4 ITER and Wendelstein 7-X

The Polish contribution to Wendelstein 7-X programme is considered to play a very important role in the integration of all Polish parties that form our Association. The Polish involvement in W7-X programme is quite extended, ranging from the cooperation on the development of NBI system through the construction of several diagnostics (X-ray PHA, C/O monitor).
Wroclaw University of Technology (WrUT) has been continuing the studies concerning the risk analysis of the ITER cryogenic. The performed risk analysis, together with the numerical investigation of the helium outflows to the confinements of cryogenic nodes, allowed identifying the most credible incidents and corresponding mitigation schemes.

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Introduction

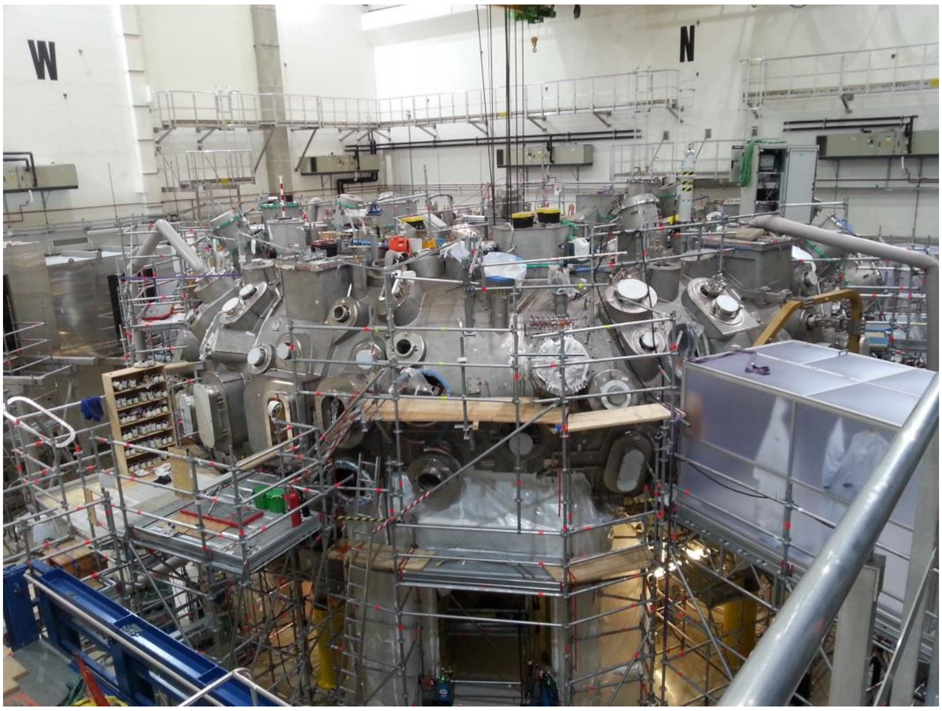
The work conducted in the framework of the ITER and stellarator W7-X in 2013 included the following tasks:

- Dymamic model of ITER cryogenic system nodes and its applicability to the ITER cryogenic system Risk Analysis
- Development of the soft X-ray spectrometry systems for the stellarator W7-X
- C/O monitor system for W7-X
- Adapting the activation technique to apply on W7-X for determination of neutron yield from deuterium plasmas

Presented report described a continuation of investigations done by IPPLM-Association group in the previous years.

ITER will be a tokamak- based machine, in which a mixture of hydrogen isotopes will be heated up to a hot plasma phase and fused to produce helium, releasing a neutron and a net thermal energy. The ITER superconducting magnet system will confine the plasma in a toroidal vacuum vessel. To obtain the superconducting state of the magnets the coils, in a large and thermally shielded cryostat, will be maintained at 4.5 K with supercritical helium. The ITER cryogenic system will be composed of three main sub-systems: the cryoplant located in a dedicated building, cryogenic distribution in the tokamak building, and transfer lines connecting the cryoplant with the tokamak machine. Due to a very complex structure, high helium content (24 tons, mostly in high density cold phases) and location in highly dense area, the ITER cryogenic system will belong to the most complicated ever built. The operation of the tokamak strongly depends on the reliability and availability of the cryogenic system.

The super conducting stellarator W7-X will run pulse of up to 30 min duration with full heating power. Electron Cyclotron Resonance Heating (ECRH) is the main heating method for steady-state operation of the Wendelstein 7-X stellarator in the reactor relevant plasma parameters. In the first phase of working a heating power of 8-10 MW is planed to be used. A wide spectrum of requirements has to be considered during the design and realization of the new X-ray diagnostics.



A photo of the stellarator Wendelstein 7-X, June, 2013

The plasma that is formed in large plasma experiments is characterized by vast numbers of parameters. All of them need to be monitored. A neutron activation method occupies a high position among others plasma diagnostic methods. The above method is off-line, remote, and time-integrated method. It doesn't interfere and interrupt plasma parameters like temperature density and purity as well. The plasma with parameters enabling nuclear fusion reactions is always a strong source of neutrons that leave the reactions area and take along energy and important information on plasma properties.

Neutrons as a product of the fusion reaction easily escape from hot plasmas and they carry important information on plasma parameters and fusion reaction mechanisms. Therefore, the neutron diagnostics are essential in estimating these parameters and fusion power. Activation techniques are especially advantageous for the estimation of some characteristics of fast neutrons emitted from hot plasma discharges and have been used in many tokamak experiments. These techniques were used to measure e.g. neutron fluence at chosen locations around the machine, even inside the vacuum vessel close to the vessel walls. Supported by neutron transport calculations the activation technique can provide information on the total neutron yield and released fusion power.

Results

The ITER cryogenic system can be treated as composed of separated cryogenic nodes grouped in six subsystems: central solenoid feeder, toroidal field magnet feeder, poloidal field magnet and correction coil feeder, structure cooling feeder, cryopump distribution and transfer lines. The total number of identified cryogenic nodes is of the order of 1000. Each cryogenic node can be characterized in terms of helium quantities, helium thermodynamic parameters, the volume of corresponding insulation vacuum, instrumentation and special equipment. To understand the system operation and to perform the risk analysis of the cryogenic system, a unified dynamic model of the system the cryogenic system node had to be developed. As the reliability of the ITER tokamak will strongly depend on the safe operation of the cryogenic system a dedicated risk analysis has been performed. The objective of the performed risk analysis was to identify all the possible risks to personnel, equipment and environment resulting from cryogenic system failures that might accidentally occur within any phases of the machine operation, and that could not be eliminated by design. All the potential failure modes have been analyzed to identify their possible effects and then to classify them according to their severity and probability of occurrence. The Pareto-Lorentz analysis has been used for ranking all the identified failures and determining the most credible incidents and scenarios. For the most credible scenarios numerical simulations of the helium outflows from the system have been performed, including the analysis of the helium flow impact on the neighboring confinements. The calculations were based on a lumped-parameter dynamic model of the tokamak cryogenic system.

Regarding the works contributed to W7-X, in 2013 three spectroscopic systems: pulse height analysis (PHA), multi-foil system (MFS) and C/O monitor system are designed and constructed for Wendelstein 7-X stellarator for long pulse operation.

The proposed PHA diagnostics is intended to provide the spectral energy distribution with energy resolution not worse than 180 eV along a central line of sight. The system consisting of 3 single Silicon Drift Detectors (SDDs) operated with different filters will be installed on the horizontal port AEK50 on W7-X. Each detector will record an X-ray spectrum in three different energy ranges from 400 eV to 20 keV. In 2013, a vacuum chamber of the PHA system was manufactured. All components of the system like piezo-slits and wobble sticks for filters have been mounted and preliminary tested.

In MFS system the recorded spectrum is determined by measurement of the total X-ray emission (as the effect from interaction of many quanta) in different ranges of energy, which are determined by the type and thickness of the filters and the thickness of the detectors (usually the ranges overlap). The MFS method is characterized by lower, in comparison with the PHA system, spectral resolution. In 2013, a new concept of the MFS system was proposed. The MFS chamber will be directly mounted to the gate valve at the AEN20 port.

The C/O monitor for W7-X will be a spectrometer of special construction with high throughput and high time resolution, suitable for concentration of main impurities in plasma. The spectrometer will be fixed at proper positions and wavelengths corresponding to Lyman-α lines of H-like ions of oxygen (at 1.9 nm), nitrogen (at 2.5 nm), carbon (at 3.4 nm) and boron (at 4.9 nm). The spectrometer will be composed of four independent channels, with individual dispersive elements and separate detectors. It will be constructed according to Johann geometry with Rowland circles radii adjusted to wavelength ranges registered by the respective channels. In 2013, the multilayer mirrors which will be applied as dispersive elements for channels measuring intensities of spectral lines were tested and accepted.

In the task related to activation technique as a method for W7-X for determination of neutron yield an activation technique with the use of Yttrium for neutron measurements has been described. Preliminary measurements of the activity of natural yttrium induced by neutrons from plasma focus device, DPF-1000U, have been carried out. Measured activity was compared with the total neutron yield measured by means of silver activation counters, which were used as a standard diagnostics on DPF-1000U. The linear relation has been found.

Conclusions

An FMEA-based methodology of the cryogenic risk analysis was applied to the ITER cryogenic system. The performed risk analysis, together with the numerical investigation of the helium outflows to the confinements of cryogenic nodes, allows identifying the following most credible incidents:

1) Drop of the oxygen concentration below acceptable level in the related confinements of the cryogenic nodes, that can cause the oxygen deficiency hazard to the personnel present in the zone of the node operated in failure mode,
2) Significant temperature decrease in the confinement related to the cryogenic node operated in failure mode that can cause danger to the personnel and to the facilities located in the zone that gets fragile at low temperatures,
3) Pressurization above 1.2 bar of the tight confinements of the tokamak building,
4) Significantly long shutdowns of the machine resulting from the necessary repair period.

The results of the simulations showed that if the confinements are considered open to the adjacent confinements through specified passages, the pressure in any confinements will not exceed the acceptable pressure value, and the oxygen concentration will drop below acceptable levels. Therefore the actions that mitigate the consequences of the most credible incidents are to implement a oxygen monitoring system and to allow sufficient free helium flow between the adjacent confinements to make the maximum use of the accessible volume in the tokamak building while maintaining not leak tight volume segregation for fire confinement. The above actions are implemented in the tokamak building design and layout.

Progress in development of soft x-ray diagnostics for W7-X in 2013 can be summarized as follows:

The PHA vacuum chamber has been manufactured and first tests of the piezo-slits and wobble sticks have been performed. A calibration port of the PHA system has been mounted and first energy calibration curve has been determined based on 9 registered spectral lines.

The MFS system has been modified. The long pipe with the turbomolecular pump at the end of port has been removed in comparison with the previous version (described in 2012). It was decided that this diagnostics will have a movable pumping system.

In case of the C/O monitor the tests of the delivered multilayer mirrors have been performed. Several obstacles causing delay of the project seem to be overcome and one can plan finishing the system before the end of OP1.1 of Wendelstein 7-X.

The research performed with the use of activation technique shows that activity induced in yttrium sample is directly proportional to the total neutron yield monitored by the method. Promising result of this experiment allows us to construct new generation fusion neutron yttrium monitor FNYM, which will be a subject of the subsequent works.

Collaboration

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References

[1] P. Prokopowicz, M. Scholz, A. Szydłowski, S. Popovichev and JET-EFDA Contributors (2007) Measurements of Neutron Yield from Deuterium Plasmas at JET by Activation Techniques, Plasma 2007, AIP Conference Proceedings Vol. 993: 251-254

[2] R. Prokopowicz, B. Bieńkowska, K. Drozdowicz, S. Jednoróg, E. Kowalska-Strzęciwilk, A. Murari, S. Popovichev, K. Pytel, M. Scholz, A. Szydłowski, B. Syme, G. Tracz, JET-EFDA Contributorsd, (2011) Measurements of neutrons at JET by means of the activation methods. Nucl Instrum Meth A 637:119–127

[3] L. Serio, "Challenges for Cryogenics at ITER" in Advances in Cryogenic Engineering, vol. 55A, edited byedited by J. G. Weisend II, et al., Melville, NY, 2010, pp.651-652.

[4] M. Chorowski, Ph. Lebrun, G. Riddone, "Preliminary risk analysis of the LHC cryogenic system" in Advances in Cryogenic Engineering, vol. 45, edited by Quan-Sheng Shu, et al., NY, 2000, pp. 1309-1316.

[5] M. Chorowski, J. FydRyćh, M. Grabowski, L. Serio, Risk Analysis of ITER Cryogenic System, in Advances in Cryogenic Engineering, vol. 47, Melville, New York, 2012, pp. 1559-1556.

[6] V.J. Parks, *Surface curvature analyzed with a grid-reflection technique*, Experimental Mechanics, 24 (1), 44–47 (1984)

[7] J.F. McGrath Jr., *New Technique for the Design of an Extreme Ultraviolet Collimator,* Rev. Sci. Instrum. 39 (7), 1036–1038 (1968)

[8] A. Weller, S. Mohr, C. Junghans, Review of Scientific Instruments **75**, 3962 (2004)

[9] H.-S. Bosch, R.C. Wolf et al., Technical challenges in the construction of the steady-state stellarator Wendelstein 7-X, Nuclear Fusion **53** (2013) 126001