The Budapest Neutron Centre Serving Science and ESS construction

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Hun-Ren Centre for Energy Research

Budapest

Introduction – Centre for Energy Research (CER)

Member of the (among 18 research centres) **Hungarian Research Network**

CER is one of the **Technical Support Organization**s of the Hungarian Atomic Energy Authority

Principal **Technical Consultant** of the **Paks NPP**

Operates Budapest Neutron Centre and is equipped by high level materials testing instrumentation:

SEM, TEM, AFM, STM/AFM, XPS, AES, FTIR, Raman

Nuclear Security Support Centre of IAEA NSSC Network together with the Hungarian Energy Authority

Operating a centralized **National Nuclear Forensics Laboratory** in Hungary (working together with the relevant national organizations and authorities) **IAEA Collaborating Centre**

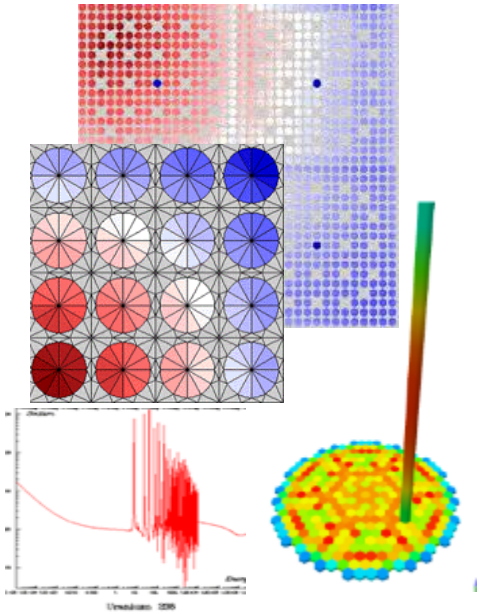
CER has about ~400 *employees (~75 % scientists)*

Age distribution is acceptable (50% of researchers are below 40)

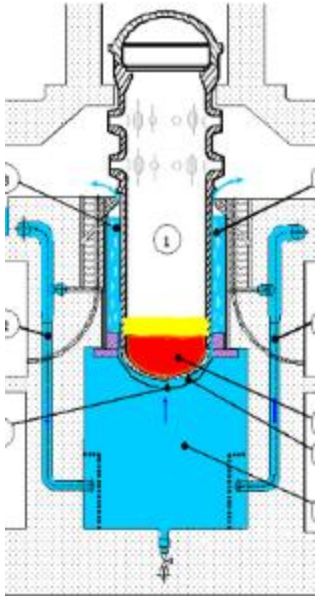
Total budget is 25-30 M€

23 departments (laboratories)

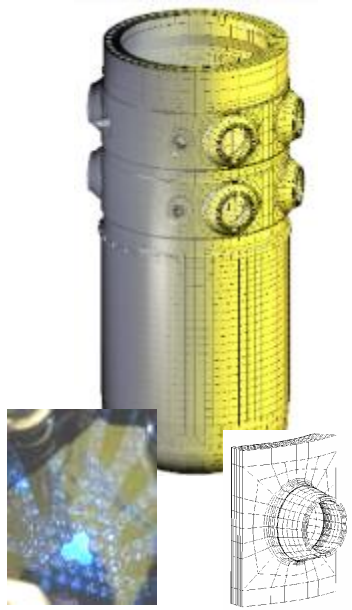
Nuclear safety research



Reactor physics,
Neutron transport calculations,
Reactor core design
Subcriticality analysis
Multi physics hot channel calculations

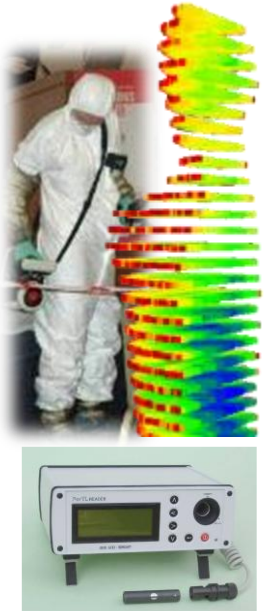


Thermal hydraulics,
Ex-vessel cooling tests
Computational Flow Dynamics
Severe accident simulations



Structure integrity analysis,
Fuel cladding thermo-mechanical properties,
Radiation damage studies

Digital I&C systems
Human-machine interface
Reactor training simulator
Core monitoring



Radiation protection,
low dose effects,
athmospheric dispersion,
environmental monitoring

Department of Reactor Monitoring and Simulation

Instrumentation & Control of Nuclear Power Plant

- The first training simulator in Paks NPP was developed by Nokia and CER
- The full scope simulator was refurbished in 2025. Presently all models running in the Simulator is developed by EK-CER (***Same team responsible for EC&I of Cask project in ESS)***

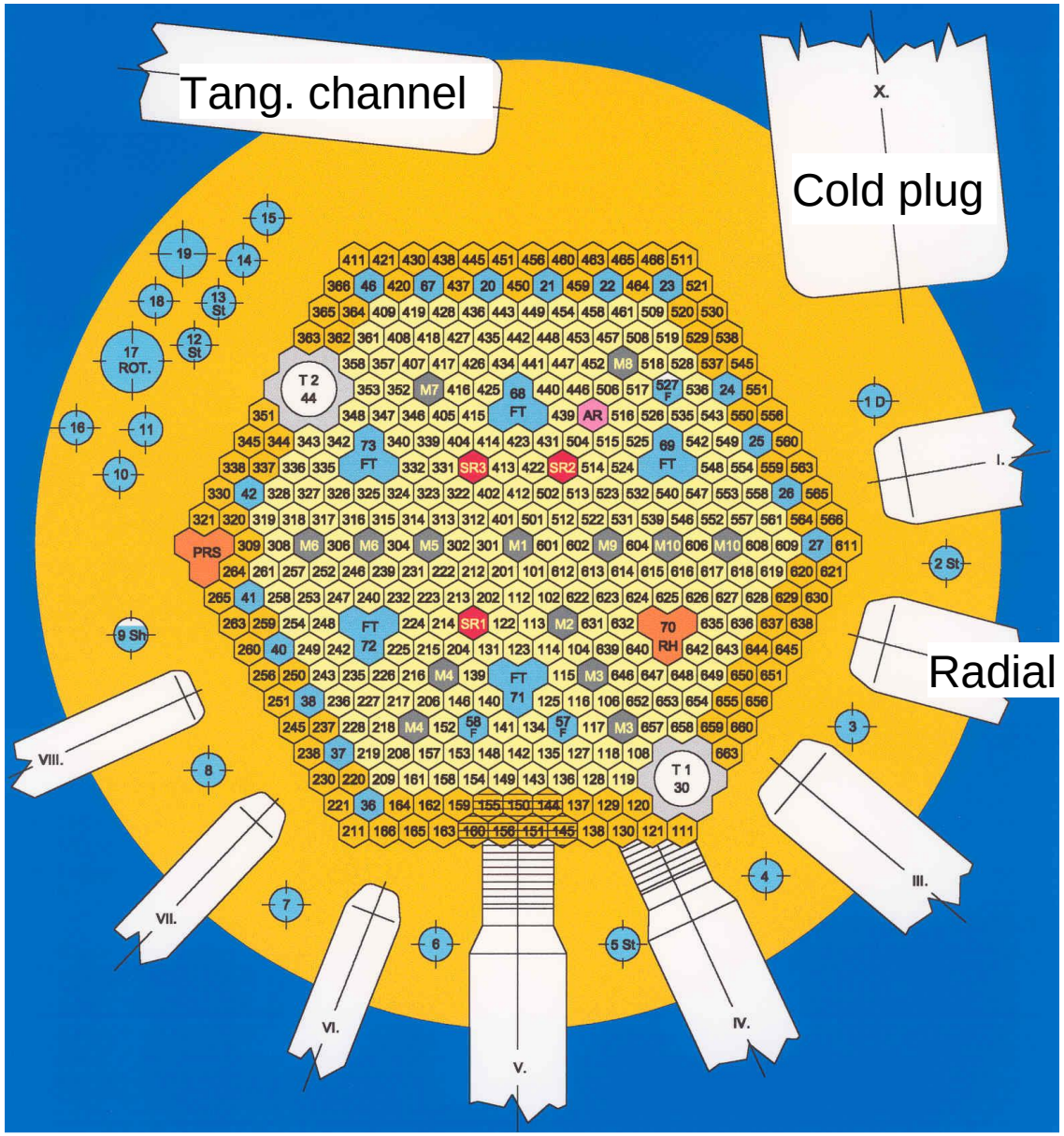
Other EC&I projects developed products:

- VERONA core monitoring is used by the operators to get data on operational margins even at the level of fuel rods
- PAZAR core noise diagnostics software is used to get data on the moderator temperature coefficient
- CERTA-VITA software is used by the Safety Authority to monitor the plant status online.
- SIMTONIA – simulator engine for power plant simulator

The Budapest Research Reactor and BNC's facilities

- 10 MW tank type
- Water-cooled
- Water-moderated
- thermal flux: 10^{14} cm^{-2} s^{-1}

- Cold source
- 3 supermirror neutron guides
- Cold flux @ PGAA: 10^{8} cm^{-2} s^{-1}
- Two 2x2 cm2 neutron beams



Reactor core

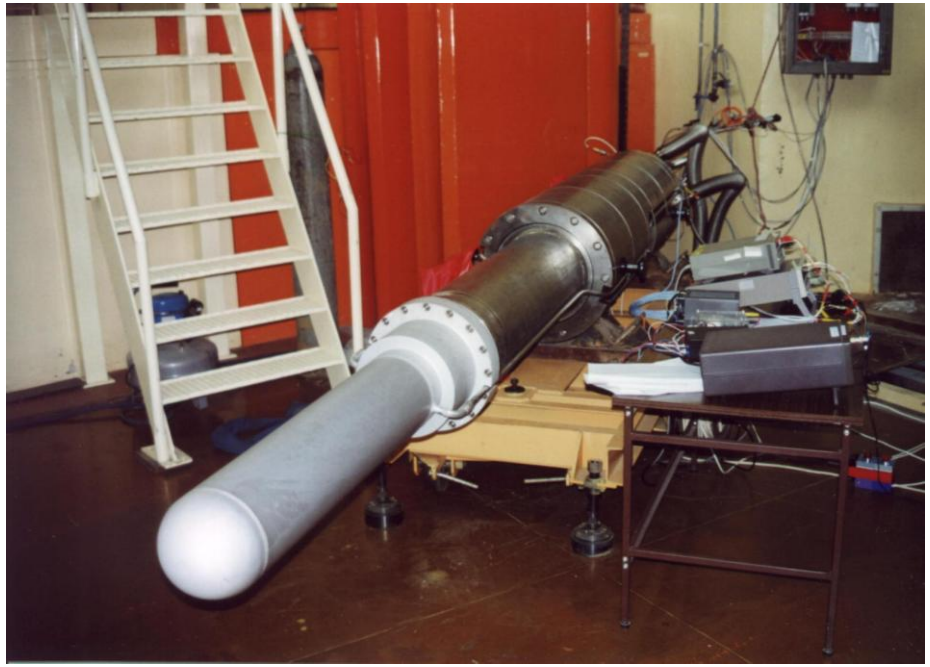
T ~ 20 K

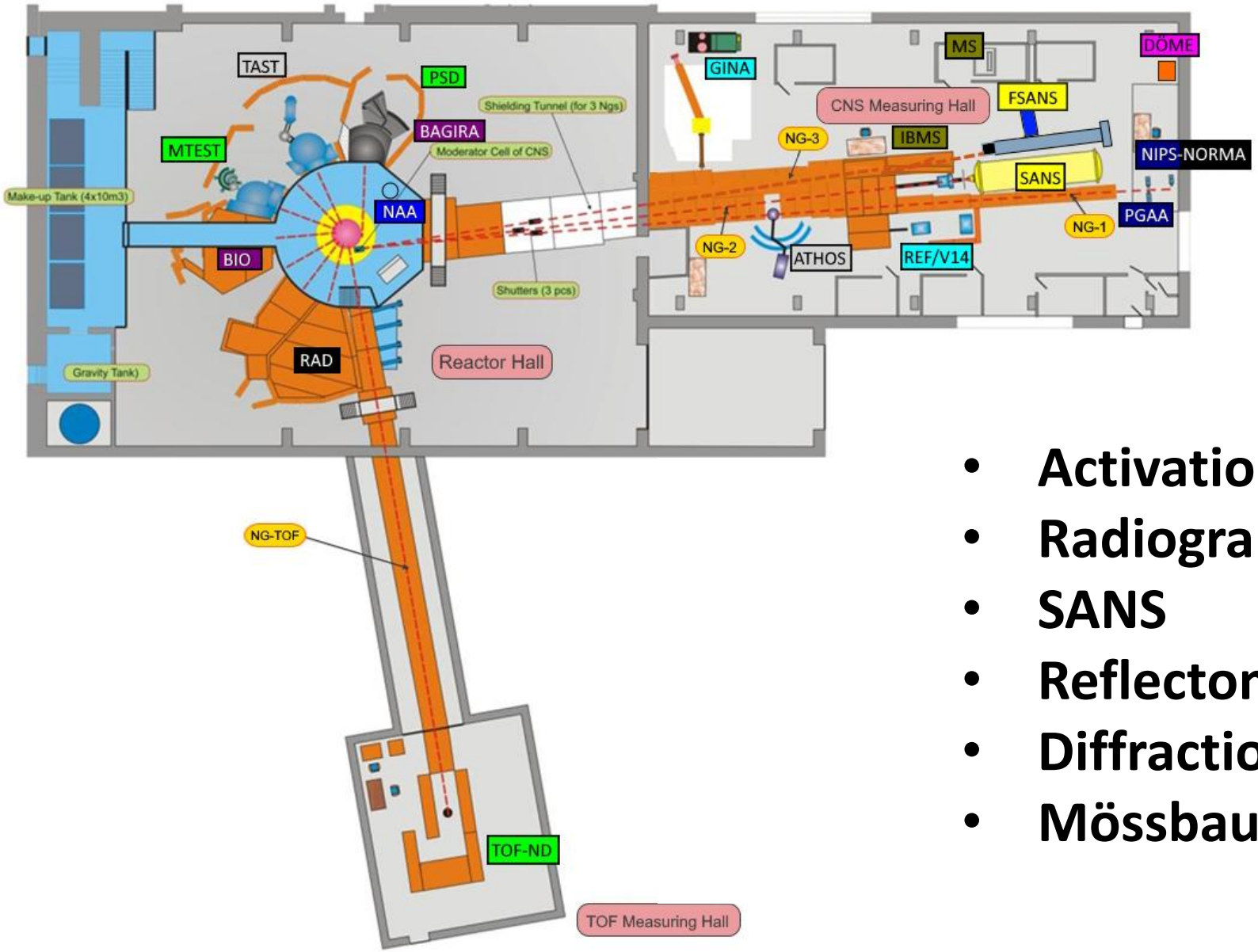
$\lambda_{\text{maximum flux}} = 4\text{Å}$

T ~ 320 K

$\lambda_{\text{max flux}} = 1.2\text{Å}$

Cold source

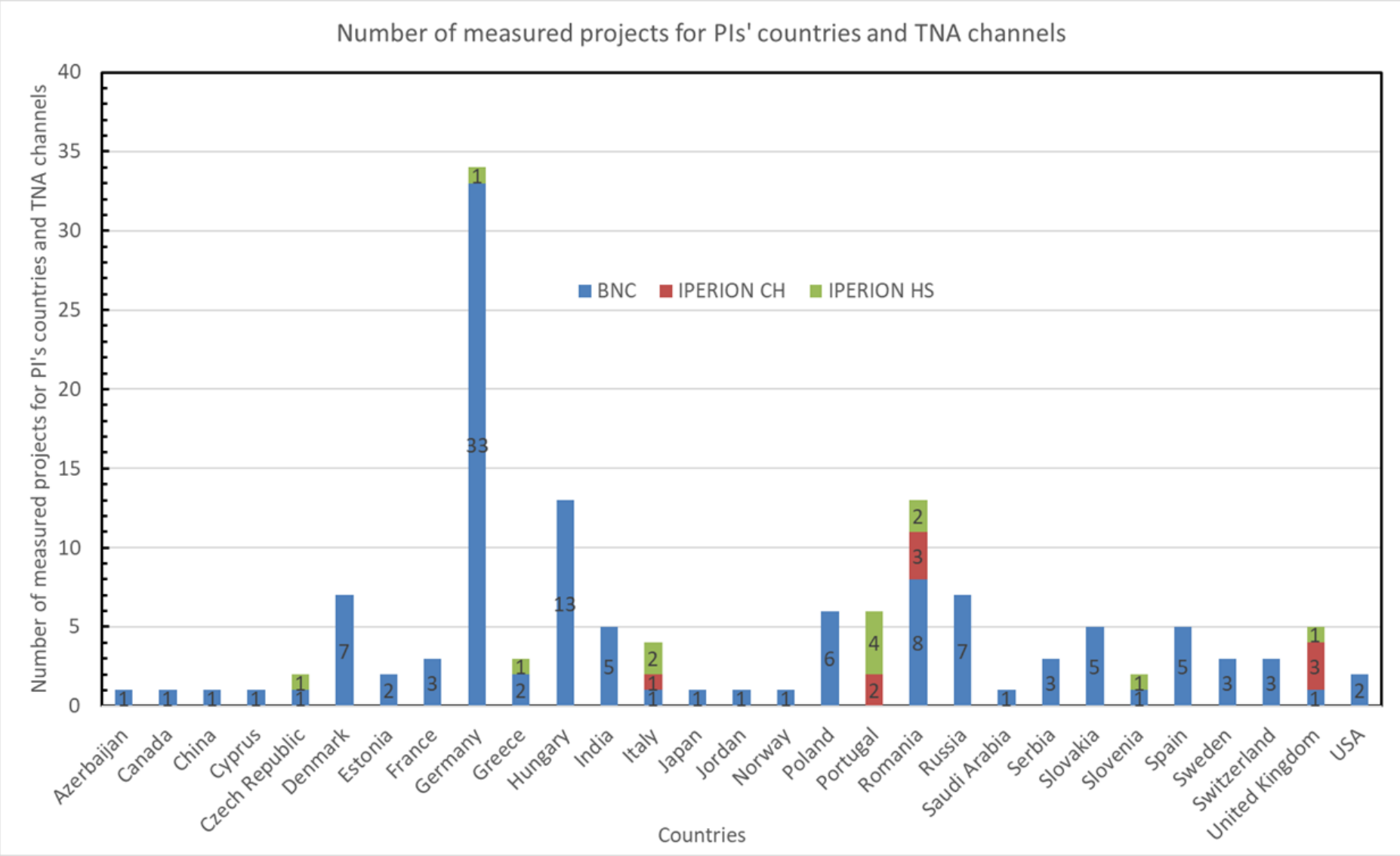




OPEN LABORATORY

- Activation analysis
- Radiography / CT
- SANS
- Reflectometry
- Diffraction
- Mössbauer spectroscopy

Open Science statistics from the 2019-2023 period
BNC, IPERON CH and IPERION HS calls (continues)



29 countries

Budapest, 4-9 October, 2026

BNC school is a regular event Central European Training
In the past 20 years **over 500 young scientists from nearly 40** countries have been trained at CETS.
Following the introductory lectures on the theory and on the different neutron techniques.

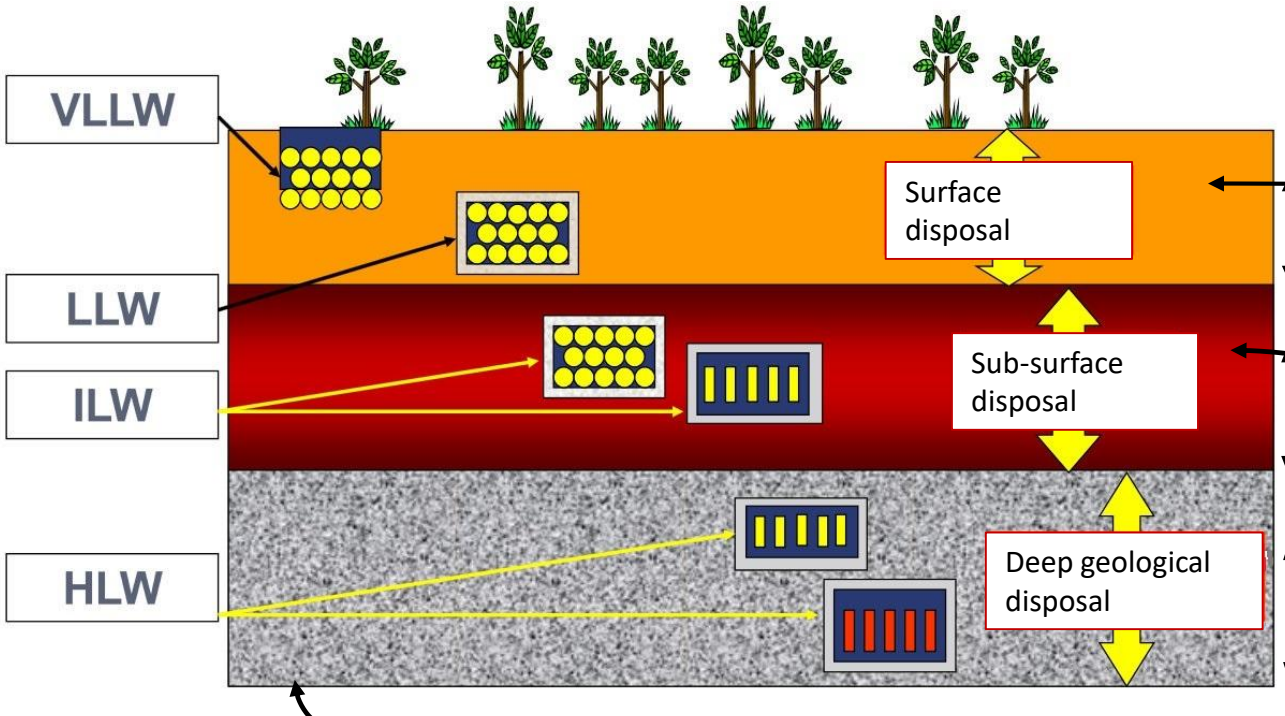
Hands-on practices will be performed on instruments:
SANS-YS - Small angle neutron scattering
GINA - Neutron reflectometry
MTEST - Neutron diffraction
ATHOS - Residual stress analysis
PGAA / NIPS / NAA - Elemental analysis
RAD / NORMA - Neutron imaging

Registration deadline: 1st June, 2026. https://bnc.hu/cets/

Participants of the 15th CETS, 2023

Experimental outstanding results: 1. Radioactive waste

Widely accepted process for storage: geological disposal



- classification based on activity concentration

$$S = \sum_i \frac{AK_i}{REAK_i}$$

where REAK is the referencia activity concentration [Bq/kg]; AK activity concentration, for radioisotope i in the waste package

Low-level waste – LLW

- 90% of total waste; from reactor operations and medical, academic, industrial uses of radioactive materials
- $1 < S < 1000$

Intermediate-level waste - ILW

- 7% of total waste; ion-exchange resins, chemical sludge, contaminated materials from reactor decommissioning, and radioactive sources used in radiation therapy
- $10^3 < S < 10^6$

High-level waste – HLW

- 3% of total waste, but az 95% of total radioactivity, generated primarily from spent fuel removed from reactors after producing electricity
- most abundant $^{238, 239, 240, 241, 242}Pu$, ^{237}Np, ^{236}U, ^{241}Am
- $S > 10^6$

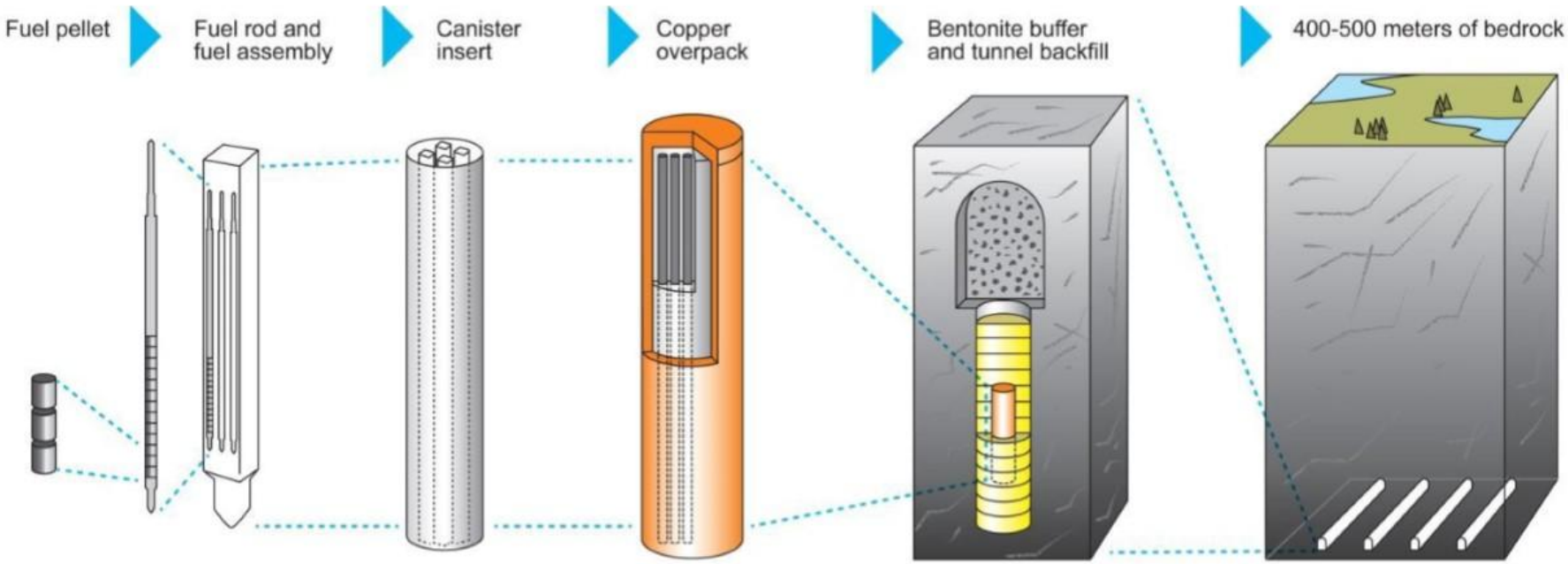
High level waste

Paks Nuclear Power Plant:

- During operation ~350 m^3
- Decommissioning ~180 m^3

Multiple barrier system for radioactive waste

Natural geological barriers and engineered barrier system with complementary safety function ensure long-term safe storage by isolating the radioactive waste from the biosphere in deep geological repositories



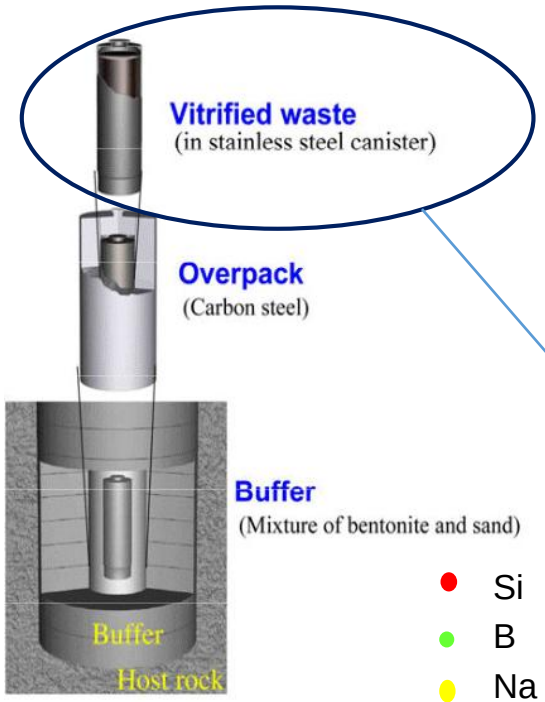
Direct disposal of spent fuel
Onkalo deep geological repository, Olkiluoto, Finland, under construction
Expected to be operational in 2026

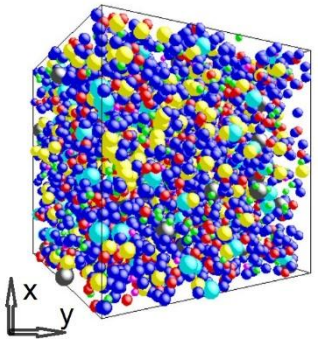
High-level waste

NKFIH, OTKA project

Multicomponent borosilicate glasses are suitable for conditioning of high-level radioactive waste
Advantages: thermal and chemical stability, good radiation resistance, economic production
lantanides to substitute actinides (Pu, Am, Cm)

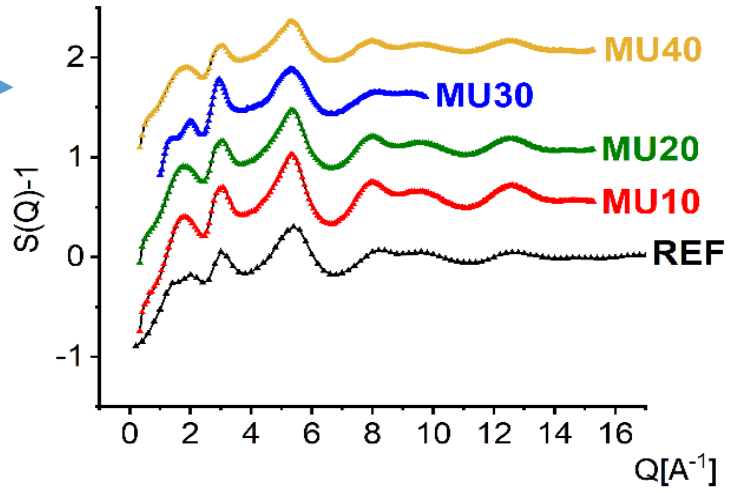
60s%[SiO_2(65-x)-B_2O_3(x)-Na_2O(25%)-BaO(5%)-ZrO_2(5%)]+40s%UO_3 x=10-20-30-40%; UB10, UB20, UB30, UB40 - neutron diffraction data calculated by Reverse Monte Carlo simulation





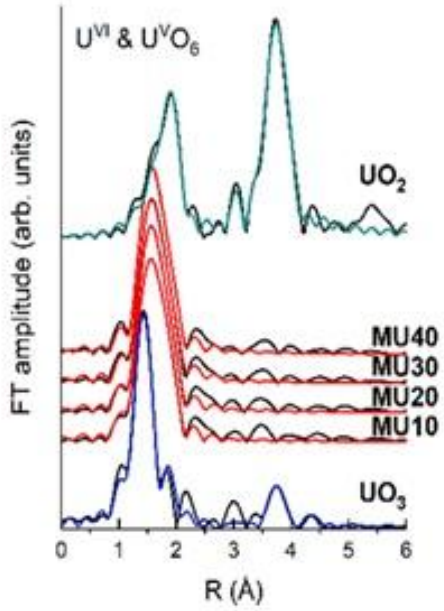
Si
B
Na
Ba
Zr
U
O

Neutron diffraction* (PSD, 7C2)



✓ ESS/DREAM -> high Q-resolution, up to 25 Å^{-1}

EXAFS (Diamond)



Structural investigation:
ND, XRD
SEM/EDX,
NMR, Raman
XANES, **EXAFS**

The chemical stability of U-glasses, leaching tests in aqueous solutions were evaluated based on **ASTM C1285-21** protocol. The glass matrix can hold up to 40% UO_3 by weight, exceeding previous limits.
The simple composition allows for better control of the interaction and escape of these elements.

**Sci. Rep. 10:7835 (2020), 11:13272 (2021), 15:28351 (2025) and JNCS 637:123054 (2024)*

Experimental result: 2. plant physiology

Climate change is contributing to several environmental challenges (e.g. dehydration):

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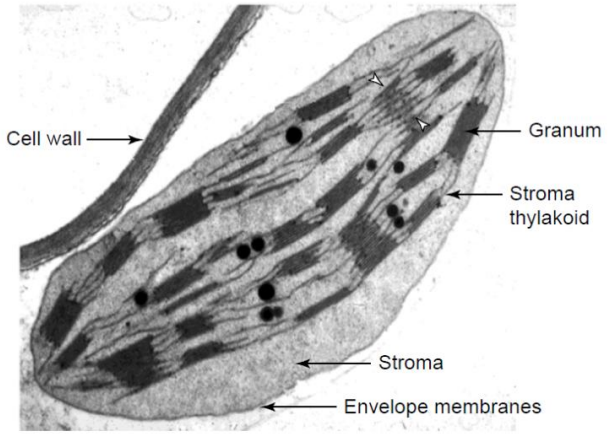
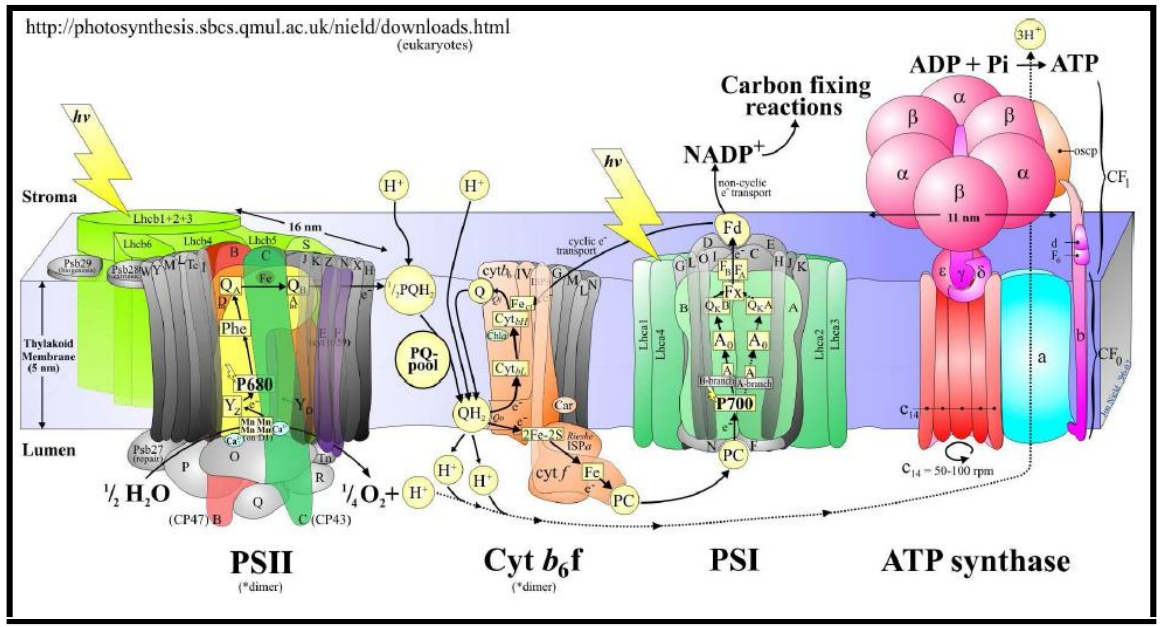
-**Extended periods of drought**, which diminish water quality and increase the **salinity of groundwater** supplies.

-Currently, approximately 1.4 billion hectares of land are affected by **soil salinization**, with an additional one billion hectares considered at risk of future salinization



Thylakoid membranes:



-Multilamellar membrane system
-Contains all components for light reactions of photosynthesis
-Highly complex, organized, finely tuned structure
-Maintains efficiency under various stress conditions

Must be studied at all structural levels

BUT : **Ultrastructural analysis is challenging**

Mustardy, L. and Garab, G., 2003. Trends Plant Sci

Literature data about how drought stress affects thylakoid membrane ultrastructure is controversial.

Electron-microscopy (EM)

-very detailed information
-sample fixation:
  -conventional (chemical fixation, dehydration)
  -cryo-sectioning (a compression artefact; high osmolarity agents used as cryo-protectants)
-not suited to monitor the kinetics of membrane reorganizations
-fixations in a water-based solution

Our purpose:

Study on the **most intact system** possible
Under drought stress:
  Duration of thylakoid structural integrity
  Nature and reversibility of changes
  Timescale of structural responses
  Efficiency of water retention

Small-angle neutron scattering (SANS)

- non-invasive technique
- providing accurate, statistically and spatially - averaged information
  - -without fixation or staining
  - -with time-resolution of minutes or shorter
  - -under physiologically relevant conditions

-on isolated thylakoids, chloroplasts, live algal cells, leaves and intact plants

Ctenanthe setosa (Roscoe)

- commonly known as ‘Never Never plant’

-it a suitable model plant for studying extreme drought tolerance

-leaf rolling an effective drought avoidance mechanism and helps to protect the leaves from photodamage

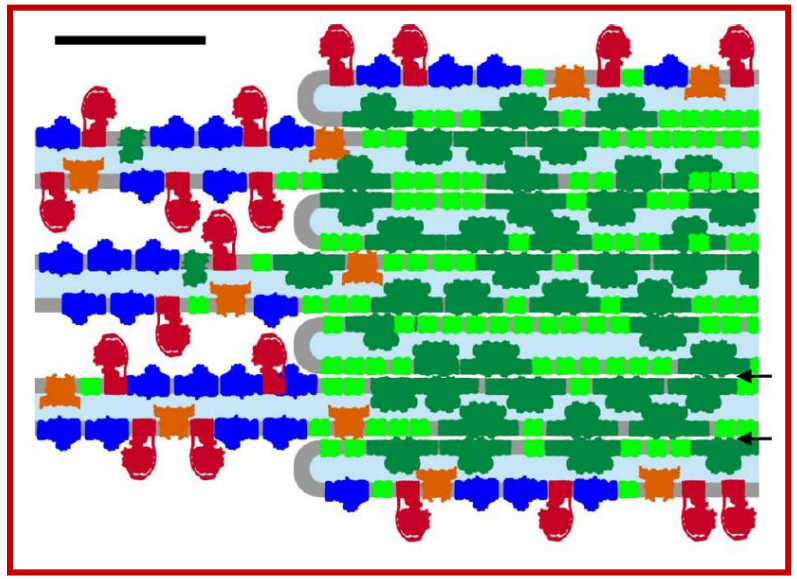
-no ultrastructural data of its thylakoid membranes

-large grana (nice diffraction peak)

Never Never Plant (drought-stress)

Hydrated plant (control)

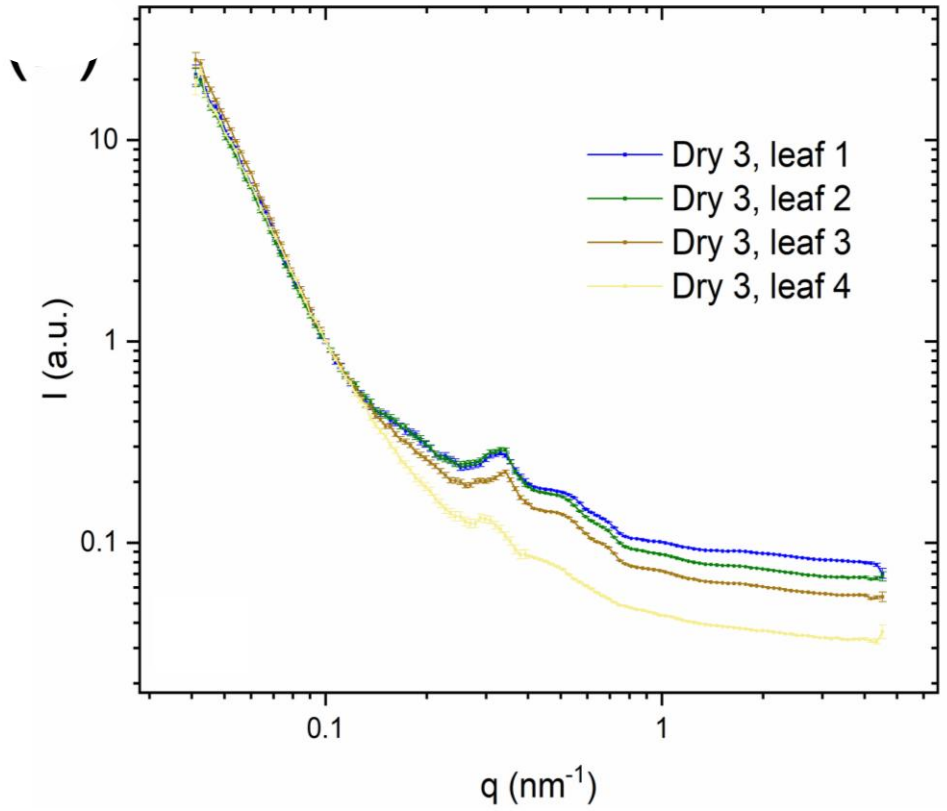
Upper limit of the repeat distance
too loose to maintain structural integrity



Dekker , J. P. and Boekema, E. J. (2005) Biochim Biophys Acta Bioenerg

Drought-stressed plant

Lower limit of the repeat distance
due to the protein subunits protrusion



Hembrom, R. (2025) Physiol. Plant

Imaging assisted PGA, unique position-sensitive prompt gamma measurements

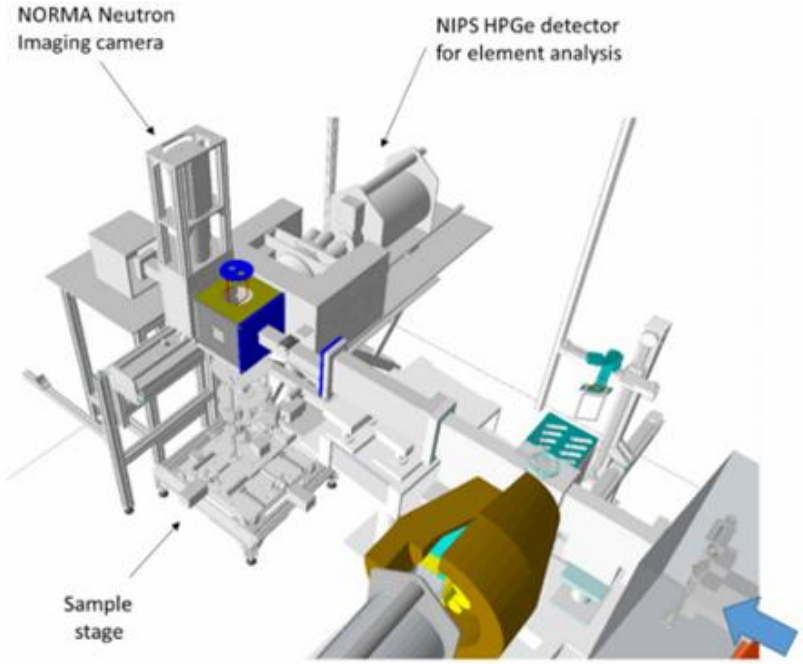
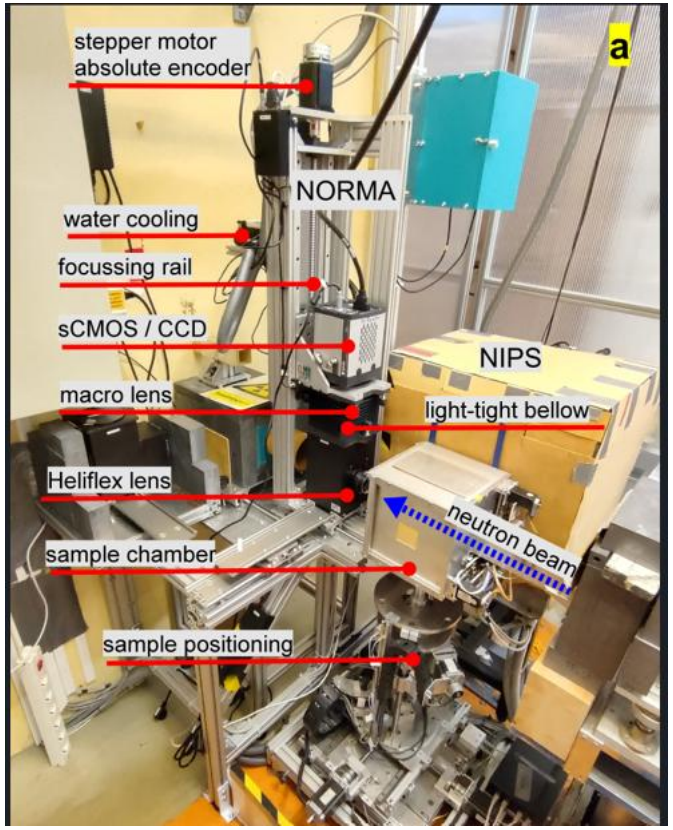


Fig. 1 The CAD model of the NIPS-NORMA setup at the Budapest Neutron Centre.



Experimental Results 3: Heritage science/Archeometry

Internal composition analysis of Edo (17th) period iron lobster

- Samurai armor metal skills used to manufacture articulated animal sculptures
- Edo period (17. century) ornament
- These were made by gunsmiths during peacetime
- The technique was passed down secretly within the family
- The positions of the neutron beams can be projected onto the radiogram.
- Real-time feedback using neutron radiography images and an XYZ motion table

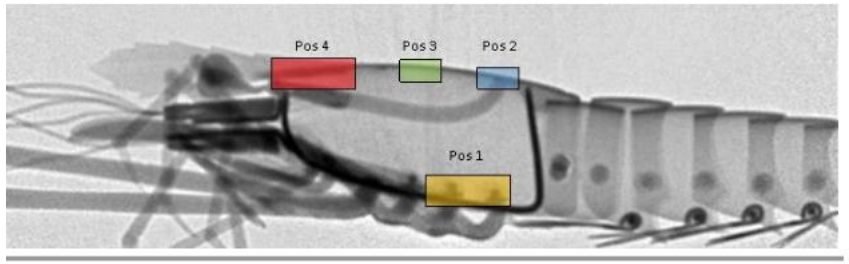


Fig. 2. Measurement positions for the position-sensitive PGAA experiment overlaid on the neutron radiogram.

Element	Pos 1		Pos 2		Pos 3		Pos 4	
	Lobster base metal + Solder 1		Lobster base metal + Solder 1 + Solder 2		Lobster base metal only		Lobster base metal + Solder 2	
	m/m%	rel. unc	m/m%	rel. unc	m/m%	rel. unc	m/m%	rel. unc
Mn	0.37	3.0	0.45	2.9	0.42	3.0	0.47	6.
Fe	99.63	0.03	99.55	0.03	99.58	0.03	99.53	0.03
Cu			61	1.3			63	1.2
Zn			39	2.0			37	2.1
Sn	27	4.	27	6.				
Pb	73	1.6	73	2.1				

able 1. Element mass fractions and 1-sigma relative uncertainties of the metal body and the two soldering materials, as determined at the four measurement positions.

J. Anal. At. Spectrom., (2021), 36 2439-2443

Contribution to ESS 1

- Joint doctoral supervision with ESS (L: Zanini and R. Hall) Dissertations 2014- 2024
- “Neutron transport simulation to support ESS decommissioning PhD Eötvös University Kókai Zsófia 2020
- Detector development (2 Ph.D Budapest TU) 2016-2021 Dian Eszter (2019) Klausz Milán (2021
- Simulations of concrete shielding capability for neutron sources, Ph.D. Pannon University Hajdú Dávid, 2024
- Fusion and NMX Ph.D. Náfrádi Gábor BME(2017) doktori iskola
- >20 ESS_CER joint publications

Commercial and In-Kind coopeation

- Preliminary decommissioning plan (2018)
- NMX beam design, guide and cave radiological design (2018-2024)
- 2021 NUVIA CASk assembly design update
- TIK 6.2 CASK assembly BTP contract

Remote handling of target activated components by shielded Cask

Cask 1

Cask 2

Cask 4

Cask 5

Cask 7

Cask 9

For details see Magnus Göran lecture Tuesday 3 pm "The ESS Target Station, Impact of Nuclear Maintenance on layout and design

His saying hovers before our eyes:

*'**Detecting the neutron** was not simply a matter of clever reasoning; it **required carefully designed experiments and precise instruments.'***