIL) phenomenon
RIL response calibrated to the neutron flux, via a linear fit between the facility monitors and the optical fiber response.



Luca Weninger et al., Potential of radioluminescent silica-based optical fibers for 14 MeV neutron beam monitoring, Results in Optics 19 (2025) 100807

Concluding Remarks

ACP loop at FNG

- **Engineering of the project completed** (both hardware and control system)
- **Installation and test** (water chemistry and thermo-hydraulic) **by July 2025**
- A proposal of **experiment of Cu dust <=11 g compliant** with safety and quality of experiment by 2025

Concrete shielding benchmark experiment

- DEMO-relevant ordinary concrete shielding benchmark experiment (36 50x50x5 cm^3 slabs) is foreseen in 2025
- Feasibility demonstrated by MCNP pre-analysis with JEFF and IRDFF-II data libraries
- **Neutron flux and fluence** will be measured at different depths of penetration both with **activation foils** and some active detectors, among which, the promising radioluminescent optical fiber developed by Laboratoire Hubert Curien.

Thank you!

nicola.fonnesu@enea.it

N. Fonnesu[a], T. Berry[b], A. Colangeli[a], F. Dacquait[c], M. Damiano[d], D. Flammini[a], S. Girard[e], X. Litaudon[c], D. Leichtle[f], S. Loreti[a], M. Lungaroni[a], A. Morana[e], F. Moro[a], S. Noce[a], A. Pietropaolo[a], A. Previti[a], N. Terranova[a], R. Villari[a], L. Weninger[e], P. Zito[a]

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK
[a] ENEA, Nuclear Department, Via E. Fermi 45, 00044 Frascati, Rome, Italy
[b] United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, OX14 3DB, UK
[c] CEA, Cadarache, F-13108 St-Paul-Lez-Durance, France
[d] University of Rome "Tor Vergata", Industrial Engineering Department, Via del Politecnico 1, 00133, Rome, Italy
[e] Laboratoire Hubert Curien, UMR-CNRS 5516, Université Jean Monnet, F-42000 Saint-Etienne, France
[g] Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Karlsruhe, Germany

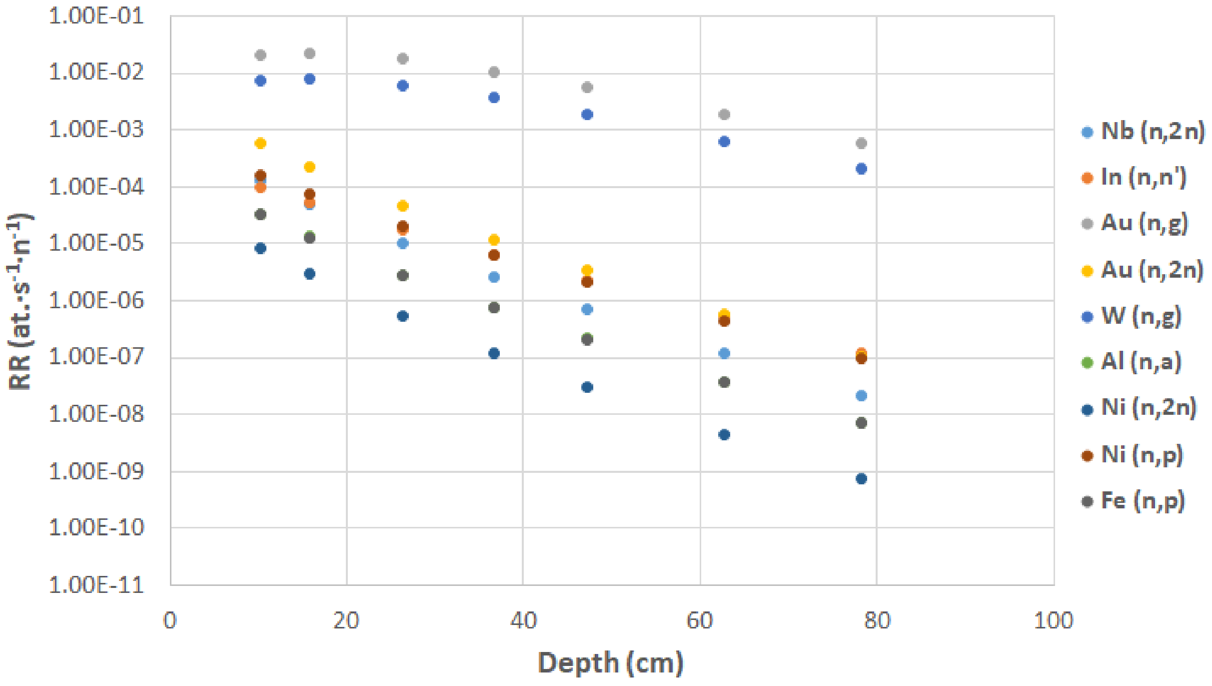
This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Spare-1

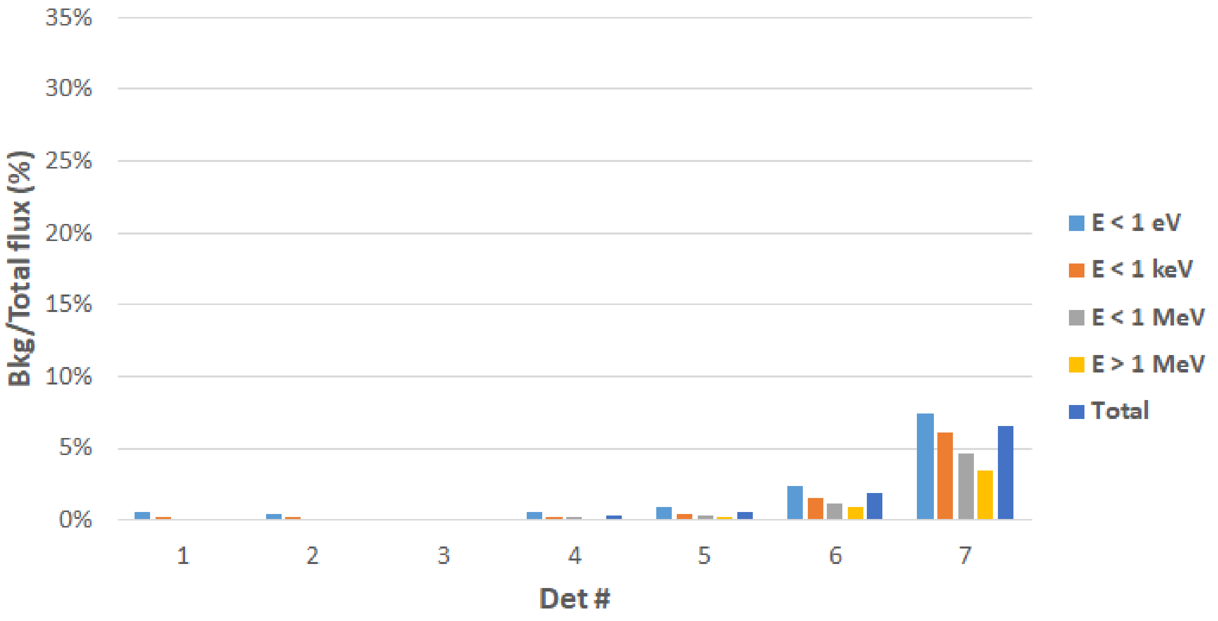
Element	Weight (%)	
	Ordinary Concrete	Heavy Concrete
H	0.35	0.3
C	10.29	-
O	49.66	28.6
Na	-	0.18
Mg	9.87	0.27
Al	0.75	0.69
Si	1.99	2.57
P	-	0.45
S	1.07	0.13
Cl	0.02	0.01
K	0.06	0.17
Ca	24.16	4.7
Ti	0.05	0.03
Fe	1.73	61.9
Density [g/cm^3]	2.55	3.94

Reaction	Half-life	Isotopic abundance (%)	Dominant γ Ray energy (keV)	Dominant γ Ray branching (%)	Reaction Threshold (MeV)
^{27}Al(n,a)^{24}Na	14.96 h	100.0	1368.63	100.0	4.2
^{56}Fe(n,p)^{56}Mn	2.58 h	91.8	847	98.9	3.0
^{115}In(n,n')^{115m}In	4.49 h	95.7	336.24	45.9	0.5
^{197}Au(n,g)^{198}Au	2.696 d	100.0	411.80	95.6	-
^{93}Nb(n,2n)^{92m}Nb	10.15 d	100.0	934.53	99.0	8.9
^{58}Ni(n,p)^{58}Co	70.82 d	68.27	810.77	68.3	1.0
^{58}Ni(n,2n)^{57}Ni	35.60 h	68.27	1377.63	81.7	12.5
^{186}W(n,g)^{187}W	23.9 h	28.6	685.75	26.4	-

Spare-2



1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
RR (at.·s-1·n-1)
0
20
40
60
80
100
Depth (cm)
Nb (n,2n)
In (n,n')
Au (n,g)
Au (n,2n)
W (n,g)
Al (n,a)
Ni (n,2n)
Ni (n,p)
Fe (n,p)



35%
30%
25%
20%
15%
10%
5%
0%
Bkg/Total flux (%)
1
2
3
4
5
6
7
Det #
E < 1 eV
E < 1 keV
E < 1 MeV
E > 1 MeV
Total