THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

Division of Applications of Physics (NO6)

Division Head: **Dr. hab. Wojciech Królas**

Scientific Departments:

- Department of Radiation Transport Physics (NZ61)
- Department of Radiation Research and Proton Radiotherapy (NZ62)
- Department of Radiation Physics and Dosimetry (NZ63)
- Department of Nuclear Physical Chemistry (NZ64)
- Department of Mass Spectrometry (NZ65)

and

- Cyclotron Laboratory AIC-144 (PCA)

Staff: 57; Researchers: 36; PhD Students: 6

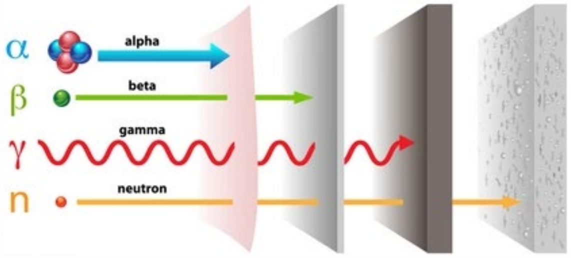
Radiation

ENERGY

Department of Radiation Transport Physics (NZ61)

HEALTH

Department of Radiation Research and Proton Radiotherapy (NZ62)



Department of Radiation Physics and Dosimetry (NZ63)

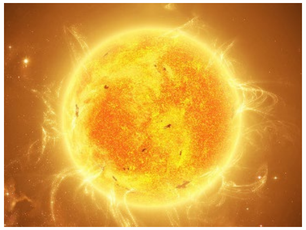
DOSIMETRY

Department of Nuclear Physical Chemistry (NZ64)
Department of Mass Spectrometry (NZ65)

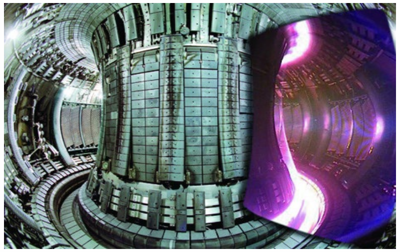
ENVIRONMENT

Department of Radiation Transport Physics (NZ61) – recent activities and achievements:

- interaction of neutrons and ionizing radiation with matter
- theoretical modelling and experimental work
- participation in the European fusion development program (EUROfusion, ITER, etc.)

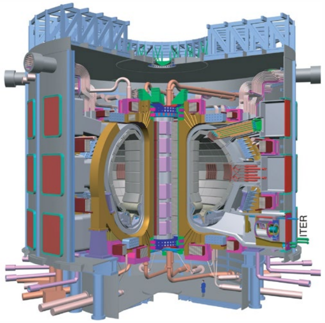


Joint European Torus (JET)



Tungsten Environment in Steady-state Tokamak (WEST)

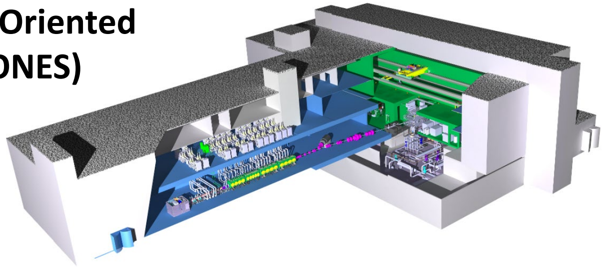
International Thermonuclear Experimental Reactor (ITER)



iter
china eu india japan korea russia usa

International Fusion Materials Irradiation Facility DEMO Oriented Neutron Source (IFMIF-DONES)

IFMIF DONES GRANADA | THE KEY TO THE FUTURE



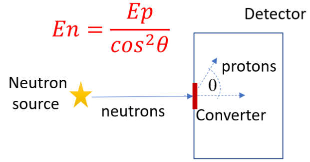
FUSION FOR ENERGY

EUROfusion

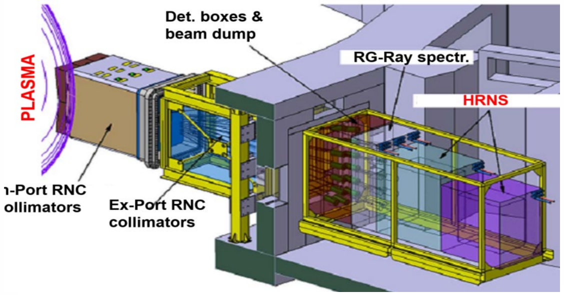
Development of neutron diagnostics for fusion devices

High Resolution Neutron Spectrometer (HRNS) for ITER

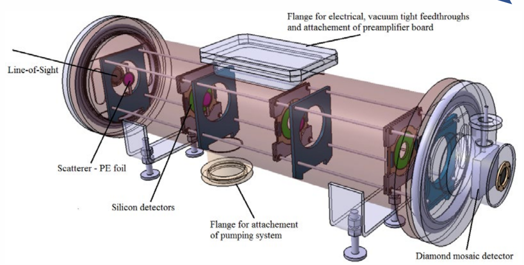
$$En = \frac{Ep}{cos^2\theta}$$



A spectrometric neutron measurement system based on neutron → proton conversion on thin PE foil has been proposed for HRNS

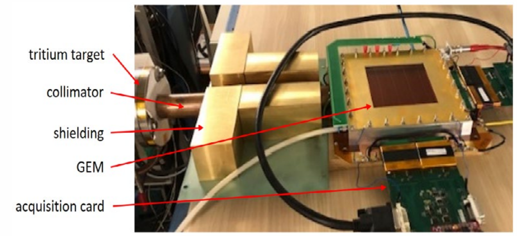


(ITER, IFJ PAN, Uppsala University, UNIMIB)

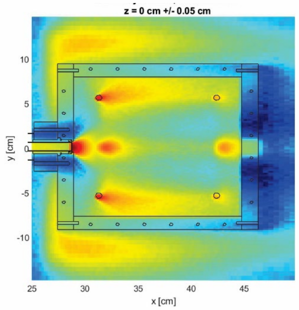


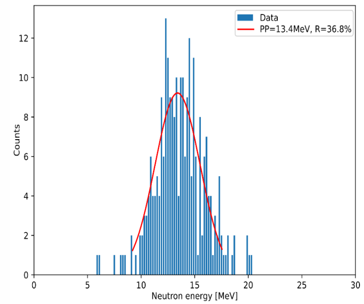
A collimated neutron beam scattered on thin PE foil produces recoil protons. The energy of neutrons can be reconstructed based on the proton energy deposited in the GEM detector.

*A **GEM** (Gas Electron Multiplier) detector for protons is being developed as a compact fast neutron spectrometer for fusion plasma diagnostics*



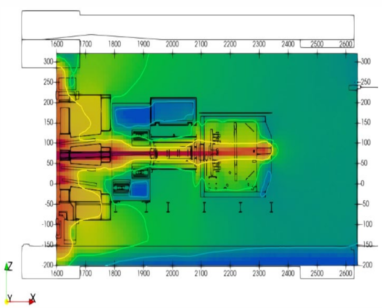
The prototype has been tested using 14 MeV neutrons produced at IGN-14 generator at IFJ

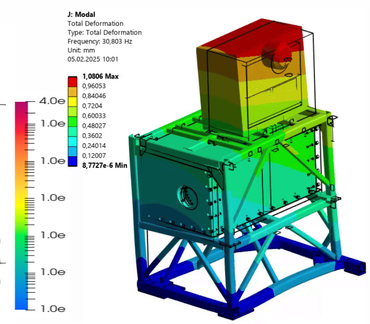




The Preliminary Engineering stage (PDR) included:

- 3D CAD project Mechanical analyse
- Magnetic analyses Numerical analyses





[M. Scholz et al, Fus. Eng. & Des. 2025]
[A. Jardin et al, Physics Plasma 31, 2024]
[V. Gerenton et al, J. Fusion Energ. 43, 2024]
[M. Scholz et al, JINST 18, 2023]

https://phys.org/physics-news

SEPTEMBER 11, 2025

PHYS.ORG Topics Week's top

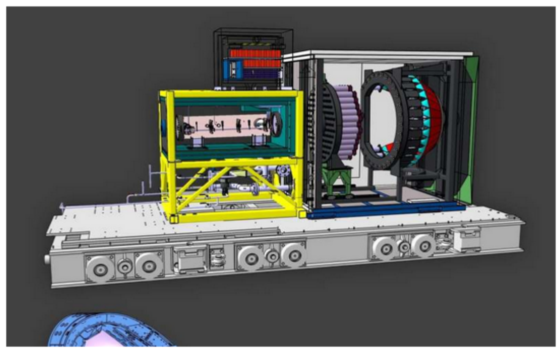
Home / Physics / Plasma Physics

SEPTEMBER 11, 2025 The GIST

Key diagnostic system for experimental fusion reactor nears completion

by Polish Academy of Sciences

edited by Gaby Clark, reviewed by Robert Egan Editors' notes



The high-resolution neutron spectrometer HRNS. The yellow structural elemen...

In the universe, thermonuclear fusion is a common reaction: it is the source of energy for stars. On Earth, producing energy using this process is difficult due to problems with controlling the plasma emitting significant amounts of energy. Of critical importance here is the knowledge of the current state of the plasma and the power released in nuclear reactions. In the ITER reactor, this knowledge will be gathered by a sophisticated neutron flux diagnostic system.

Installation of a neutron diagnostics system in the laboratory of the Institute of ...

"Equally important was the calculation of the radioactive activity of individual components of the HRNS spectrometer. This knowledge guarantees both the proper functioning of the device and the safety of the personnel operating it," notes Dr. Urszula Wiacek, head of the Department of Radiation Transport Physics at the IFJ PAN.

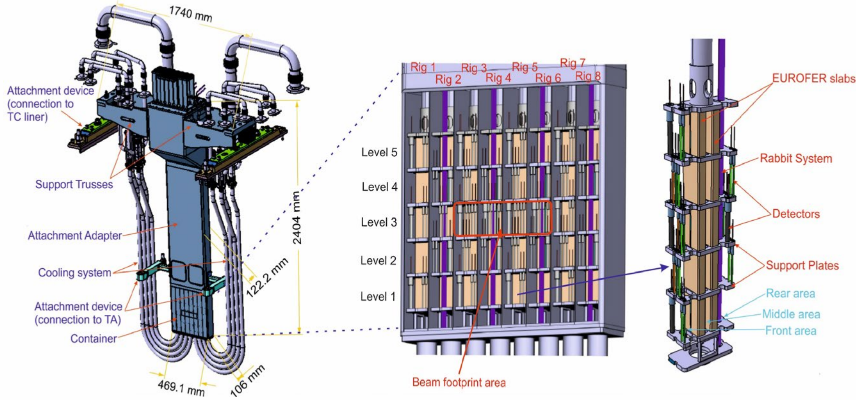
Scientists expect that a prototype of a high-resolution neutron spectrometer for the ITER fusion reactor will be developed within two years.

More information: J. Dankowski et al, Development and performance of the thin-foil proton recoil spectrometer for ITER plasma diagnostics, *Fusion Engineering and Design* (2025). DOI: 10.1016/j.fusengdes.2025.115263

Provided by Polish Academy of Sciences

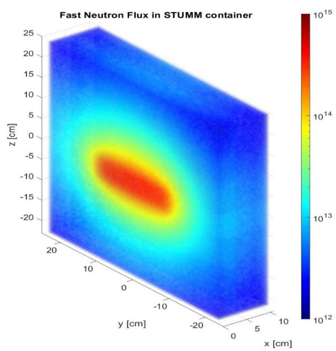
Development of Start-Up Monitoring Module (STUMM) for the IFMIF-DONES neutron source

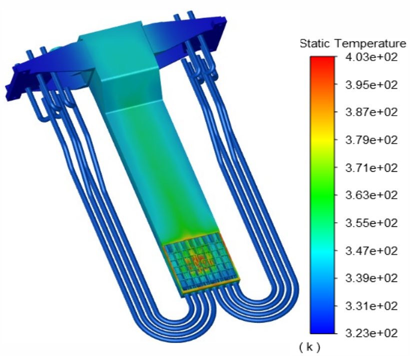
Start-Up Monitoring Module (STUMM) is a module designed for the commissioning phase of IFMIF-DONES. It will be placed behind the neutron source in the irradiation space for material samples to characterize the neutron and gamma radiation field



Design development and optimisation:

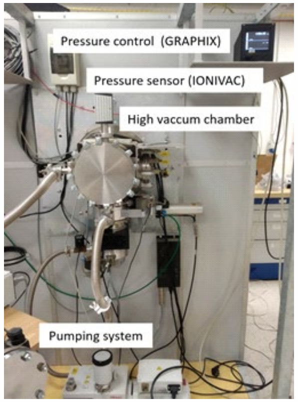
- 3D CAD project
- Mechanical analyses
- FEM analyses
- Numerical analyses



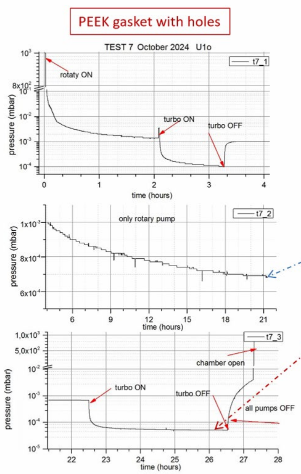


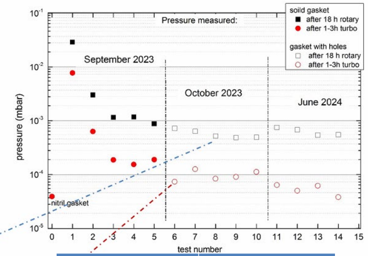
Several variants of the STUMM module have been proposed and analyzed to verify the fulfillment of project requirements.

[U. Wiącek et al, Fus. Eng. & Des., 216 (2025) 115125]
[R. Ortwein & U. Wiącek, Fusion Eng. Des., 188 (2023) 113451]
[R. Ortwein et al, Fus, Fusion Eng. Des., 171 (2021) 112601]
[U. Wiacek et al, Fus, Fusion Eng. Des., 172 (2021) 112866]



E.g. the experimental validation of the re-use of the gasket proposed for STUMM





PEEK solid	~4.78 x 10^{-6}
PEEK with holes: October 2023 June 2024	 ~1.91 x 10^{-6} ~3.33 x 10^{-6}
Cu solid	~4.42 x 10^{-2}

Increased involvement in the construction of the IFMIF-DONES laboratory

Start-up and Monitoring Module (STUMM)

STUMMEX is an experimental programme to characterise and increase the knowledge about the different types of sensors and detectors that will be part of the STUMM instrumentation.

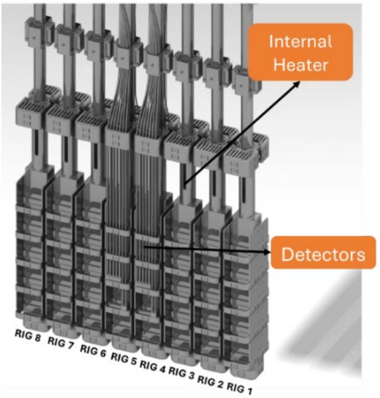
IFMIF-DONES Escúzar site, 18 km from Granada, Spain

DONES

Contribution to:

- experimental activities
- supporting neutronics analyses
- validation of detector performance
- electronics and signal processing
- transmission lines (long mineral-insulated cables)

STUMM-PROTO



RIG x8
- Rig 1 & 8 without internal heater
- 2 rigs instrumented

[S. Becerril-Jarque, (U. Wiącek) et al., Nucl. Mater. Energy, **40** (2024) 101712]

Impact of **tungsten impurities** on electron dynamics of thermonuclear plasma in tokamaks

Elastic ion-electron collisions:

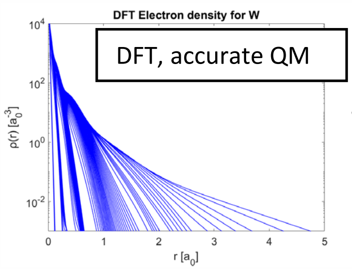
- Calculate electron density
- Ab-initio DFT *or* fast numerical approximation (e.g. TF)
- Obtain form factor

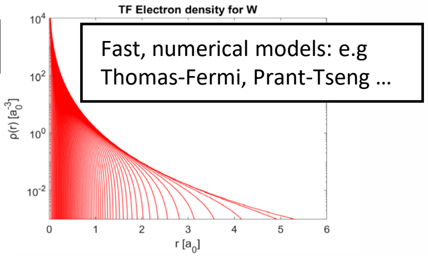
Inelastic collisions:

- Local plasma approximation
- Calculate Mean Excitation Energy of ions as a function of Z and ionisation

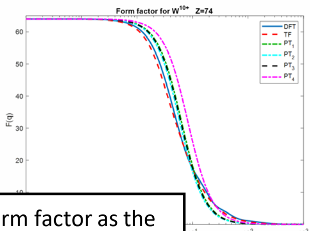
- Use both as input to Fokker-Plank solvers
  (e.g. LUKE, DREAM codes)
- Derive plasma parameters and dynamics

Electron density:



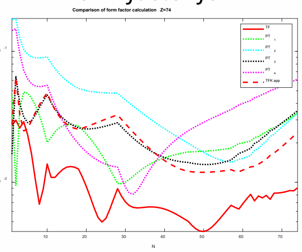


Form factor:



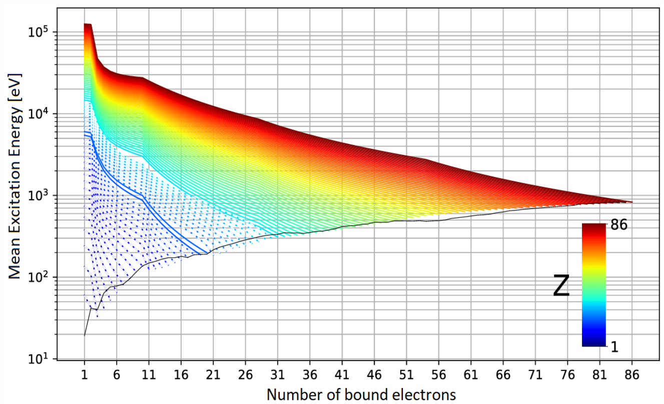
Form factor as the Fourier transform of electron density

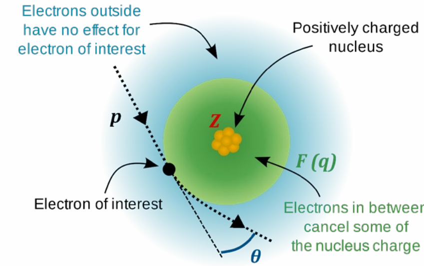
Form factor for W



Comparison of form factors for W, calculated based on various modes of electron density, as a function of ionization

Mean excitation energy for all ions (1 ≤ Z ≤ 86) and for all ionization degrees





Visualization of „partial screening" effect <-> Form factor F(q)

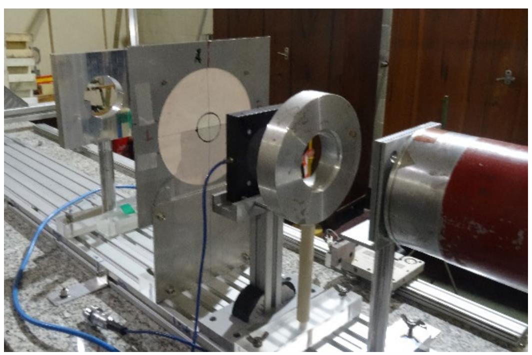
[J. Walkowiak et al, Nucl. Fusion 64 (2024) 036024]
[J. Bielecki et al, EPJ Web of Conf. 306 (2024) 01032]
[J. Walkowiak et al, At. Data Nucl. Data Tables (2024)]

Department of Radiation Research and Proton Radiotherapy (NZ62) – activities:

- design and application of proton and heavy-ion beams for cancer radiotherapy
- experimental radiobiology and radiation damage of solid-state systems
- development of dosimetry of novel radiotherapy methods and radiobiological models and systems of ion beam transport for radiobiological experiments
- studies of the radiation damage to electronic systems and samples irradiated by energetic proton beams

AIC-144 cyclotron 60 MeV proton beam irradiation:

- precision positioning system
- proton energy tuned 60 → 0 MeV
- broad intensity rage up to 100 nA
- fluence up to 10^{13} p/cm^2
- high field homogenity > 5%
- dose rate up 10 Gy/s
- precise dosimetric information



Beam current up to 100 nA
Spot size < 10 mm
Flateness > 15%

Horizontal beam line - eye-treatment room
Tuned energy: 0-58 MeV
Dose rate 0.001 – 1 Gy/s in water

Irradiation areas and setups built and operated by Dept. NZ62

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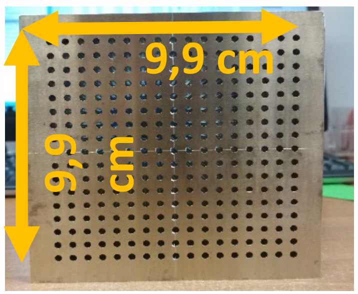
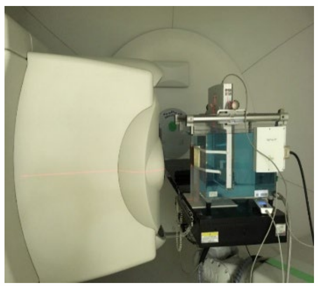
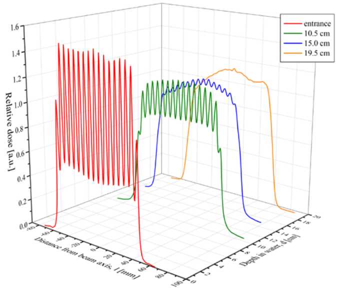
Division of Applications of Physics

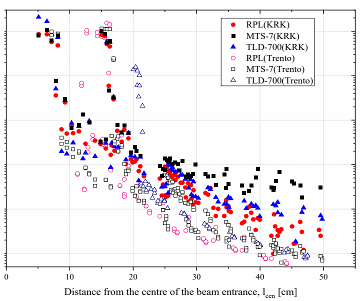
Department of Radiation Research and Proton Radiotherapy (NZ62) – recent achievements:

development of new methods for proton radiotherapy and development of dosimetry of novel radiotherapy methods and radiobiological models and systems of ion beam transport for radiobiological experiments: FLASH and GRID proton radiotherapy, radiobiological modelling, development of treatment planning methods in proton radiotherapy, 3D printing for beam modification in proton therapy, modeling of the PET signal detected by the J-PET system, RBE and LET modeling for proton radiotherapy;

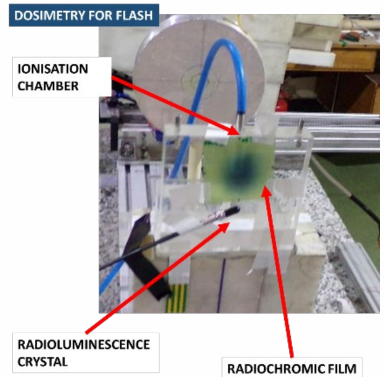




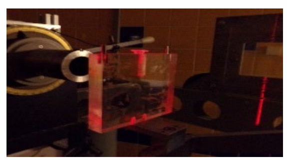




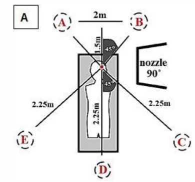
Proton GRID radiotherapy

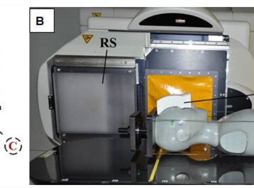


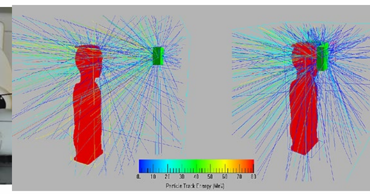
Proton FLASH dose rate 40 – 200 Gy/s



Experimental setup for biological sample FLASH irradiation *(collaboration with UJ)*







3D printed beam compensator

Reduction of scattered radiation by a 3D-printed beam compensator compared to a classic range shifter

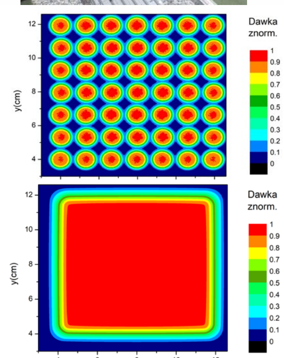
Five Ph.D. theses completed, one in progress

InspireProject

Horizon 2020 - INfraStructure in Proton International REsearch INSPIRE
(Networking, Joint Research Activities, Trans-National Access)

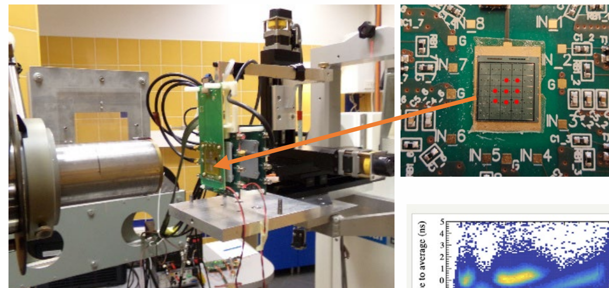
Department of Radiation Research and Proton Radiotherapy (NZ62) – recent achievements:

studies of the radiation damage to electronic systems and samples irradiated by energetic proton beams and gamma rays;

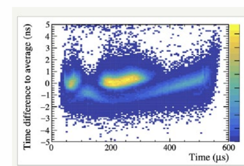


XY Scaner

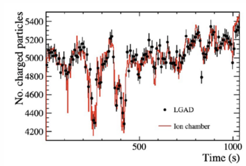
Development of proton irradiation - optical line at the experimental room



LGAD pixel sensor array at the irradiation facility



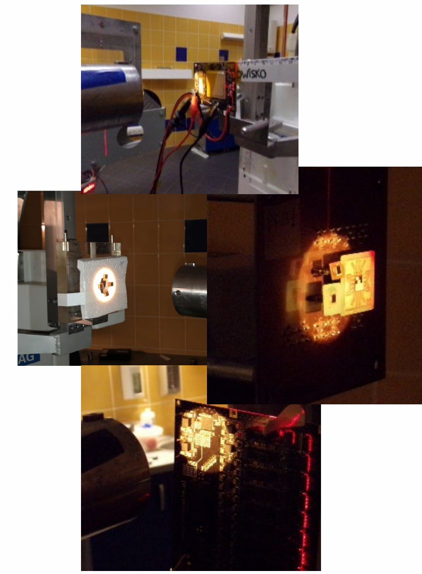
Macro-pulse structure of the AIC-144 proton beam



LGAD can be used as a dosimeter

Investigation of the possibility of using LGAD for beam diagnostics and as a dosimeter

(collaboration: CERN, Dublin University)



Electronic components Irradiated with proton beam during the experiment

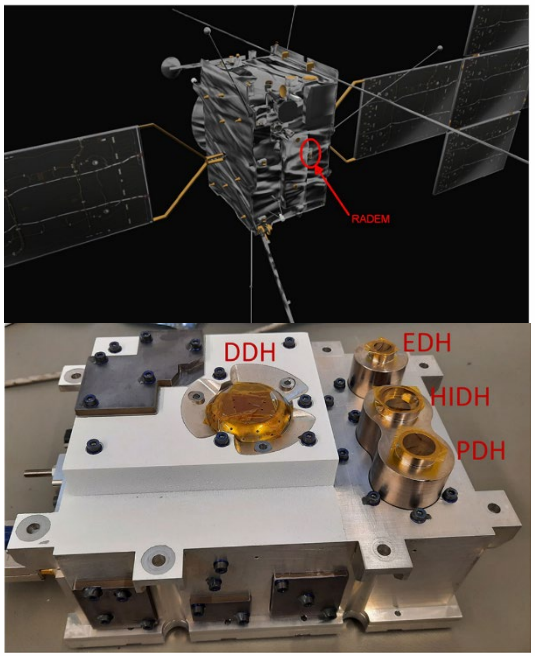
One Ph.D. thesis in progress, a second one is just starting

EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

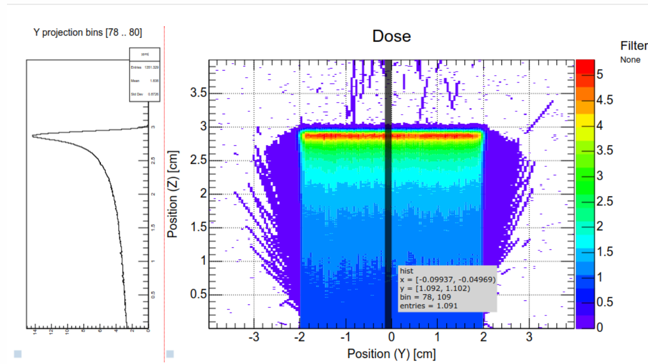
EURO-LABS project (EURATOM) work package 4 „Access to Research Infrastructures for Detector R&D” (11 experiments so far)

Department of Radiation Research and Proton Radiotherapy (NZ62) – recent achievements:

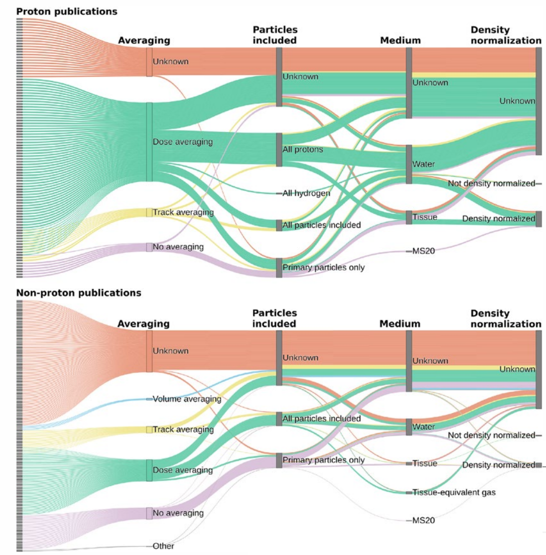
RADEM: An instrument measuring particle flux, onboard the JUICE mission (ESA) heading towards Jupiter. LET: Modeling the radiobiological effectiveness of particle therapy relies on beam quality factors such as linear energy transfer (LET). Yaptide: Development and implementation of a network interface supporting particle transport simulations. The Yaptide platform is integrated with the HPC cluster at ACK Cyfronet, enabling large-scale simulations.



RADEM collaboration with PSI, contributing to data curation workflows and develop methods for data analysis, including the detection of solar energetic particles



Yaptide: Web interface to run particle transport simulations (Fluka, SHIELD-HIT12A) Integrated with the HPC cluster at ACK Cyfronet, enabling large-scale simulations



A systematic review on the usage of averaged LET in radiation biology for particle therapy

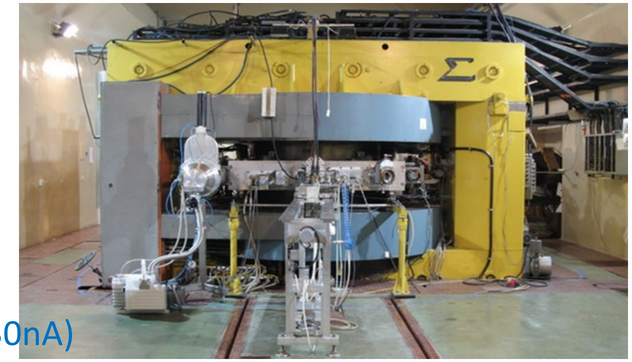
Fredrik Kalholm, Leszek Grzanka, Erik Traneus, Niels Bassler

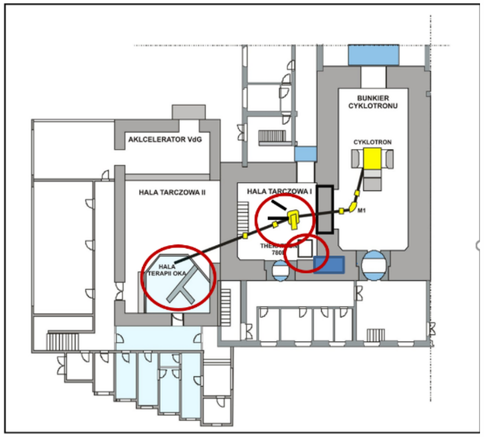
Show more

The research highlights the need for scrutiny in averaged LET reporting and suggests optimal factors for modeling

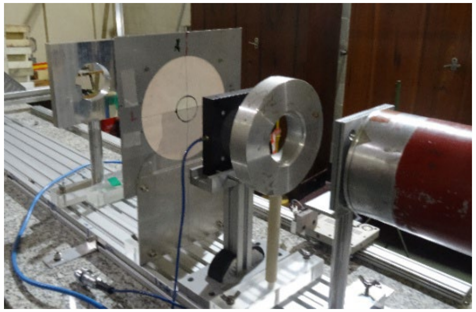
AIC-144 Cyclotron Laboratory (PCA)

Magnetic Field:	0.85 ÷ 1.8 T;
Main Coil Current:	0 ÷ 650 A;
Number of Dees:	1 (α=180º);
RF Frequency:	10 ÷ 27 MHz;
RF Power:	120 kW;
Dee voltage:	65 kV;
Proton Energy:	60 MeV
Beam currents:	2nA – 100 nA (short 130nA)

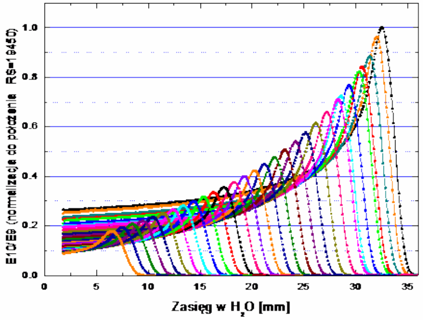




High beam intensities in the experimental room, beam spot flexibility!



Beam current up to 100 nA
Spot size < 10 mm
Beam field ≤15 cm
Flateness > 15%



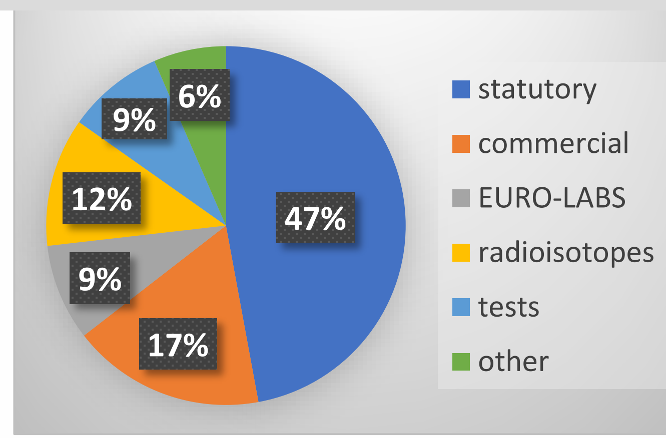
Small field horizontal beam line - eye-treatment room
Tuned energy: 0-58 MeV
Dose rate 0.001 – 1 Gy/s (in water)

Users:

- EURO-LABS work package 4 „Access to Research Infrastructures for Detector R&D” (11 experiments so far)
- Three Ph.D. Theses
  - Irradiation facility for electronic components iradiation hardness
  - Dosimetry of FLASH beams
  - Accelerator-based neutron calibration source for dosimetry
- Nuclear chemistry
  - Nuclear reaction cross-section measurements for isotope production
  - Study for medical radionuclide and other long lived impurities in natZn (p,x)
  - Irradiation of nano Silicon and Silicon doped Cr material for medical applications
- Dosimetry
  - Accidental dosimetry, OSL gel detectors, LiF track detectors
- Irradiation of electronics for space operation (AGH, Lunaris project, Polar 2, Uni Geneva, NCBJ, Univ. Luxemburg)
- Irradiation for commercial customers (ca. 500 kPLN during the last 4 years)

Young research group. Old reliable machine!

Cyclotron activities 137 shifts in 2024

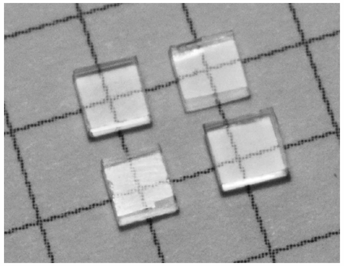


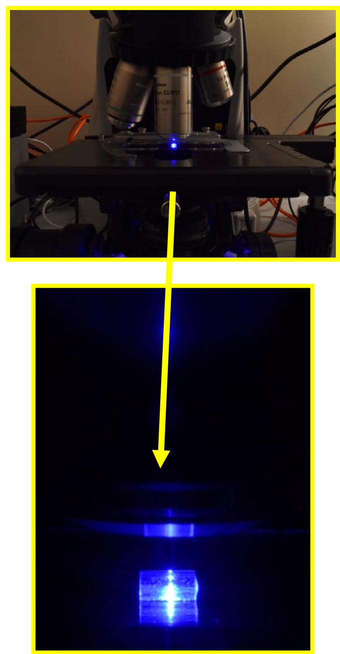
Department of Radiation Physics and Dosimetry (NZ63) – recent activities and achievements:

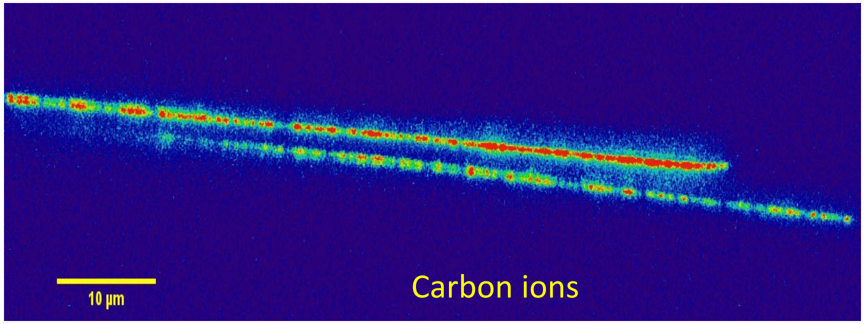
Development of new radiation detectors and measuring techniques:

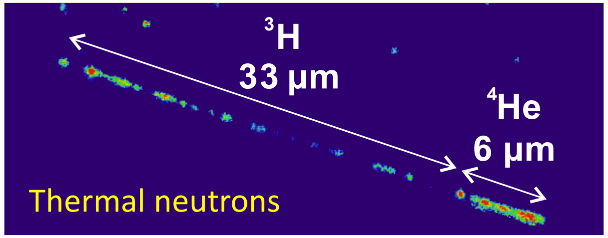
- Fluorescent Nuclear Track Detectors (FNTD) based on LiF crystals

LiF crystals









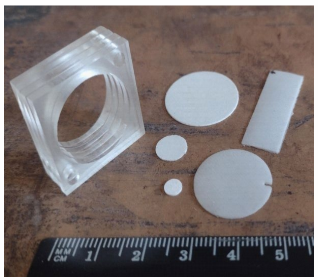
^{6}Li(n,α)^{3}H

- ➢ most prospective application: personal neutron dosimetry

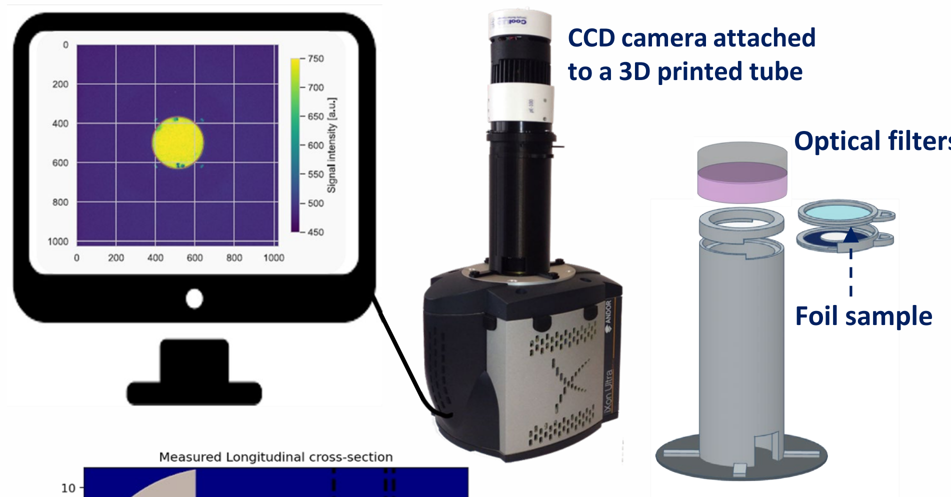
Department of Radiation Physics and Dosimetry (NZ63) – recent activities and achievements:

Development of new radiation detectors and measuring techniques:

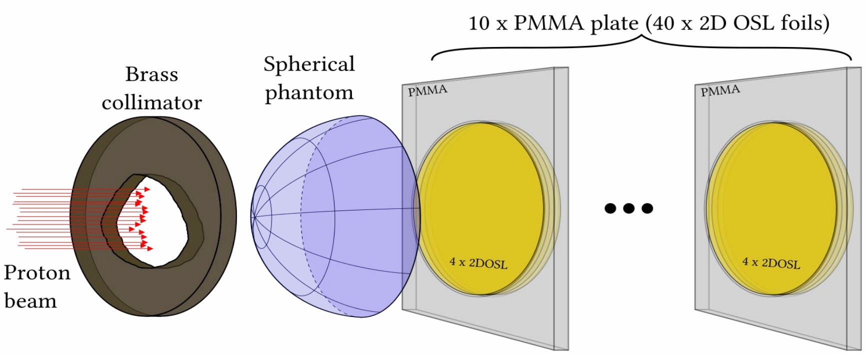
- 2D/3D dosimetry with Optically Stimulated Luminescence (OSL) foils

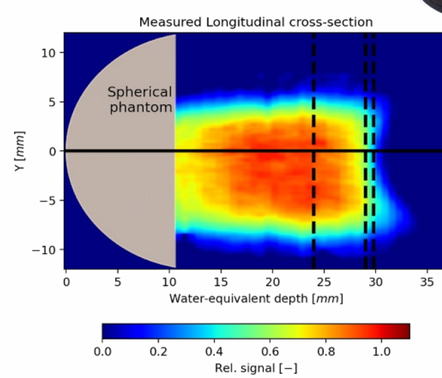


Silicon foils:
- Flexible
- Waterproof
- Adjustable shapes
- Reusable



Verification of the real proton eye treatment plan:





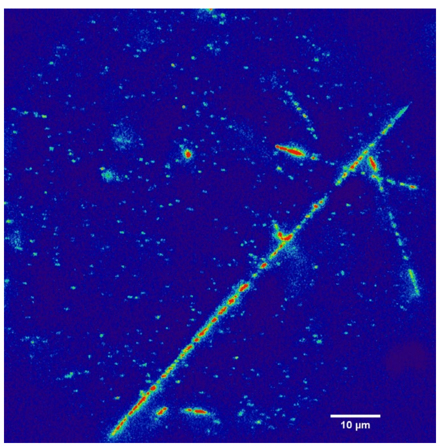
Dose distribution measured using silicone foils in the eye phantom

Department of Radiation Physics and Dosimetry (NZ63) – recent activities and achievements:

Dosimetry of cosmic radiation in space

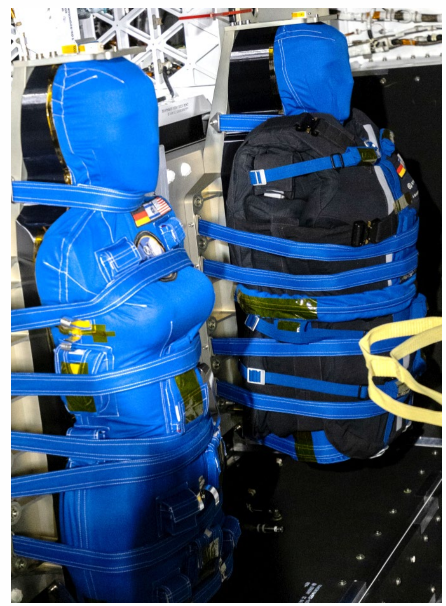
application of thermoluminescent (TLD) and track detectors developed at IFJ PAN:

- continuous dose measurements inside space station (ISS) – project DOSIS-3D/ESA
- human phantoms with detectors on lunar orbit – experiment MARE (NASA Artemis-1 mission)



Fluorescent tracks created by cosmic radiation in LiF crystals exposed on Earth orbit

Mounting TLDs inside the phantom



Phantoms on-board Artemis-1 spacecraft

Department of Nuclear Physical Chemistry (NZ64)

RESEARCH ACTIVITIES:

Environmental Radioactivity – α, β, γ spectrometry

- Geological samples (rocks, sediments, soil…)
- Biological samples (animal and human bones, plants, insects, mushrooms, …)
- Internal contamination of humans (whole body spectrometer)
- Development of measurement techniques (instruments and radiochemistry)
- Radioactivity of air (state monitoring network, aerosoles and fallout)

Activation using cyclotron AIC-144

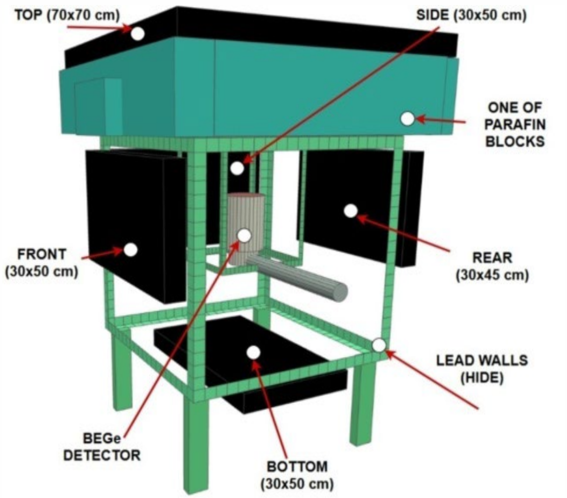
- Isotopic tracers (Sr-85, Tc-95m, Rb-83, As-73, Gd-148…)
- Cross section measurements
- Charged particle induced activation
- Nano-particles labelled with radionuclides (new topic!)


Air sampling station

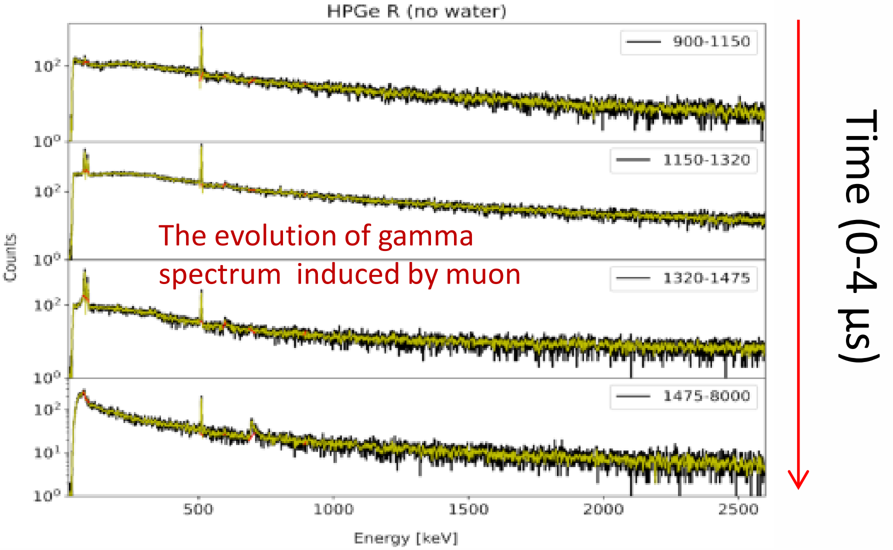
Department of Nuclear Physical Chemistry (NZ64) – *Development of scientific equipment:*

In recent years we developed a flexible digital coincidence system for gamma spectrometry based on CAEN digitizers and home written software:

1. Gamma-gamma coincidences (two HPGe detectors)
2. Gamma-muon anticoincidences/coincidences (HPGe + 5 plastic scintilators)
3. Gamma-beta-muon anticoincidences/coincidences (HPGe + 6 plastic scintilators)



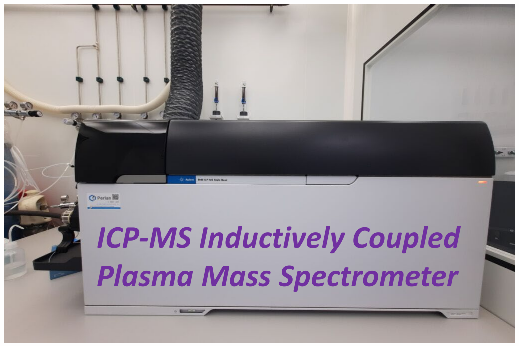
Elements of active shield of one of the gamma spectrometric systems

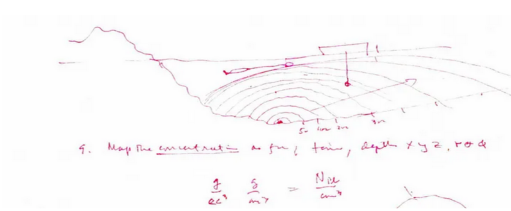


The system allows for low-background measurements and off-line analysis of different phenomena,
e.g. the studies of periodicity of muon and cosmic radiation background

Department of Mass Spectrometry (NZ65) – recent activities and achievements:

High precision mass spectrometry with ultra-low detection limits
applied for the studies of northern and southern hemisphere glacial environement





Mars Crash of '96: what will happen to plutonium and us?

Carolyn Bentley · Follow
6 min read · Mar 23, 2018

2 1

Sketch by Professor William Bickel, The University of Arizona

On Sunday, November 16, 1996, the Russian spacecraft, Mars '96, was launched. It was funded over half of its $300 million budget by several countries other than Russia with the high hopes of landing four vehicles on Mars for exploration. Shortly after take-off, the booster rocket malfunctioned in its fourth stage preventing the unmanned craft to break out of the Earth's orbit. It reentered the Earth's atmosphere the same day above the southern Pacific Ocean and crashed into the sea west of South America. It is uncertain at this time whether or not the rocket and the spacecraft landed together or separate.

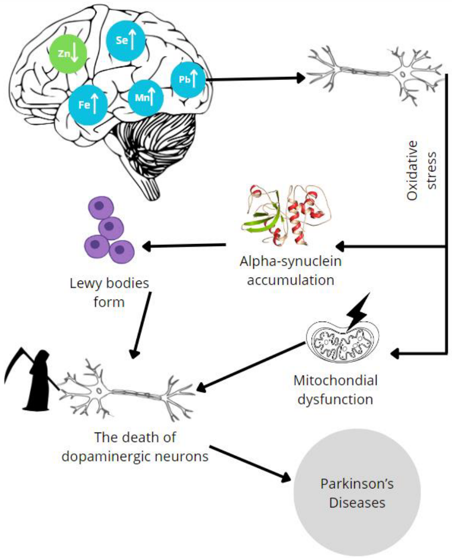
- Measurements of the contamination of glaciers with natural and man-induced radioisotopes and heavy metals
- Studies of the circulation of these contaminants in the environment, between the melting glaciers and the surrounding ecosystem, including the effect on the population

- Development of new methods for Pu and U isotopic ratio determination ($^{240}Pu/^{239}Pu$, $^{236}U/^{238}U$, $^{239}Pu/^{236}U$) to study the radioactivity deposition and contamination in the Arctic
- First observation of anomalous $^{238}Pu/^{239+240}Pu$ isotopic ratios in crioconite samples taken from Patagonia glaciers
- The excess of ^{238}Pu can be attributed to the fallout following the crash of the Russian Mars-96 space probe which sunk in the Pacific off the coast of Chile in 1996. [Sci. Total Environ., 951 (2024): 175356]

Department of Mass Spectrometry (NZ65) – recent activities and achievements:

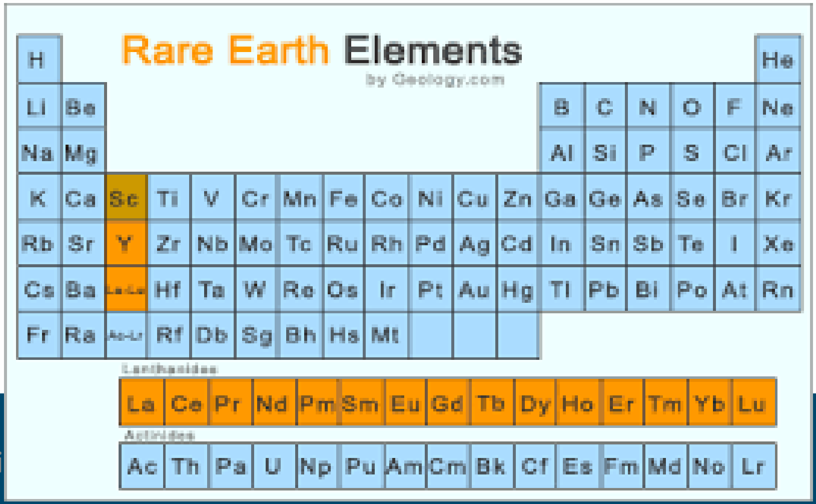
Biophysics and medicine

- Enhancement of follicular thyroid carcinoma diagnostics through the application of mass spectrometry techniques
- Assessment of alterations in metal concentrations in biological specimens across different stages of Parkinson's disease progression
- Identification of early-stage biomarkers of Alzheimer's disease development based on isotopic ratios of trace elements



- Human Exposure to Heavy Metals over the Last 100 Years *[B Environ Contam Tox, 113*(2), (2024), 20]
- Human Exposure to Rare Earth Metals in General Public

In collaboration with
the Collegium Medicum
Jagiellonian University



Thank you for your attention!

Thanks to the team for their hard work, dedication and passion

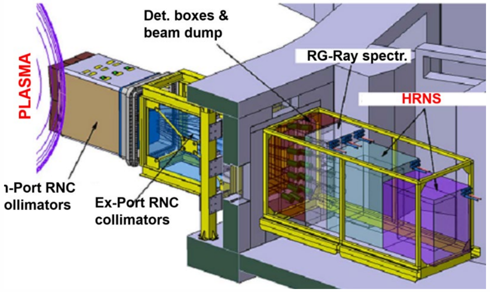
Continue activity in the area of Tokamak Exploitation

- **ITER, Cadarache, France**
  Development of the neutron diagnostic system
    Final Engineering design (FDR) of HRNS-TPR.

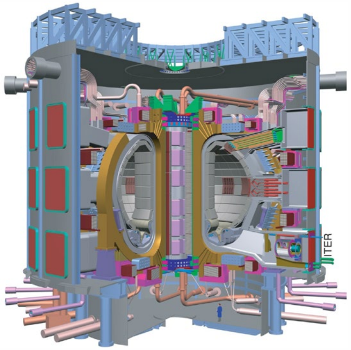
- **COMPASS-U, Prague, Czech Republik**
  Development of the neutron diagnostics
  Neutronic calculations

- **WEST, Cadarache, France**
  Testing advanced diagnostics of the generated fusion plasma, mainly fast neutron imaging and ultraviolet and X-ray tomography

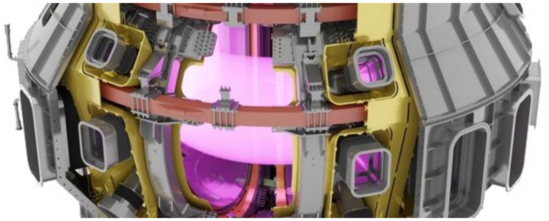
- **JT60-SA, Japan**
  Commissioning and enhancements for JT-60SA
  Analysis of the experimental data
  Plasma modelling
  Data validation



ITER



COMPASS-U

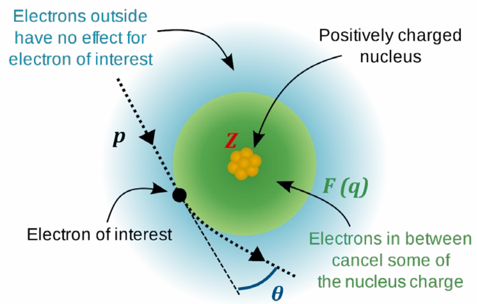


JT60-SA

WEST

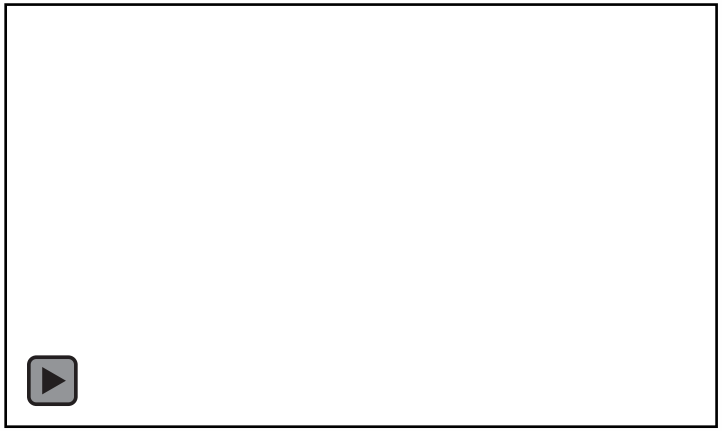
Impact of **tungsten impurities** on electron dynamics of thermonuclear plasma in tokamaks

- **Runaway Electron (RE)** generation in ITER-like disruption with tungsten (W) impurities
- New description of **inelastic scattering** between impurity ions and suprathermal electrons
- Collaboration with CEA IRFM, and Chalmers Univ.



Runaway electrons:

If plasma density is low, mean free path of electron increases. High momentum electron beams cause distruptions of tokamak operation and damage the machine



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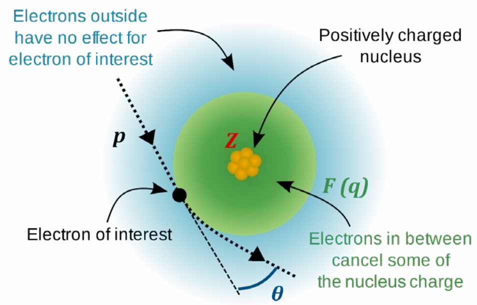
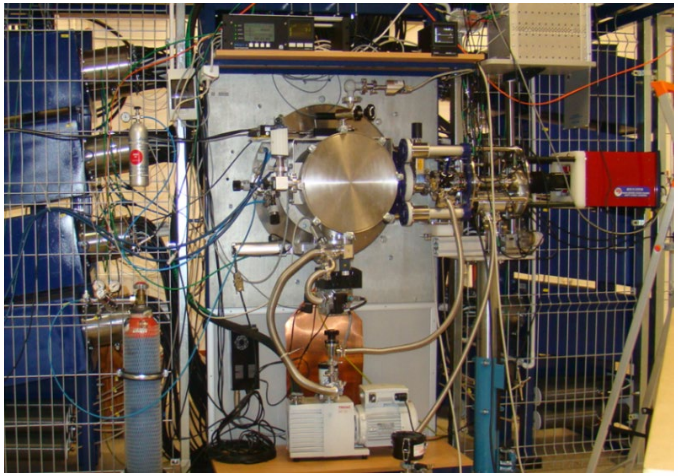


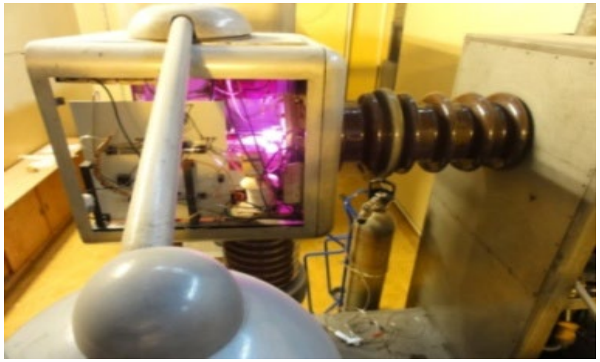
Runaway electrons:

If plasma density is low, mean free path of electron increases. High momentum electron beams cause distruptions of tokamak operation and damage the machine

Plasma Focus PF-24 z-pinch device

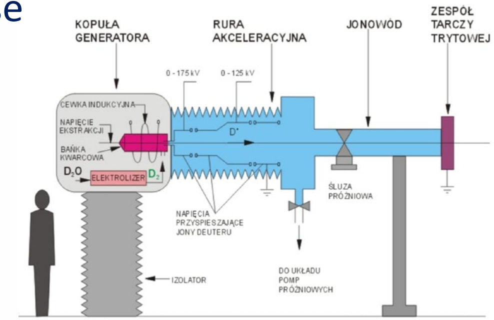
- D + D → ^{3}He (0.82 MeV) + n (2.45 MeV)
- Stored energy 15-93 kJ, charging voltage 16-40 kV
- Neutron output ca. 10^9 per shot
- Short pulses, ~ 50 ns
- Measurement systems for electric parameters, neutron diagnostrics, VUV/SXR imaging of plasma





IGN-14 fast neutron generator

- D + T → ^{4}He (3.561 MeV) + n (14.029 MeV)
- Neutron output ca. 5 × 10^8 n per pulse
- Pulse length tuned from 1 – 25 ms
- Neutron monitors



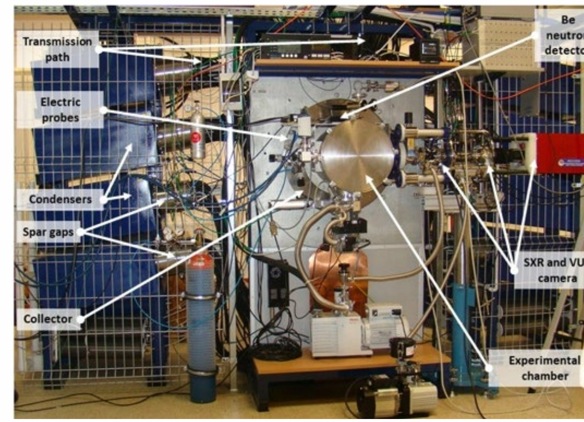
http://nz61.ifj.edu.pl

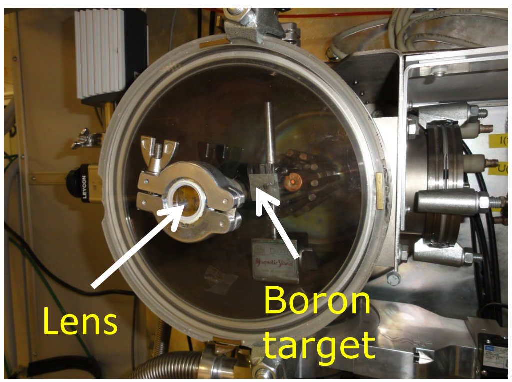
Selected goals of the Applications of Physics at IFJ PAN for the coming years

Upgrade of the Plasma Focus PF-24 device to study the $p+^{11}B$ fusion reaction

- In Plasma Focus an electron-ion (e.g., deuterium) plasma is generated by an electrical discharge between coaxial electrodes.
- We propose to investigate the ignition of $p+^{11}B$ fusion reaction in the PF by means of laser ablated boron from a solid B target placed in the PF anode.

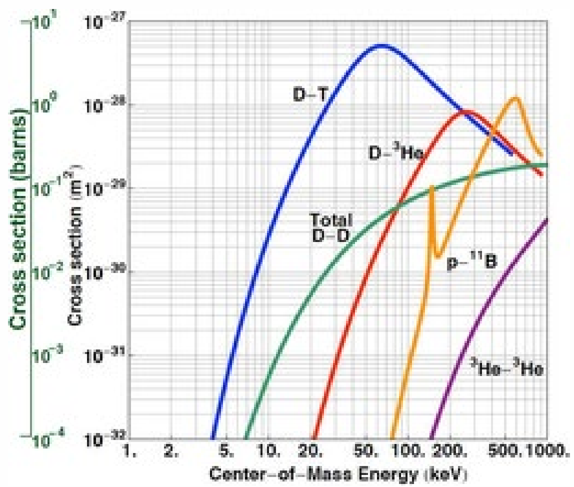
$D+D \rightarrow {}^3He\ (0.82\ MeV) + n\ (2.45\ MeV)$





Nd:YAG laser

$$p + {}^{11}B \rightarrow 3\alpha + 8.7\ MeV$$



- The main difficulty for $p + {}^{11}B$ fusion reaction is the high ion temperature needed to achieve high reactivity.

[M. Scholz, K. Król, A. Kulińska, L. Karpiński, A. Wójcik-Gargula, M. Fitta, Journal of Fusion Energy 38 (2019)]

Department of Nuclear Physical Chemistry (NZ64) – *A search for really rare radionuclides:*

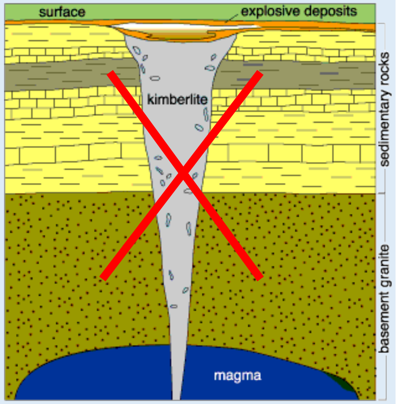
I. U-236 measurements in polar regions

- Almost 100 samples of mosses and lichens analyzed for U-236 using AMS technique in collaboration with VERA, Vienna University, Austria
- Results normalized to U-238 and Pu-239
- First results ever for the determination of U-236/Pu-239 ratio in Antarctic samples
- Main finding: the U-236/Pu-239 ratio in Global Fallout at Arctic double that for Antarctic
- Paper ready for publication, the data was already presented on Conferences

II. A search for isotopic traces of baryonic dark matter interactions in geological samples

Hypothesis:

1. Kimberlite pipes (where diamonds are mined) were formed by the impact of ultra dense baryonic dark matter objects
2. During the impact nuclear reactions produced isotopic anomalies



Verification:

1. A search for extinct radionuclides such as Pu-244 or Sm-146
2. Received grant financing from ANSTO (Sydney AMS Center, Australia) for measurements of Pu fractions from 20 samples (10 from kimberlite rocks, 10 others), samples were prepared and sent for AMS analyse
3. The Sm fraction for Sm-146 measurements by alpha spectrometry at IFJ PAN is under preparation