4 Wendelstein 7-X and ITER

Polish contribution in the Wendelstein 7-X programme is considered to play a very important role in the integration of all Polish parties, that form our Association. Polish involvement in the W7-X programme is quite extended, ranging from cooperation on device assembly and development of NBI system through development of several diagnostics (X-ray PHA, C/O monitor, neutron and microwave diagnostics) to structural mechanical calculations and neutron MCNP calculations.

- Contribution to the project W7-X
    - Contribution in preparation of W7-X assembly process: including work organization, documentation of assembly process, modifications of equipment and training of technicians. Assembly of bus bars powering superconducting coils on the stellarator modules. Design of tooling necessary during modules assembly
    - Spectrometry of soft X-ray emission from W7-X stellarator with the use of PHA and MFS diagnostics
    - C-, O- monitor system for W7-X
    - Development and application of neutron diagnostics based on activation method for magnetic confinement devices (W7-X)
    - Detection of the delayed neutrons from activation of fissionable materials in the neutron field at fusion-plasma devices

Participation of the Polish institutions to the ITER project is done through direct ITER IO contracts and F4E grants. Wroclaw University of Technology (WrUT) has been continuing the contract on Risk Analysis of ITER Cryogenic System and the following tasks have been performed in 2011: scaling of safety devices (impact of Fukushima case), main cryostat risk analysis and risk analysis of He tank damage – TNT versus thermodynamic approach. AGH University of Science and Technology has carried out works in the frame of F4E grant related to Nuclear Data studies/experiments in support of TBM activities, in which the following tasks have been included: the first - Developing innovative 3H measurement procedure directly in LiPb and the second Conceptual design of a direct TPR measurement system without Tritium escape or with Tritium escape control.

4.1 Contribution to the W7-X project

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Introduction

Polish contribution to the Wendelstein 7-X programme concerns the realization of the following tasks:

1. Contribution to W7-X assembly process (IFJ PAN)

W7-X is currently under assembly in Greifswald. In 2011 the installation of the bus bar systems was completed by the IFJ PAN group on the last module 3. Then assembly of the joints at Module Separation Planes (MSP) have started i.e. the bus bars of neighbouring modules have been connected. The joints at MSP 5-1 (between module 5 and module 1) were completed and at MSP 4-5 advanced.

2. Spectrometry of soft X-ray emission from W7-X stellarator with the use of PHA and MFS diagnostics (IPPLM)

Two spectroscopic systems: pulse height analysis (PHA) and multi-foil system (MFS) are currently under design for W7-X for long pulse operation. The proposed PHA diagnostic is intended to provide the spectral energy distribution with energy resolution not worse than 180 eV along a central line of sight. In MFS system the recorded spectrum is determined by measurement of the total X-ray emission in different ranges of energy, which are determined by the type and thickness of the filters and the thickness of the detectors.

3. Development and application of neutron diagnostics based on activation method for magnetic confinement devices (IPPLM)

The activation technique is widely used in large magnetic confinement devices for the measurement of the neutron yield and the evaluation of the neutron spectra for DD and DT operations. A spectrometric system for the activation technique, the gamma ray detector together with the particular sample must be calibrated each time if even one part of the setup is varied. Numerical optimization of activation samples used for the activation technique to measure neutrons in large fusion devices such as JET, W7X and ITER has been elaborated.

4. C/O monitor system for W7-X (OU)

A soft X-ray spectrometer, called C/O monitor for W7-X, is designed for monitoring intensities of Lyman-α lines emitted by hydrogen-like ions of carbon, oxygen, nitrogen and boron with high time resolution. The spectrometer will be fixed at suitable wavelengths and position (at AEK 30 port) and should work with high throughput and high time resolution. As it will be positioned in the vicinity of the torus, the spectrometer will be subject to neutron and gamma irradiation. Appropriate shielding have to be provided in order to protect electronic elements and reduce influence of this radiation on measured signals.

5. Detection of the delayed neutrons from activation of fissionable materials in the neutron field at fusion-plasma devices (IFJ PAN)

One of the techniques used in hot plasma diagnostics to evaluate the neutron field is the activation method. A sample of a selected well known material is irradiated by neutrons exiting the fusion facility. Next the sample is quickly transported to a spectrometer and a secondary spectrum is analysed. It is possible to use fissionable isotopes (U or Th, for instance) as the sample material and to measure delayed neutrons emitted after the initial irradiation. A device, named DET-12, for the delayed neutron detection was designed and constructed at the Institute of Nuclear Physics IFJ PAN in Kraków.

Results

1. Contribution to W7-X assembly process

The presented scope of work in 2011 was realized by about 30 technicians conducted and supervised by 4 Line Officers (LO) from the IFJ PAN. Within the range of collaboration between IPP in Garching and IFJ PAN in Kraków the following tasks were realized:

- Completion of the bus bar system on module 3: final installation of 24 bus bars on the module, assembly and electrical insulation of 28 joints, assembly of Quench Detection system (QD) on all joints, painting and clamping.
- Completion of the bus bar system on Module Separation Plane (MSP) 5-1: reinforcement of QD wires, assembly and electrical insulation of 8 joints, assembly of Quench Detection system (QD) on all joints, painting and clamping.
- Advancing of the bus bar system assembly on Module Separation Plane (MSP) 4-5: reinforcement of QD wires, assembly and electrical insulation of 10 joints.

2. Spectrometry of soft X-ray emission from W7-X stellarator with the use of PHA and MFS diagnostics

The PHA system for W7-X has been designed. In 2011, details of the positioning of individual components have been fixed. The prototype of the filter control mechanism by a wobble stick using a small (fast) and large pneumatic cylinder as actuator for both diagnostics has been proposed and tested in the laboratory. The positioning is a two-stage: fast adjustable is made by a small cylinder and a big cylinder is used for the large (about 20 mm) movement. The precision of the adjustment will be 0.1 mm. A two way pressure valve (supply and exhaust of pressurized air 3 to 5 bar) controls with a feedback reading the 3 filter positions.

3. Development and application of neutron diagnostics based on activation method for magnetic confinement devices

In the case of a spectrometric system for the activation technique, the detector-sample setup must be calibrated each time if even one part of the setup is varied. The size optimization of cylindrical indium samples for low neutron flux measurements has been worked out. The Integrated Absolute Full Energy Peak Efficiency and the Mass Integrated Absolute Full Energy Peak Efficiency parameters have been used as the useful estimators of the sample properties. The systematic analysis of aluminium, indium, yttrium, titanium, zirconium, iron, cadmium, nickel, cobalt, hafnium and gold samples have been performed. The newly introduced mixed sample (homogeny composition of desirable elements) has been energy-efficiency calibrated by numerical method. This mixed sample, characterized by relatively high Absolute Full Energy Peak Efficiency, was widely used in experiments on JET Campaigns 20-25.

4. C/O monitor system for W7-X

The conceptual design of the spectrometer has been prepared. The position of the spectrometer at the port, its line of sight and acceptance angle have to be defined and optimized. Defining those factors one need to take into account the available space and type of the optical system as well as the simplicity of the construction and its robustness. The required accuracy of mechanical construction as well as adjusting and alignment parameters have to be defined too. Because the spectrometer will be situated in the torus hall, its elements could be irradiated by neutrons and gamma radiation. The most vulnerable part of spectrometer is the detector (multistrip gas chamber) and its electronics. In order to minimize the distortion of the spectrometer operation and possible damage, appropriate shielding construction have to be provided.

5. Detection of the delayed neutrons from activation of fissionable materials in the neutron field at fusion-plasma devices

Monte Carlo simulations concerning the DET-12 measuring chamber were carried out. Time distributions of the delayed neutrons radiated from activated fissionable material samples were computed. An influence of using various numerical models of the neutron source and of the irradiated material sizes on the registered time decay of the delayed neutrons was tested. Sintered U_2O pellets have been examined as the sample tablet material. The tablet was modelled as a cylinder of 1.8 cm diameter and 1.16 cm height. The simulations were performed employing the MCNP5 code installed in the computer cluster (McRadiat) in the IFJ PAN. The obtained general results are a base for planning real experiments with the delayed neutrons from activated fissionable samples at fusion-plasma devices.

Conclusions

1. Completion of the bus bar system on module 3 and bus bar interconnections at MSP 5-1 and MSP 4-5 are completed.
2. In 2011 manufacture drawings with all details of proposed PHA system have been performed. The DN160CF detectors flange with multipin connectors has been ordered. For both diagnostics a mechanism with wobble stick, which will be used for changing filters or/and cut the radiation from plasma, has been proposed and tested in laboratory. It is worth noting that all components will be made of specials materials, mainly of the steel SS316LN or 1.4429 quality with low magnetic permeability μr<1.01 and Co-content <2000ppm.
3. The elaborated method allows the evaluation of the absolute full-energy peak efficiency (AFEPE) of samples with good accuracy. The following capabilities of the new software are: the analysis of the accuracy of the Laboratory Sourceless Object Calibration Software; three dimensional AFEPE and optimization of the sample geometry. AFEPE for the mixed sample has been compared with Al and Au samples. The technique presented has been implemented on JET and is promising for such devices as W7-X, JET and ITER.
4. The conceptual design of the spectrometer has been prepared. Requirements for the precision of design and manufacture has been defined. The amount of the steel mass and its influence on the stellarator's magnetic field has been estimated. The influence of the neutrons on the most vulnerable parts of spectrometer has been considered and appropriate shielding system has been proposed.
5. A final MCNP model of the DET-12 device was prepared and used. Time distributions of the delayed neutrons emitted from activated ^{238}U material were simulated. They differ slightly from analytical curves which are obtained from the eight-group model due to different data used by MCNP. The obtained general results will be helpful for modelling of neutron activation of selected samples (material, size) and for interpretation of the decay curves of the detected delayed neutrons using DET-12 device.

Collaboration

Association EURATOM–IPP, Garching, Germany
Association EURATOM–CCFE, Culham, United Kingdom

4.2 Contribution to ITER

Risk Analysis of ITER Cryogenic System (At no cost for EURATOM Contract of Association. ITER IO contract)

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The collaboration between Wroclaw University of Technology and ITER IO has been focused on the risk analysis of the ITER cryogenic system, especially the main cryostat. The cryostat of the ITER tokamak constitutes a large cold box, where superconducting magnet system with the blanket, vacuum vessel and measurement systems are positioned. The vacuum created inside the cryostat restricts the heat loads to inner components. The cryostat is equipped with numerous openings providing access to the vacuum vessel for cooling systems, magnet feeders, auxiliary heating, diagnostics, and the removal of blanket and divertor parts.

The scope of the task performed in 2011 was the risk analysis of the ITER tokamak cryostat. The possibility of failure in the form of cold helium leak from one of the coils to the vacuum space of the cryostat has been profoundly analysed. Consequence of such a defect is loss of vacuum and dislocation of the superconducting magnets and a sharp increase of helium pressure in the space of the cryostat. The analysis has been performed for the coils at nominal operation and during fast energy discharge. Additionally the safety valves for the ITER cryogenic system have been scaled.

Nuclear Data studies/experiments in support of TBM activities (At no cost for EURATOM Contract of Association. F4E grant)

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Measurement of the 203Hg production in Pb/PbLi

One of the most important radionuclide dominating in Pb after irradiation in fusion power plant during the period of a few months to several years and determining the possibility of the breeder material treatment after irradiation is ^{203}Hg (half-live of 46.59 days) produced from Pb isotopes by fast neutrons. The objective of the present work is to measure and compare with available computational tools and nuclear data ^{203}Hg activity in Pb/PbLi material irradiated in 14 MeV D-T neutron fields.

The PbLi samples have been irradiated in several days during the experiment performed at FNG in Frascati. Neutron fluencies in samples from 7.8 x 10^{11} to 1.3 x 10^{12} 1/cm^2 have been achieved. A stack of 5 Pb and 4 PbLi samples in the form of discs in Al tube on polystyrol cylinder was positioned under FNG target at 21 cm distance from FNG axis. Four sets of samples each consisting of one Pb and one PbLi sample packed in thin Al foil were placed in front of FNG target on the surface of the Cu/stainless steel block (5.3 cm distant from FNG target). Only one parasitic radionuclide generated in Pb in fast neutron field i.e. ^{203}Pb must be taken into account in 203Hg activity measurement. Fortunately, the half lives of these nuclides are sufficiently different to measure ^{203}Hg after practically complete decay of ^{203}Pb.

^{203}Hg activity due to very low production cross section was very low and depending on the sample varied from 0.05 Bq to 0.3 Bq in one sample. Samples have been measured with the use of two HPGe spectrometers during long measurement time – at least 105s. The total uncertainty consisted of measurement statistical uncertainty (±5% to ±15%) and detector calibration uncertainty (±5%). Uncertainty connected with irradiation geometry description (uncertainty of a sample - FNG target distance) is assumed to be negligible in our calculations.

The neutron fluxes in each sample have been calculated with the use of MCNP and FENDL2.1 transport cross sections. The calculated fluxes have been used with FISPACT-2007 code and EAF-2010 library to calculate ^{203}Hg activities in our samples. The mean C/E value for samples on the block and for samples under target amounts 0.85(5). C/E values were also obtained with the use of JEFF3.1 library. They are about 0.85 with uncertainty equals 0.05. The results with the use of FENDL2.1 data are nearly one range of order overestimated against experiment. The MCNP results with the use of the JENDL4.0 library are overestimated against experimental values with a mean value equals 1.16. The experimental results are located between JEFF3.1.1 and JENDL4.0 based MCNP simulation results.

The available cross sections present rather big differences in the interesting 10-15 MeV neutron energy region. For example cross section of ^{206}Pb(n, α)^{203}Hg reaction for 14.69 MeV neutrons in JEFF3.1, JENDL4.0 and FENDL2.1 are 4.506E-04, 5.77E-04 and 2.93E-3 barns respectively.

Conceptual design of a direct TPR measurement system without tritium escape or with tritium escape control

A very important ITER parameter is tritium production rate (TPR) crucial for the thermonuclear reactor proper functioning. The objective of the present work was to propose a concept of tritium measurement system, which could be used for TPR assessment in TBM in ITER. On the basis of developed in previous grant innovative 3H measurement procedure directly in LiPb material with the use of the Liquid Scintillator Technique (LSC) and application of the diffusion theory we tried to propose such a concept.

Literature study and carried out experiments entitle us to formulate following conclusions on TPR measurement using LSC technique:

1. Measurement of TPR directly in LiPb eutectic in online system or in system with short delay after irradiation is beyond technical possibilities. Activity produced in Pb (^{203}Pb for example) and in trace elements comprised in Pb will be in remarkable degree disturbing tritium signal. Chemical procedure that could be used to eliminate parasitic radiation is relatively complicated and time consuming but possible.

2. Theoretical approach of tritium escape from sample by diffusion model (Bi-velocity method) was applied in developed rCADiff PC program. The results of this program applied for temperature above melting point well confirms experimentally measured loss of tritium from LiPb sample. Numeric results currently obtained an uncertainty of TPR values in the order of 10%, however, decrease of this value is attainable. It will be useful to compare developed rCADiff program results with TMAP code used for tritium related problems for ITER.

3. Activation of analogous /substitute material and then corrected, if necessary, to TPR in LiPb eutectic seems a promising way, especially, as the used substitute material in form of lithium compound of the same isotopic composition can be used. Possible correction will come out after the laboratory comparable test experiments. Decrease of a delay to hours between irradiation and start of measurement seems realistic. Good candidates for such material are: Li_2O, or LiF with some limitations. The problem of choosing an optimal compound as well as specific procedure of preparation before LSC measurement needs further investigations.

4. The samples transport (rabbit) system has to be developed and applied in TBM design.

5. The sample container function to be assessed:
to protect sample mechanically during transfer to and from TBM
to prevent tritium penetrating outside in case of significant escape from the sample

The first function seems to be not very difficult problem. On the contrary, to prevent tritium penetration through container wall, especially if the sample presents liquid LiPb in high temperature will be no trivial challenge. The detailed assessment of container material, eventual application, permeation barrier on its surface could be performed when details of transfer system will be known.

Post-analysis of the whole experiment including sensitivity and uncertainty analysis

In this task, the analysis of the HCLL TBM mock up experiment has been completed and conclusions have been derived on the validity of JEFF-3.1 and FENDL-2.1 nuclear data in the design of these systems.

The direct measurement of the tritium activity in PbLi technique was used by AGH group to further confirm the ^{6}Li content in the PbLi material (in addition to other methods used by collaborating teams) PbLi samples were irradiated in a very well characterised thermal neutron field at the nuclear reactor MARIA in Poland. Both Li2CO3 powder and LiF (TLDs) samples were also irradiated in the reactor thermal neutron field as reference materials. From the measured tritium activity, the ^{6}Li content in the PbLi samples could then be derived (no tritium is produced from 7Li in a thermal neutron field). The average ^{6}Li content is 0.183 $\pm$ 0.005 mg/g.

The measurements of the tritium specific activity directly in the PbLi samples obtained from TLD holders, and irradiated at FNG, are very well reproduced by the calculations. As there is an important contribution from the 7Li(n, n't)α reaction in the front positions, this result proves that the reduced amount of ^{6}Li in PbLi is due to depletion in 6Li of lithium, and not to a reduced amount of lithium with natural isotopic composition: the data, in fact, are well reproduced in the numerical simulation assuming 0.615wt% (nominal) Li content with 3.46% fraction of ^{6}Li, 6Li/Pb-Li = 0.183 mg/g, fully in agreement with the other measurements mentioned above.