Gamma spectrometry at European Spallation Source (ESS)

NKS GammaSkill 2023

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European Consortium ESS

Host Countries of Sweden and Denmark

47,5% Construction

15% Operations

In-kind Deliverables ~3%

Cash Investment ~97%

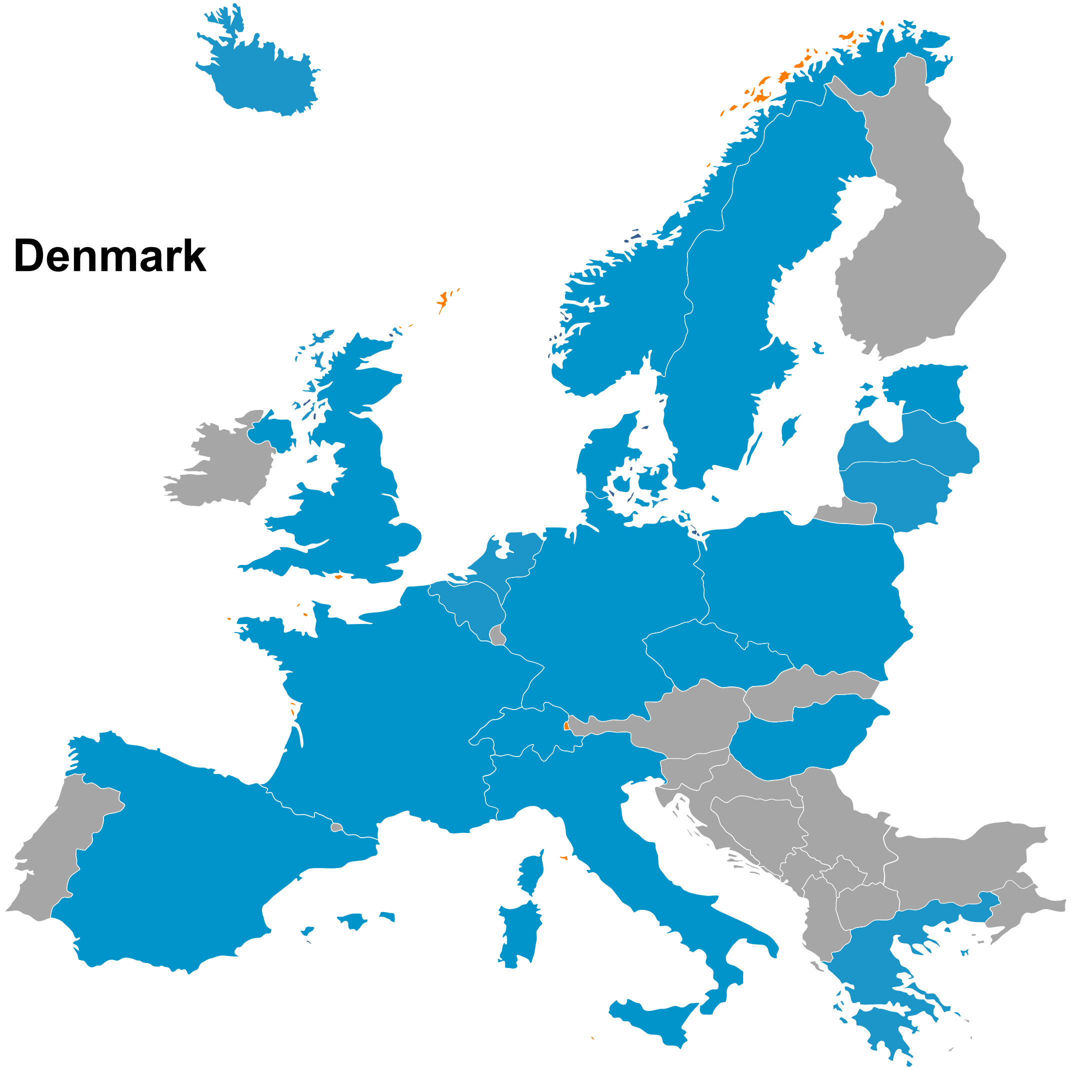
Non Host Member Countries

52,5% Construction

85% Operations

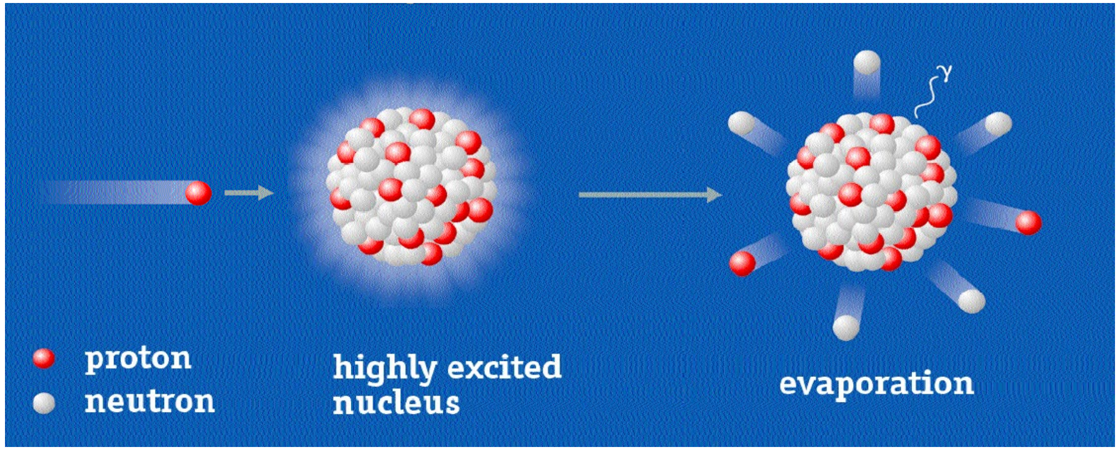
In-kind Deliverables ~ 70%

Cash Investment ~ 30%



Exciting Science with Pulsed Neutrons

From a hydrogen bottle → fast protons → pulsed neutrons → data → knowledge



Spallation: A nuclear process in which a high energy proton (particle) excites a neutron rich nucleus which decays by sending (steaming) out neutrons (~1 µs)

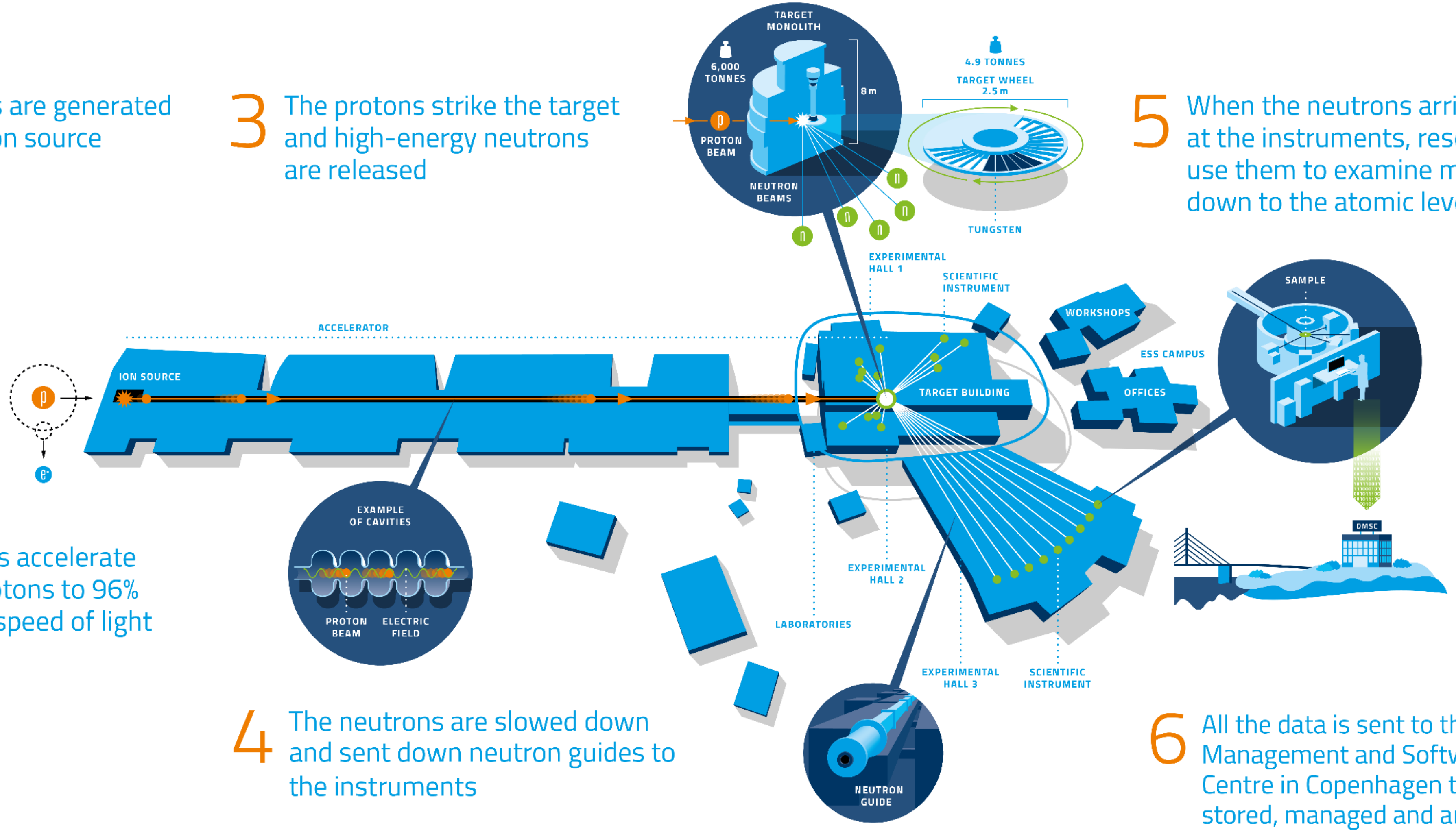
(and other particles such as gammas, protons, muons, pions, neutrinos…)

ESS Design and Layout

1 Protons are generated in the ion source

3 The protons strike the target and high-energy neutrons are released

5 When the neutrons arrive at the instruments, researchers use them to examine matter down to the atomic level



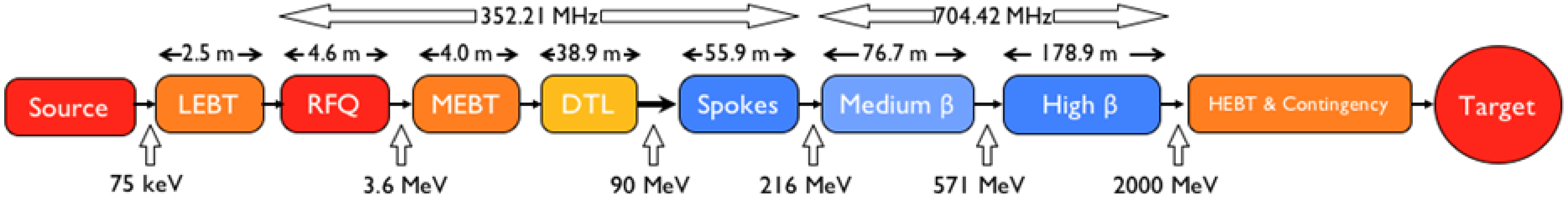
2 Cavities accelerate the protons to 96% of the speed of light

4 The neutrons are slowed down and sent down neutron guides to the instruments

6 All the data is sent to the Data Management and Software Centre in Copenhagen to be stored, managed and analysed with the researchers

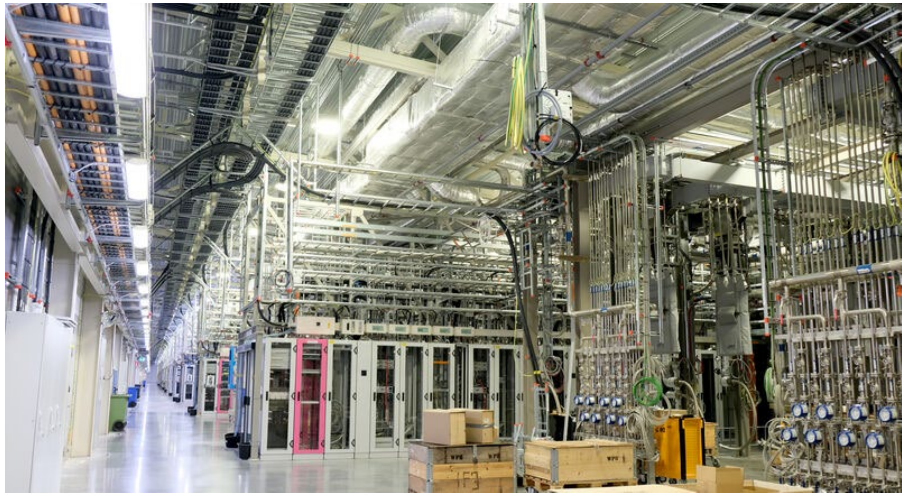
Visit us in Lund or check at https://europeanspallationsource.se/

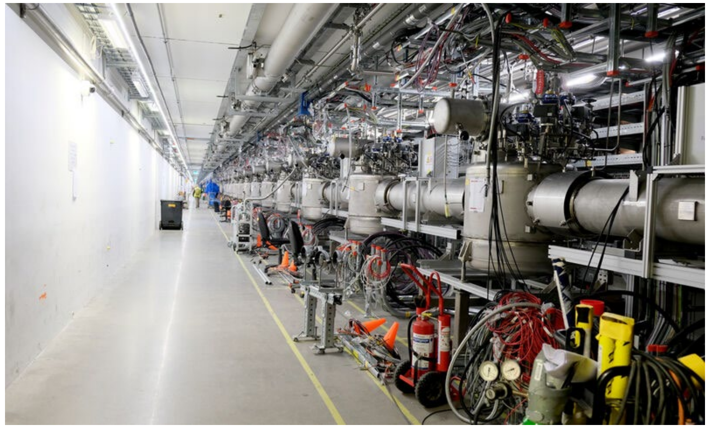
ESS Accelerator



1. Prompt radiation 2. Residual radiation 3. Contamination

- Activation of components, air, coolants: **H-3, Be-7**, C-14, (Be-10) …
- Steady state beam loss: 1W/m: Fe-55, Co-60, Co-58, Co-57, Co-56, Mn-54, Zr-88, Sr-85, Y-88, Rb-83, Se-75, Ni-63, V-49, Sc-46 …
- Full point beam loss: local spallation source, short exposure time
- Nasty specialist: Gd-148 (LL alpha emitter, spallation product)



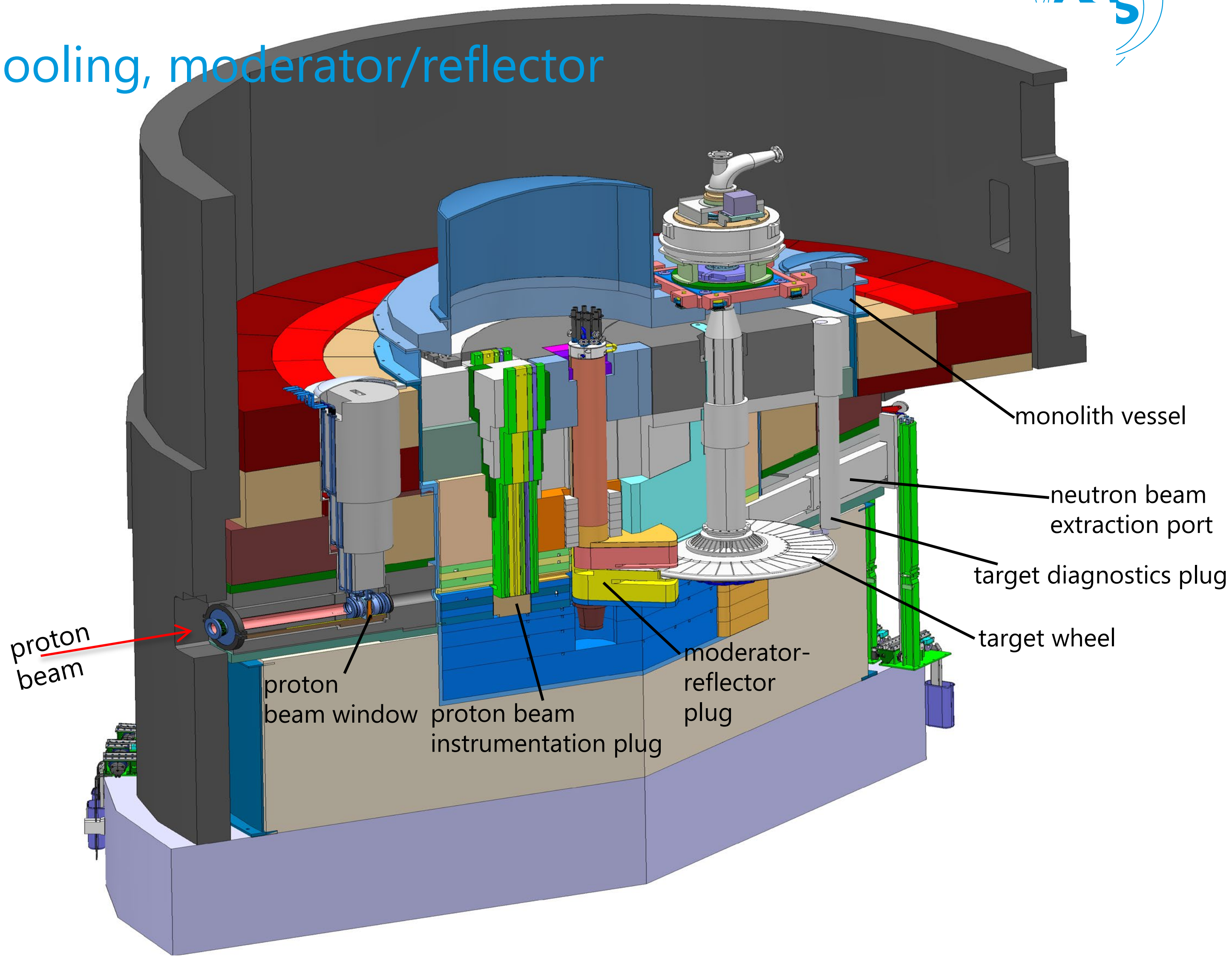


ESS Target Station

Monolith, target wheel, He-gas cooling, moderator/reflector

Main components:

- Monolith:
  - Vessel (6 m diameter x 8 m height)
  - Steel shielding (6000 tons)
  - Instrumentation plugs
  - Proton beam window
  - Neutron shutters
  - Neutron beam extraction system
- Rotating Tungsten target
  - 2.5 m diameter x 10 cm height
  - 7500 Tungsten bricks (3.5 tons)
  - 0.39 rev./s
- Target He gas-cooling
  - 3 MW capacity
  - 3 kg/s flow rate
  - ΔT = 200 °C
- High brightness moderators
  - 2 liquid H_2 moderators
  - Water premoderators and moderators
  - He cryoplant (35 kW – 16 K)



Gamma spectrometry at ESS

An example of interdisciplinary work: Faraday cup activation

Involved in this "project":

Douglas di Julio, Spallation Physics Group
Elena Donegani, Beam Diagnostics Section

→ Activation Calculations (MCNPX/CINDER'90 and PHITS 3.31/DCHAIN-PHITS)

Per Roos, Group leader Radiation Protection Group
Lena Johansson, Radiation Protection Expert
Fredrik Tidholm, Radiation Protection Engineer
Catarina Inácio
Gustav Pennsäter
Nikola Markovic

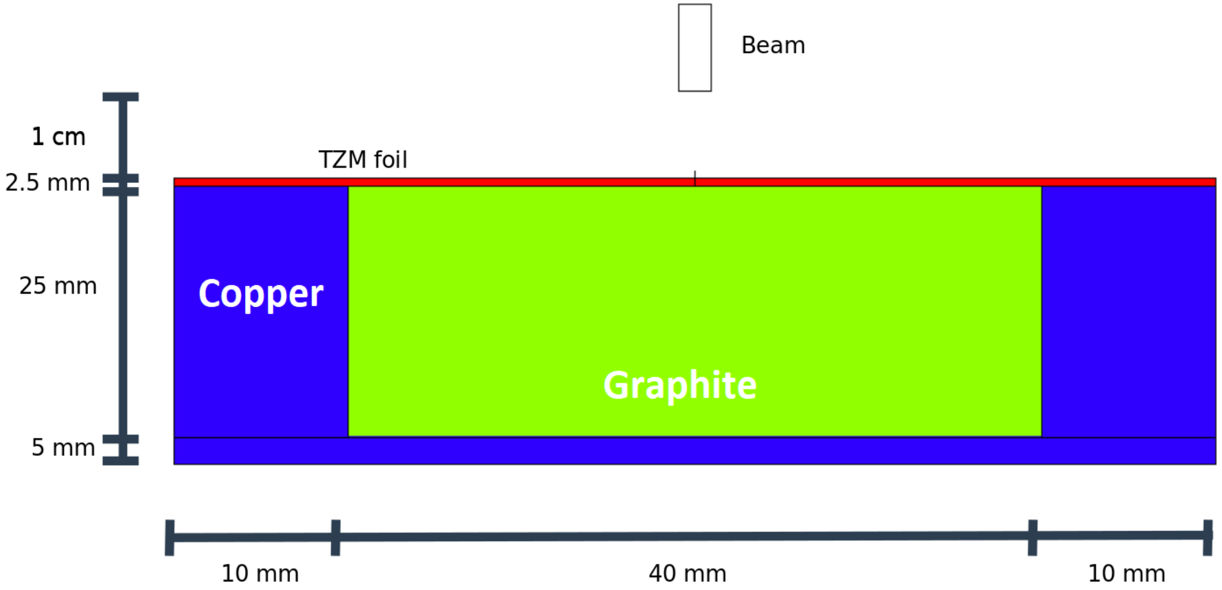
→ HPGe measurements and analysis (an Aegis in-situ detector BEGE5030 and one BEGE3830P lab detector)

Patric Lindqvist Reis, Spallation Physics Group

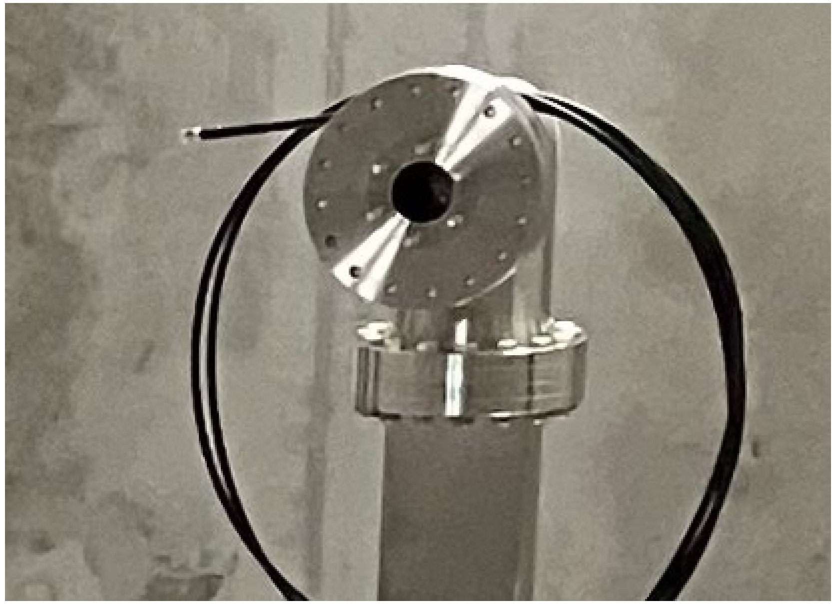
→ Analytical radio-chemistry material characterisation (XRF – as for now)

Faraday cup

Beam current measurement



Schematic view for the FC, exported from the MCNPX visual editor.



In reality (steel around, was placed inside a thick concrete shield)

Beam energy	Actual irradiation time
21 MeV	20 min
39 MeV	7 min
57 MeV	5 h
74 MeV	60 h

Actual irradiation times at the various possible proton beam energies.

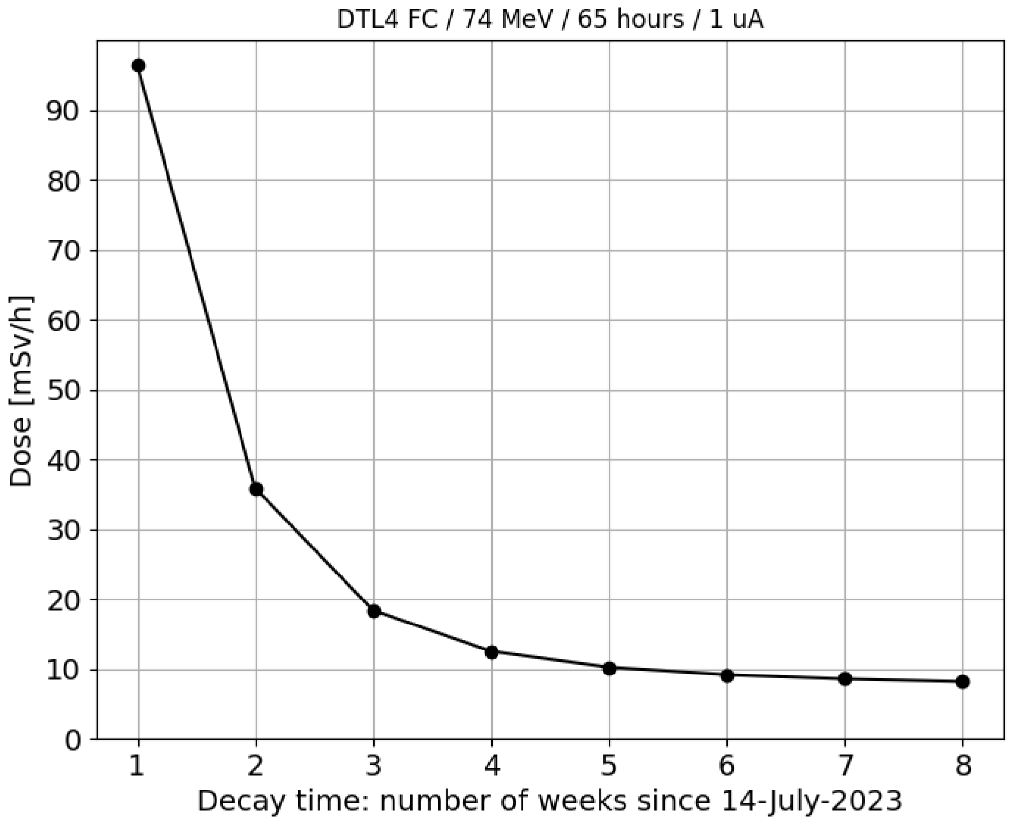
Dose rate calculations

Measured compared to calculated

6 weeks after the last day of commissioning:

- Teletector inside 7 mSv/h (contact)
- 2 mSv/h on the outside
- Safe to rotate and take direct HPGe.

Good agreement with activation calculations.



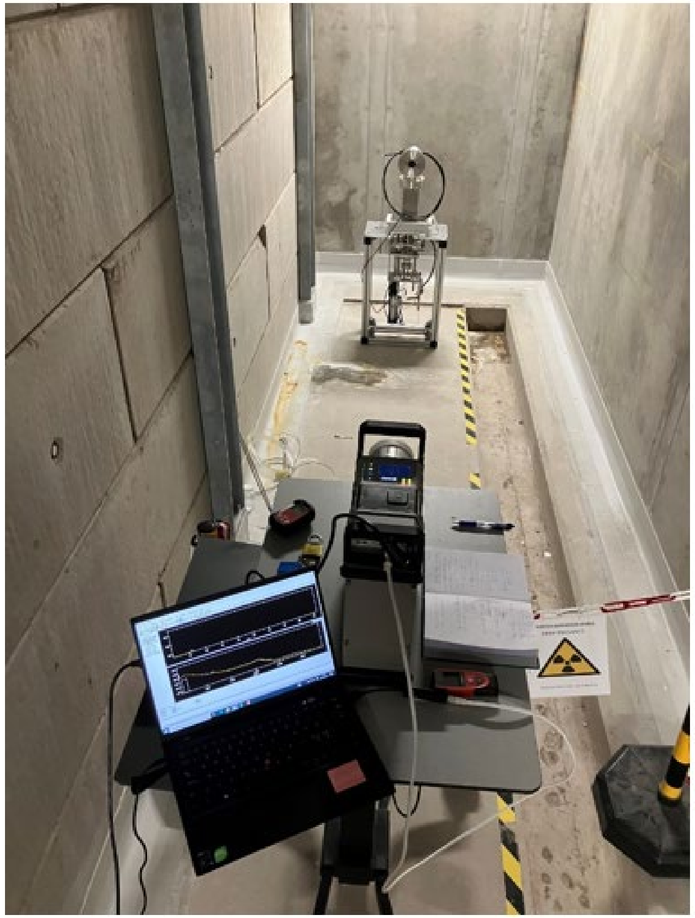
Calculated residual dose rate DTL4 Faraday cup.

Gamma spectrometry

Experimental

- Measured at different distances

- Measured over longer time period (multiple measurements)



- Room background was not known (collimators under procurement).
- Some isotopes peaks overlap with background peaks (e.g. 934,1 keV Bi-214 and 934,4 keV Nb-92m, 1120,3 keV Bi-214 and 1120,5 keV Sc-46, 765,8 keV Nb-95/Tc-95 …)
- Some isotopes have same/similar fingerprint (e.g. Sr-85/Kr-85).

Gamma spectrometry

Results

- Gamma spectrometry result consistent between different measurements (decay, distance), and between different emission energies from the same isotope.
- Preliminary results show good agreement between gamma spectrometry measurements and activation calculation results.
- Some adjustments needed (beam time profile for activation calculations).

Other samples/objects

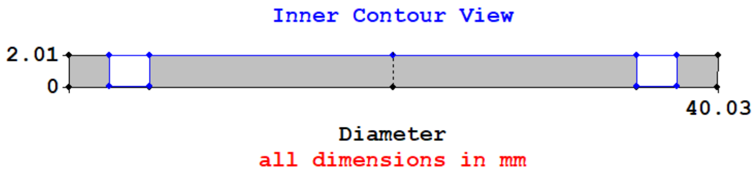
Cu O-rings

Laboratory gamma spectrometry

Nuclide	Activity (Bq)	Unc (Bq)
Co-57	5,2E-01	1,1E-01
Co-58	6,5E+00	5,1E-01
Co-60	3,6E+00	3,0E-01

Elemental composition of two copper O-rings measured by XRF.

	copper ring from flange, DTL4/FC			
	wt.%	± (3σ)	at.%	± (3σ)
Cu	99.81	0.01	99.65	0.01
Fe	0.027	0.002	0.031	0.002
Si	0.13	0.01	0.29	0.02
P	0.006	0.004	0.012	0.007
Cr	0.015	0.001	0.019	0.001
Ni	0.003	0.001	0.003	0.001
Co	0.0015	0.0006	0.0016	0.0007

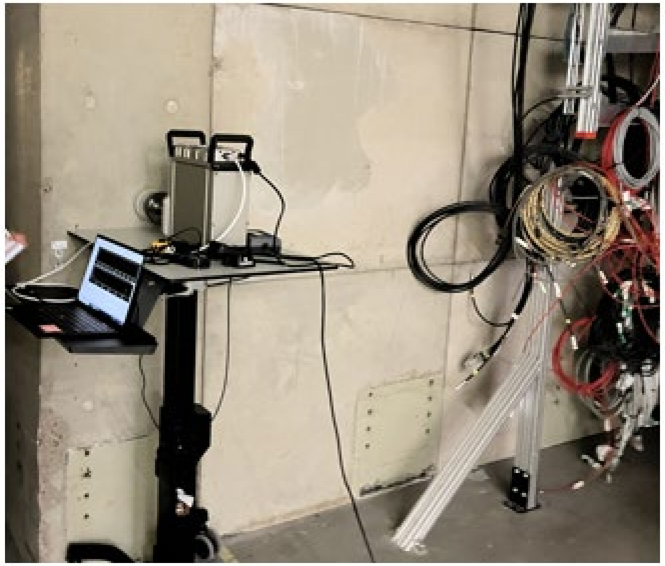


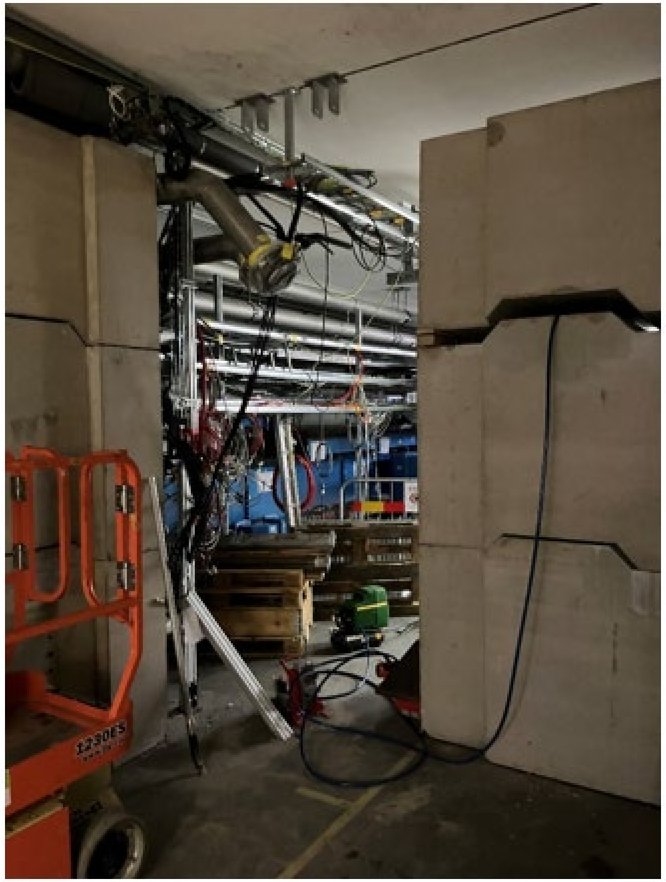
Other samples/objects

Temporary shielding wall

Calculated nuclide vector:

Nuclide	Bq/cm³
Ar-37	3,3E-02
Ca-45	7,5E-03
S-35	1,5E-03
P-32	1,2E-03
Fe-55	1,1E-03
Mn-54	6,4E-04
Be-7	4,7E-04
Sc-46	4,5E-04
Fe-59	3,3E-04
H-3	2,2E-04
Ca-47	1,3E-04
Co-58	6,7E-05
Sc-47	4,1E-05
Cr-51	2,4E-05





- Nothing detected with in situ HPGe.
- Could be cleared based on calculated NV and MDAs for key-nuclides.
- Verification of NV needed (material input files for concrete – impurities, water content, carbonates ...).
- Rebar
- Sampling from more activated FC shield is planned.

Conclusions

- Any good suggestions or ideas?
  How to produce with activation calculation (and general model) validation?
  (place activation foils, use existing material …)

- Radiochemistry and analysis of DTM nuclides for validation of scaling factors (nuclide vectors) will be needed in future.

- We will hopefully be able to produce (isolate) some exotic nuclides.

- Development of chart/trolley for in-situ HPGe
  (we have some ideas, let’s wait for the next gamma seminar).