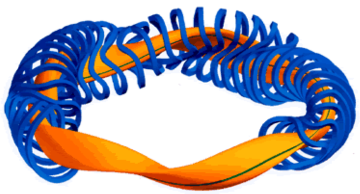


Participation of Polish scientific institutions in the Wendelstein 7-X project: present status and future directions

Urszula Woźnicka

Association Euratom-IPPLM Council Meeting
Institute of Nuclear Physics PAN
March 15, 2013

Participation
of Polish scientific institutions
in the Wendelstein 7-X project:
present status and future directions

Euratom-IPPLM Association members:

- Institute of Plasma Physics and Laser Microfusion, Warsaw
- National Centre for Nuclear Research, Świerk
- The Henryk Niewodniczański Institute of Nuclear Physics, Kraków
- (Warsaw University of Technology)
- Opole University, Opole

2012 Main fields of Polish contributions in W7-X

Construction stage

Dr. Marek Stodulski (IFJ): Contribution in preparation of W7-X assembly process: including work organization, documentation of assembly process, modifications of equipment and training of technicians.

Prof. Jacek Jagielski (NCBJ): Polish participation in NBI construction for W7-X stellarator: Construction of components for W7-X Neutral Beam Injectors.

Plasma diagnostics & research

X-ray

Dr. Monika Kubkowska (IPPLM): Spectrometry of soft X-ray emission from W7-X with the use of PHA and MSF diagnostics

Dr. Ireneusz Książek (OU): C-, O- monitor system for W7-X

Neutrons

Prof. Krzysztof Drozdowicz (IFJ): Detection of the delayed neutrons from activation of fissionable materials in the neutron field at fusion-plasma devices

Construction stage, 2012

Dr. Marek Stodulski (IFJ): Contribution in preparation of W7-X assembly process

Completion of the bus bar system on Module Separation Planes)

(At no cost for EURATOM Contract of Association except Mobility)

Staff

Leszek Hajduk, Marek Stodulski, Zenon Sułek

The Henryk Niewodniczański Institute of Nuclear Physics, Kraków

The Henryk Niewodniczański
Institute of Nuclear Physics
Polish Academy of Sciences

IFJ PAN Involvement In W7-X

Annual Reception and the Colloquium
on the IFJ PAN Contribution for Wendelstein 7-X

Greifswald, 30th October 2012

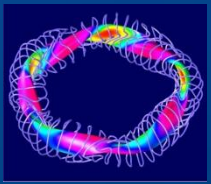
Prof. Marek Jeżabek

Director General

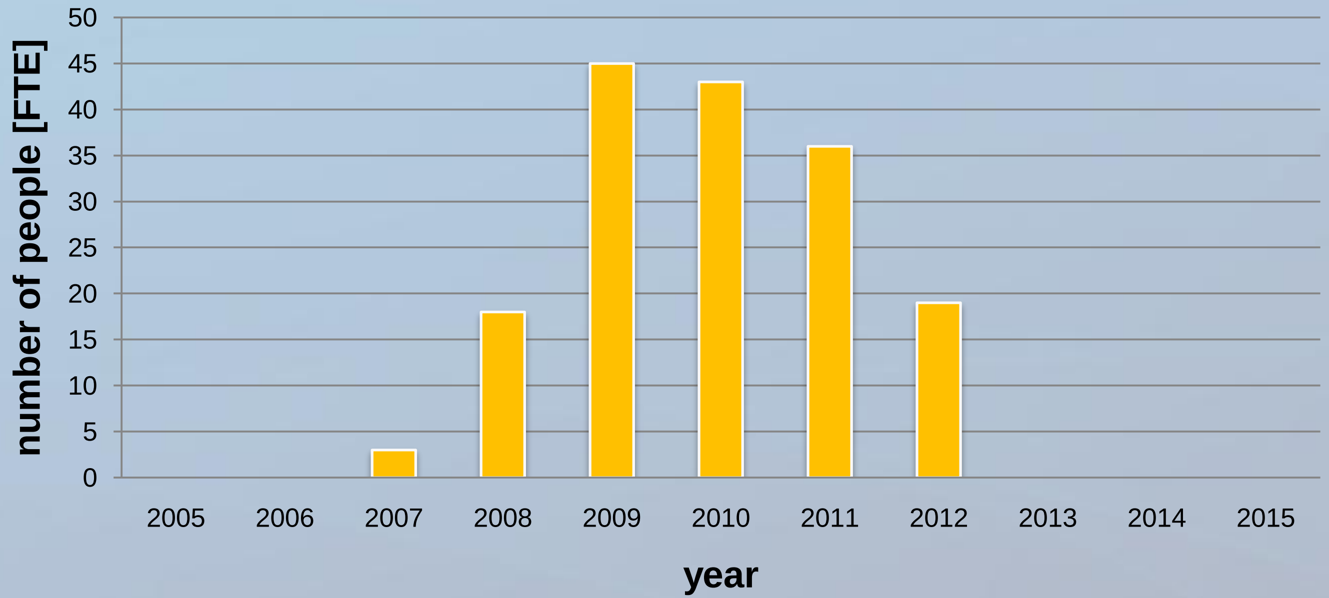
Greifswald, 30th October 2012

Greifswald, 30th October 2012

Greifswald, 30th October 2012



IFJ PAN involvement in W7-X construction



Total number of FTEs over 6 years	**~164**
Total number of IFJ PAN people involved	**~ 50**

FTE – full time equivalent

IFJ PAN – W7-X
(2007 – 2012)

Fusion Engineering & Design, 2013:

1. **On the accuracy of port assembly at Wendelstein 7-X**
   Torsten Bräuer, The Metrology Team Max-Planck-Institut für Plasmaphysik,
   h i g h l i g h t s
   Wendelstein 7-X ports are assembled within the general position tolerances.
   3D metrology turned out to be a key factor to achieve the required position accuracy.
   A measurement accuracy of typically 0.3, . . ., 0.6 mm is appropriated.
   Fusion Eng. Des. (2013), http://dx.doi.org/10.1016/j.fusengdes.2013.01.098

2. **Design principles for handmade electrical insulation of superconducting joints in W7-X**
   K. Rummel[a] , A. John[a], **Z. Sułek**
   [a] Max Planck Institute for Plasma Physics, EURATOM Association,
   [b] Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences,
   Available online 7 March 2013 http://dx.doi.org/10.1016/j.fusengdes.2013.01.017

Construction stage, 2012

Prof. Jacek Jagielski (NCBJ): **Polish participation in NBI construction for W7-X stellarator. Construction of components for W7-X Neutral Beam Injectors**

Jacek Jagielski
National Centre for Nuclear Research (NCBJ)

Construction stage

Magnets for ion removal

- Construction of the one and upgrade of the second magnet
- Design and construction of lifting slings and fixtures for upright position, as well as transportation fixtures
- Status of progress:
  - accomplishment of delivery: TESLA UK
  - upgrade of the second magnet completed
  - lifting slings and fixtures ready.
- Expected time of delivery: October 2013.

Cooling system

- Design, construction and certification of the cooling systems:
  - High Pressure, low Pressure, plasma grid, RF generators
- Status of progress:
  - Design completed and approved
  - Completion of components in progress.
- Expected time of delivery: April/May 2013

National Centre
for Nuclear Research

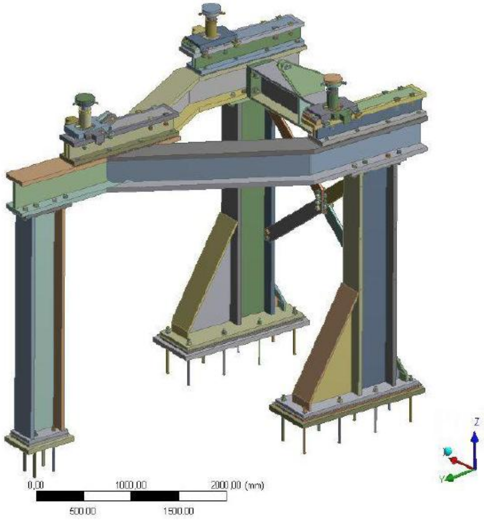
Construction stage

Support structures for the NBI boxes

- Design, calculations of durability, construction and installation of two support structures for NBI
- Design, construction and installation of hydraulic positioning systems,
- Certification of whole structure in accordance with the CE standard (EN1090, EN1993, Eurocode)
- Status of progress:

  Technical design completed, ANSYS calculations completed and certificated, hydraulics design completed, support structures assembled, hydraulics installation in progress.

- Expected time of delivery: March/April 2013

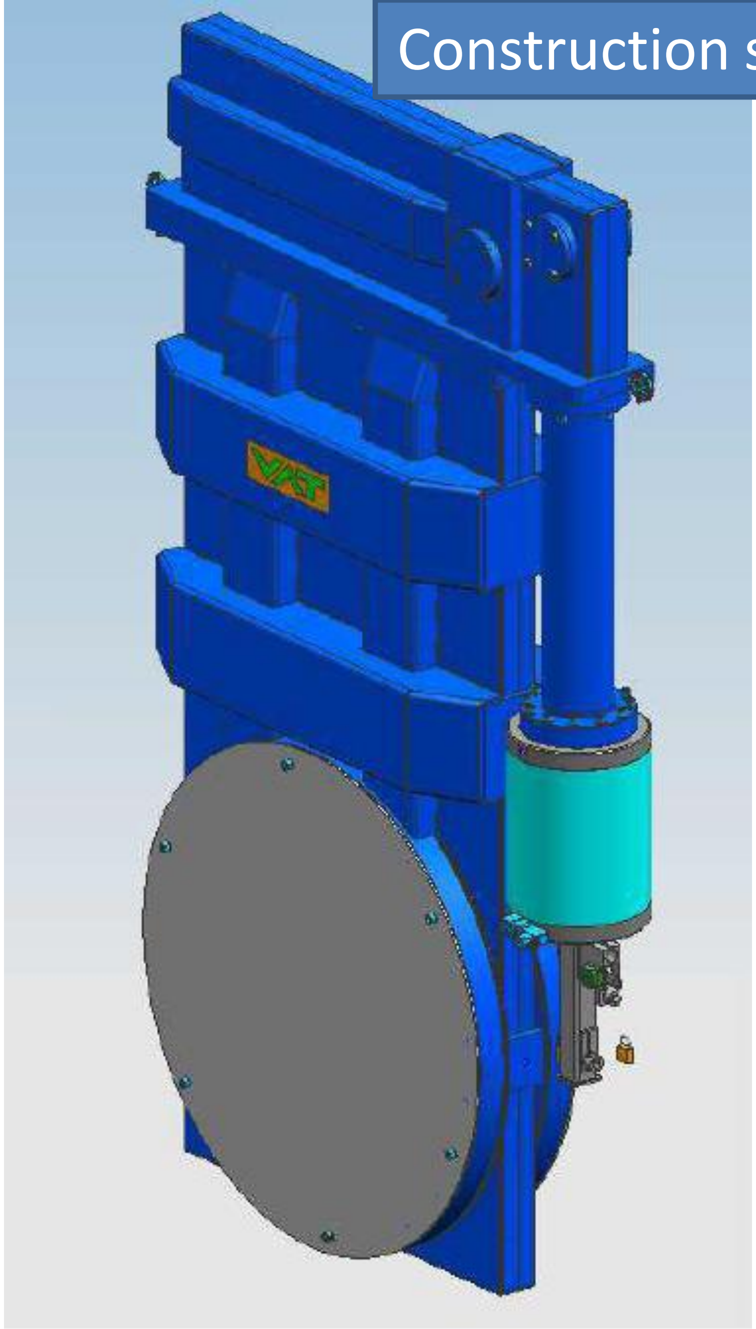


Gate valves

- Construction of the one and upgrade of the second DIN-800 valve
- Design, construction and installation of blocking mechanisms
- Design, simulation and installation of heating systems:
  - Four independent systems for each valve,
  - Two independent heating loops for each system,
  - Independent thermic protections thermocouples,
  - Sensing devices, suppliers and control systems.
- Status of progress:

  Design completed, simulations of temperature distribution ready and installation in progress
- Expected time of delivery:

  April/May 2013



Summary

- Fulfilment of Polish in-kind contribution to the W7-X project
- NCBJ implement a project as a not co-financed one (Decision of Ministry MNiSW 882/N-W7X/2010/0 dated on December 17, 2010).
- Budget - about 20 000 000 PLN (~4.5 mln Euro)

Future directions

The National Centre for Nuclear Research (NCBJ) teams might be engaged in **further design and construction of equipment** needed for the W7-X experiment.

In general the NCBJ offers a broad range of **research- and engineering-services** for both domestic and foreign customers.

The centre accumulated experience in **producing ionizing radiation detectors** and materials for their construction, as well as in constructing unique electronic instruments, e.g., those for individual circuits and entire systems at the LHC in CERN, Geneva.

Future directions

For W7-X program, NCBJ might prepare diagnostics of :

- primary and fusion-produced ions
- fast electron streams generated during plasma discharges
- optical emission spectroscopy of plasma to be produced inside the W7-X machine.

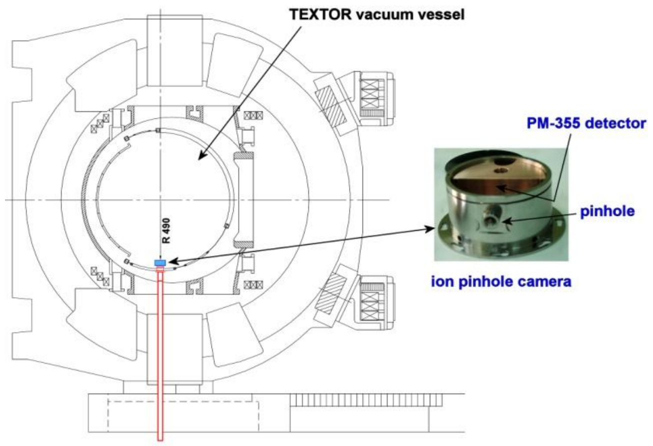
Study of fast primary and fusion-produced ions

High-current plasma discharges are sources of the accelerated primary ions (e.g. deuterons, tritons) and fusion-produced protons, tritons or ^{3}He. Such fast ions were measured in different plasma experiments by means of ion collectors, nuclear track detectors (NTD) and various analyzers.

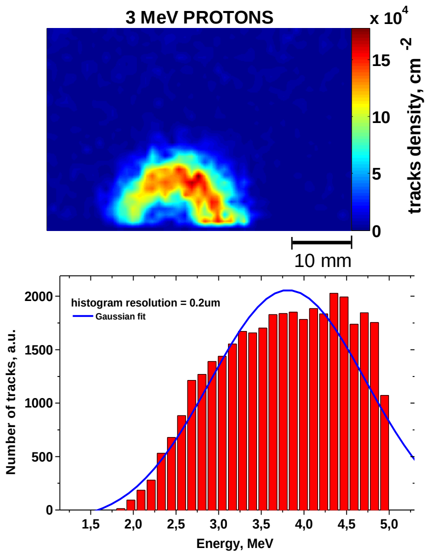
V.A. Gribkov, M.J. Sadowski, et al., J. Phys. D: Appl. Phys. 40 (2007) 3592-3607
A. Szydlowski, A. Malinowska, et al., Radiat. Measur. 43 (2008) S290-S294.

Measurements of the emitted ions deliver important information about plasma dynamics and various processes as well as emission characteristics of investigated plasma facilities, ranging from pulsed Z-pinches to magnetic traps.

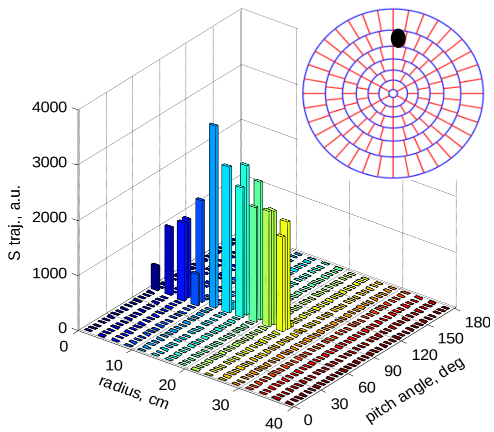
A. Malinowska, A. Szydlowski, et al., Radiat. Measur. 43 (2008) S295-S298
M.J. Sadowski, K. Czaus, et al., Rev. Sci. Instr. 80 (2009) 053504
R. kwiatkowski, M.J. Sadowski, et al., Nukleonika 57 (2012) 211-214



Cross-section of the TEXTOR chamber and positioning of
an ion pinhole camera for measurements of fusion-protons.
A. Szydlowski, M.J. Sadowski, et al., AIP CP 993 (2008) 247-250



Color-enhanced proton image and
corresponding energy spectrum
measured in the TEXTOR at 1.5MW NBI.



Computer simulation of a fusion-proton
image in the chosen sector of NTD
for future COMPASS-U experiment.
R. Kwiatkowski, et al. – to be published

New ion probes for fusion-oriented plasma experiments are elaborated by the NCBJ team under a national contract with NCBiR.

Similar ion probes might be used for W-7X stellarator research, but appropriate adaptations of the measuring heads are needed.

Study of fast electrons from plasma discharges

Fast ripple-born and run-away electrons were observed in many tokamak experiments. They were investigated mainly by measurements of the synchrotron radiation, but such studies did not deliver local information.

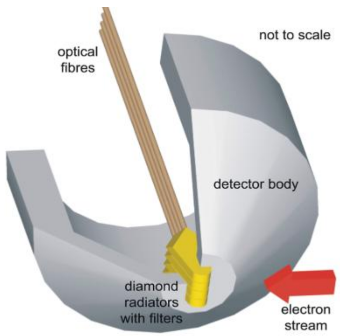
R. Jaspers, K.H. Finken, et al., Proc. ICPP, Innsbruck, Austria, July 1992, p. I:155.

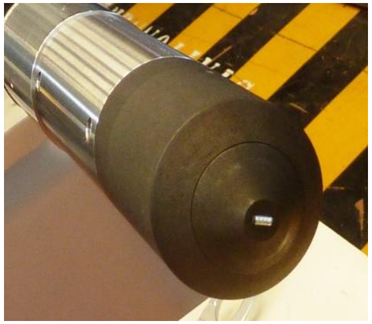
The fast electrons may improve the plasma confinement and their interaction with waves may result in an energy transfer to plasma, but interaction of energetic electron streams with the internal walls of the vessel may result in severe damages of fusion facilities, e.g. in TORE-SUPRA.

M. Lipa, G. Martin, et al., Fusion Engin. Design 66-68 (2003) 365-369

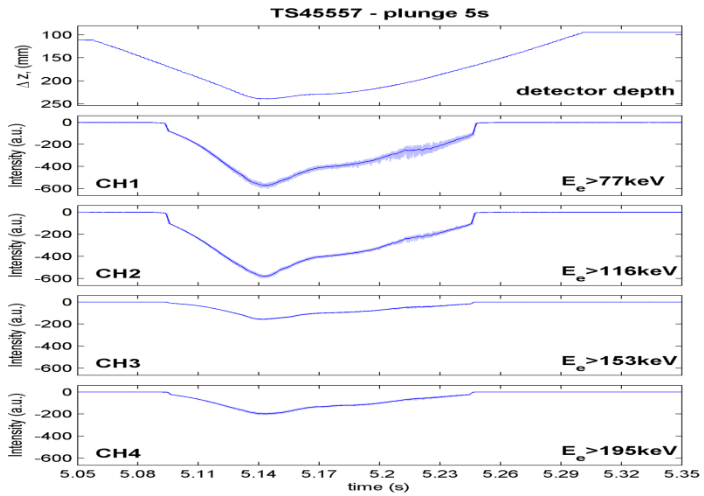
To perform direct and local measurements of fast electron beams, a Polish team developed special probes base on the Cherenkov effect. Such probes have successfully been applied in several tokamaks, eg., CASTOR in Prague, ISSTOK inLisbon, TORE-SUPRA in Cadarache, and recently COMPASS-U in Prague.

M.J. Sadowski et al., Czech. J. Phys. Czech. J. Phys. 54 (2004) C74-C81
L. Jakubowski, M.J. Sadowski, et al., Proc. 34th EPS Conf. CFPP, Warsaw, Poland; ECA 31F (2007) 5.097
L. Jakubowski, M.J. Sadowski, et al., RSI 81 (2010) 013504
M.J. Sadowski, Nukleonika 56 (2011) 85-98





Scheme and view of the modified Cherenkov measuring head designed for the TORE-SUPRA experiment.
L. Jakubowski, M.J. Sadowski, et al., RSI 84 (2013) 016107



Signals from the Cherenkov detectors recorded for TS45557 shot (B_T = 3.75T, LH power = 2.6 MW, I_P = 1.0 MA) during the first insertion of the probe.

The IPP KIPT in Kharkov has already expressed interest in the use of such probes for electron measurements in the U3M stellarator.
Similar Cherenkov-type probes might be used for W-7X stellarator research, but it requires special adaptations of the measuring head.

Future directions

Teams from the Material Physics Department (DFM) might design and construct special equipment as well as investigate various **materials needed for fusion-oriented experiments.**

Other teams from the Nuclear Energy Department (DEJ) might perform studies with the use of reactor-produced thermal neutrons and fast ones obtained by special converters. Such **fast neutrons might be exploited** to investigate a resistance of various constructional materials and responses of a diagnostic equipment.

The NCBJ offers also **PhD studies in plasma physics and technology** as well as in other research directions. It might be used to prepare physicists and engineers for future W7-X experiments.

Future directions

WUT is currently engaged in research devoted to **development and characterization of materials for fusion applications in** the scope of the Euratom Programme.

The activities, carried out in cooperation with European Fusion laboratories form Germany (Garching and Karlsruhe), Sweden (Stockholm) and Portugal (Lisbon) are devoted to post mortem analyses of ASDEX-U tiles, dust collected in present day experimental devices, development of tough tungsten materials, nano-structured ODS steels and low-activation austenitic steels, characterisation of radiation damage in tungsten and evaluation of microstructure and properties of steel tiles.

In the scope of national project the interactions of deuterium plasma with tungsten and CFC targets are studied as well as fabrication and characterisation of durable steel to CuCrZr alloy joints is carried out.

Future directions

Depending on the structure and needs of the W7-X materials programme WUT can participate in activities devoted to **monitoring of the in-vessel materials degradation** at the early stage through advanced microscopic and analytical methods including high-resolution transmission electron microscopy, X-ray photoelectron spectroscopy, Auger electron microscopy, nano-indentation, profilometry, focussed ion beam, micro x-ray tomography and many others.

WUT is also interested in cooperation concerning in **general development of new materials and materials technologies for stellarator based fusion reactors**.

Dr. Monika Kubkowska (IPPLM): **Development of the soft X-ray spectrometry systems for the stellarator W7-X**

Staff
Monika Kubkowska , Agata Czarnecka, Waldemar Figacz, Sławomir Jabłoński, Jacek Kaczmarczyk, Leszek Ryć

Institute of Plasma Physics and Laser Microfusion, Warsaw

Development of the soft X-ray spectrometry systems for the W7-X

Two spectroscopic systems are under design by IPPLM for measurement of soft X-ray emission from W7-X stellarator :

1. **Pulse Height Analysis (PHA) system** – to obtain the shape of X-ray spectrum by the measurement of energy carried by individual quanta (the height of a pulse measured is proportional to this energy).

2. **Multi-Foil System (MFS)** - is a method destined to obtain the shape of the X-ray spectrum from the data recorded with the use of different semiconductor detectors.

X-ray

- **At the beginning of 2012 a new Agreement on Cooperation between IPPLM and IPP Greifswald has been signed for 3 next years.**
- In 2012 manufacture drawings with all details of proposed PHA and MFS systems have been performed and present IPP Greifswald.
- The DN160CF detectors flange with multipin connectors for PHA system has been delivered. The detector cooling system for PHA diagnostics has been manufactured at IPPLM workshop.
- In 2012 detector arrays have been bought and tested for MFS diagnostics. Also thicknesses of beryllium filters have been chosen.
- For both diagnostics a mechanism with wobble stick, which will be used for changing filters or/and cut the radiation from plasma, has been made and tested in laboratory.

Future directions

- The IPPLM's group which is responsible for **design and manufacture the PHA diagnostics is also interested in participation in measurements using this system.**
- The proposed X-ray pulse height analysis system (PHA) is intended to provide the spectral energy distribution with an energy resolution of about 200 eV along a central line of sight and will **provide a sufficiently good characterization of the impurity radiation in the plasma core.**
- The measurements yield impurity survey spectra in the X-ray region above 0.5 keV (up to 20 keV typically) allowing to identify the line radiation from all relevant impurities (with exception of elements lighter than nitrogen) and to determine their concentration in the hot plasma core.

X-ray

Future directions

- The slope of the hydrogen and low-Z continuum radiation is used to determine the central electron temperature.
  The intensity of the continuum radiation along with additional spectroscopic data allows to assess Z_{eff} values in the plasma center.
- All mentioned parameters could be measured by the PHA system. We are planning to measure these parameters according to power of ECRH heating and generally, different plasma scenarios.
- **Similar plans are related to MFS diagnostics. Our group also want to participate in experiments with the use of this system**.

Plasma diagnostics & research

X-ray

Dr. Ireneusz Książek (OU): C/O- monitor system for W7-X

Staff

Ireneusz Książek, Adam Bacławski, Tadeusz Kulig, Józef Musielok,

Institute of Physics, Opole University, Opole, Poland

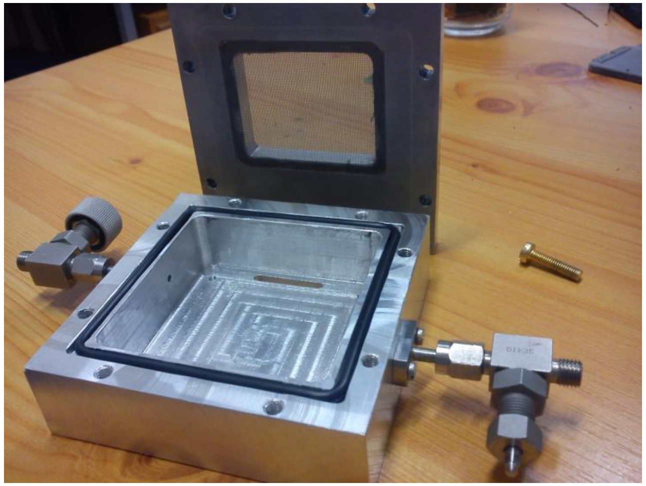
C/O- monitor system for W7-X

- dedicated soft X-ray spectrometer,
- located at AEK30 port,
- it consists of four independent channels,
  fixed at wavelengths corresponding to Lyman-α lines of hydrogen-like ions of:
  - boron (at 4.9 nm),
  - carbon (at 3.4 nm),
  - nitrogen (at 2.5 nm),
  - oxygen (at 1.9 nm);
- should work with time resolution <0.5 ms,
- should provide stable and reliable data for all W7-X lifetime.

C/O- monitor system for W7-X

The detectors of the spectrometer will consist of proportional counters (MSGC – multistrip gaseous chamber) of special construction with multichannel readout electronics.
The detection system is under development by the IFJ PAN Kraków.

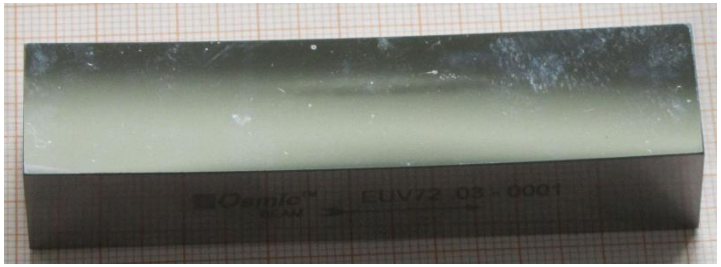
The design of the multistrip glass plate is based on a similar solution working in the ASDEX-U experiment. Unlike ASDEX solution, where all electrodes are galvanically connected, this solution assumes separate connections and construction of a position sensitive detector.
The design of the electronic system is based on the ASIC analog system and FPGA digital data preliminary analysis system. The data will be send to the CODAC system via fast-ethernet connection. Unfortunately the prototype presented in 2012 didn't fulfil the requirements and could not be accepted. The detector is still under improvement.



Opole University,
Institute of Physics, Opole

C/O- monitor system for W7-X

The dispersion elements provided for three channels will be **multilayer mirrors**.
As the first as well as second set of mirrors, delivered to the IPP,
due to imperfectness of the mirror surface, could not be accepted,
their were returned to the manufacturer.



Problems with multilayer mirrors:
part 1, delivery July 2011

Problems with multilayer mirrors: part 2,
delivery: March 2012:

SPHERICAL curvature

instead of

CYLINDRICAL curvature

C/O- monitor system for W7-X **Future directions**

- dedicated soft X-ray spectrometer,
- located at AEK30 port,
- it consists of four independent channels,
  fixed at wavelengths corresponding to Lyman-α lines of hydrogen-like ions of:
  - boron (at 4.9 nm),
  - carbon (at 3.4 nm),
  - nitrogen (at 2.5 nm),
  - oxygen (at 1.9 nm);
- should work with time resolution <0.5 ms,
- should provide stable and reliable data for all W7-X lifetime.

Plasma diagnostics & research

Neutrons

Prof. Krzysztof Drozdowicz (IFJ): Detection of the **delayed neutrons from activation** of fissionable materials in the neutron field at fusion-plasma devices

Krzysztof Drozdowicz[2], Barbara Bieńkowska[1], Grzegorz Tracz[2], Andrzej Igielski[2], Barbara Gabańska[2], Urszula Wiącek[2] and Urszula Woźnicka[2]

[1] Institute of Plasma Physics and Laser Microfusion, Warsaw
[2] The Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences, Kraków

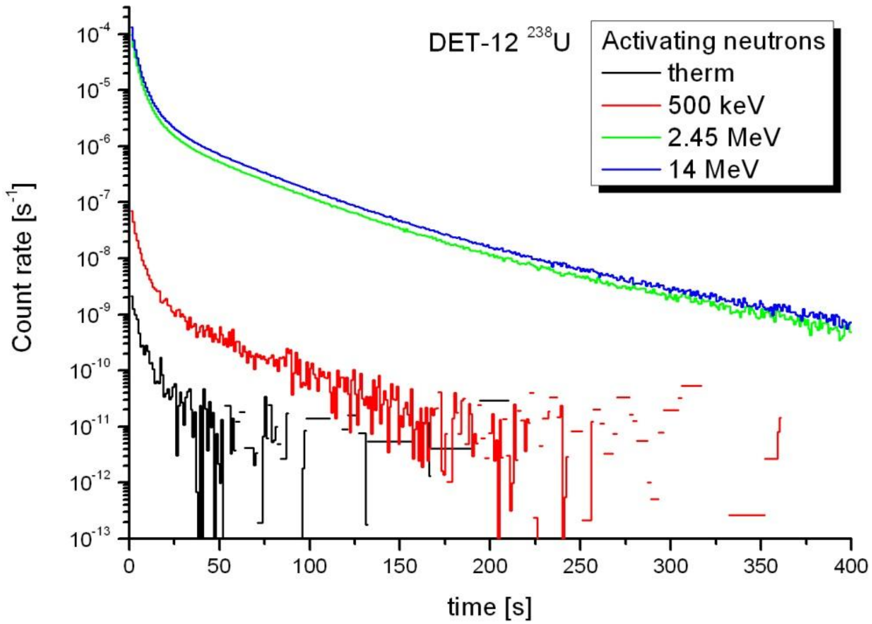
Activation System for W7-X – delayed neutrons technique

Activation of the fissionable isotopes is a valuable supplementary technique to the standard neutron activation method.

Isotopes such as ^{235}U, ^{238}U or ^{232}Th emit prompt neutrons (~99 %) at the fission and later the delayed neutrons (~1 %) from the fission products which decay with the β emission.

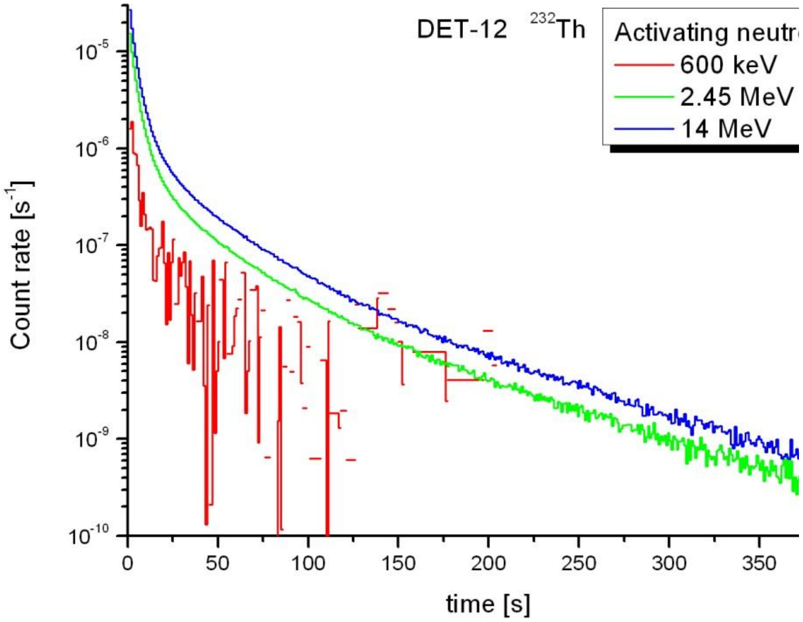
Activation System for W7-X – delayed neutrons technique

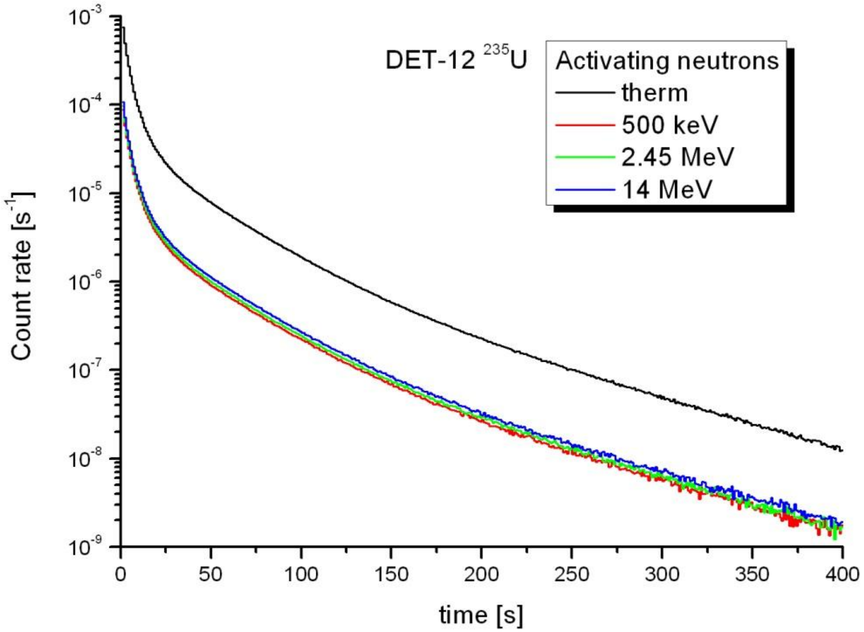
Simulation of the measurement by the MCNP code



Time distributions of the response of DET-12 for the delayed neutrons emitted from the activated ^{238}U tablet.

Simulation of the measurement by the MCNP code





This can suggest a method to estimate (at least roughly) an energy spectrum of primary neutrons if two types of sampling tablets were used, of ^{232}Th or ^{238}U and of ^{235}U simultaneously.

Future directions

Collaboration with the W7-X stellarator project

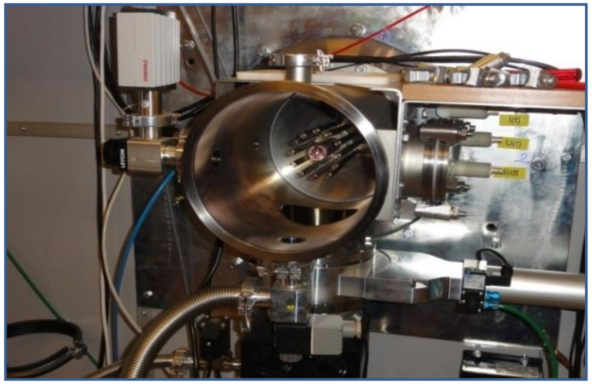
Draft PROPOSAL of the of IFJ PAN

program, opportunities, potential,

interest, possible cooperation…

R&D at the IFJ PAN focused at the nuclear fusion programme

- MAIN RESEARCH FIELD: Development of neutron and charged particle detection methods.
- RESEARCH EQUIPMENT: Laboratory of neutron sources & experimental lines



NSNS-2

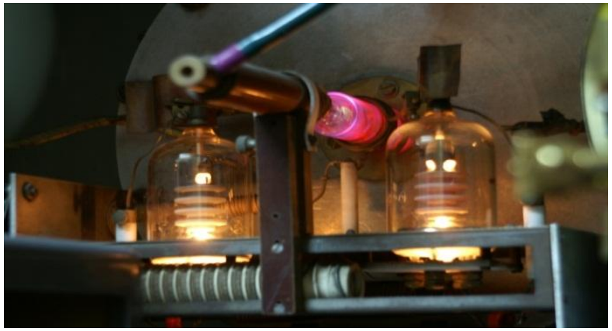
Two-module nanosecond source of 2.45 MeV fast neutrons.

The Plasma-Focus device (PF) for generation of neutrons from a high electric current discharge in deuterium gas which initialized the nuclear reaction:

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

Module I: neutron pulse 10 to 20 ns; neutron yield: $\geq 10^{6}$ / pulse

Module II: neutron pulse 50 to 100 ns; neutron yield: 10^{9} / pulse



IGN-14

14 MeV pulsed neutron generator.

Pulsed neutron generator working in a system of acceleration of deuterium ions which bombarded a solid tritium target:

$D + T = {}^{4}He$ (3.561 MeV) + n (14.029 MeV)

Pulsed regime: duration: from 25 to 1000 μs (step 1)
repetition: from 0.3 to 100 ms (step 0.1)
neutron yield during the pulse: 5×10^{8} n/s

Introduction

The W7-X is large devices with superconducting coils that aim for high plasma parameters, steady-state conditions, and divertor operation.

At the high performance of DD discharge it becomes feasible to extract information by measuring:

- fluxes and energy of charged fusion products
- hard X-ray radiation from superthermal electrons
- gamma emission from reactions between fast hydrogen ions and nuclei of impurities
- neutronics

Outline of questions of the program

Polish (IFJ) elements of the W7-X program can be directed to the following questions:

- Losses, confinement, and slowing-down of fast charged fusion products
- MHD activities and other fluctuations versus fast particle behavior
- Monitor of superthermal electrons by hard X-ray radiation

Proposed diagnostic system

1. A set of charged particle detectors measuring fluxes and energy of escaping charged fusion products

   This provides information of energy distribution and fluxes of lost charged fusion products

2. Gamma detector measuring gamma energy spectra from nuclear reaction between fast hydrogen ions and impurities

   This may provide information on fast ions generated during ICRH-heating

3. Hard X-ray monitor measuring non-thermal bremsstrahlung emission in the HXR region

   This may provide information about presence of superthermal electrons during ECRH-heating

4. Neutronics

Simulation codes / modelling

Neutron transport code MCNP helpful for the fast particle, gamma and HXR diagnostics system in order to assess **effects from neutrons** scattered and attenuated in the material structure of the W7-X **on the data measured with detectors**

Summary

Main fields of Polish contributions in W7-X: future directions

Interested Participants

Euratom-IPPLM Association members:

- Institute of Plasma Physics and Laser Microfusion, Warsaw
- National Centre for Nuclear Research, Świerk
- The Henryk Niewodniczański Institute of Nuclear Physics, Kraków
- Warsaw University of Technology
- Opole University, Opole

Main fields of Polish contributions in W7-X: future directions
Summary

Engineering & Technology:

- design and construction of equipment
- research- and engineering-services
- producing ionizing radiation detectors
  (construction materials, unique electronic instruments)

Material Research:

- monitoring of the in-vessel materials degradation
- development of new materials and materials technologies
  for stellarator based fusion reactors
- investigation of various materials needed
  for fusion-oriented experiments.

Main fields of Polish contributions in W7-X: future directions
Summary

Plasma Research:

- Losses, confinement, and slowing-down of fast charged fusion products
- MHD activities and other fluctuations versus fast particle behavior
- Monitor of superthermal electrons by hard X-ray radiation

Main fields of Polish contributions in W7-X: future directions
Summary – Plasma Diagnostics

Present (under construction)

- Soft X-ray diagnostics (PHA) system, (MFS), C/O- monitor system)
- Primary and fusion-produced ions
- Fast electron streams generated during plasma discharges
- Optical emission spectroscopy.

Further program

- Charged particle detectors measuring fluxes and energy of escaping charged fusion products
- Gamma energy spectra from nuclear reaction between fast hydrogen ions and impurities
- Hard X-ray monitor measuring non thermal bremssthralung emission in the HXR region
- Neutron diagnostics: activation systems, monitoring, neutron transport calculations (MCNP code)