



**Annual Report of the
Association EURATOM / LEI**

2007

ISSN 2029-1612

© Lithuanian Energy Institute, 2008

Content

1	The overview of association EURATOM/LEI	5
2	Accident analysis and evaluation of consequences for W7-X	7
3	The activities in the field of physics	10
3.1	Energy spectra of tungsten W^{29+} – W^{34+}	10
3.2	Interpretation of the intensive emission of tungsten ions at about 5 nm	12
3.3	Relativistic electron-ion scattering calculation	14
4	The activities under Cost Sharing Actions	16
4.1	Hydrogen deflagration/detonation analyses in ITER HNB (Heating Neutral Beam) and DNB (Diagnostic Neutral Beam) -boxes and cryopumps following a LOVA	16
4.2	Characterisation of W-Coatings for Fusion Applications	16
5	The activities in the field of socio-economic studies	18
6	Training, education and public information	19
7	Mobility program 2007	21
8	Publications	22
9	References	23

1 THE OVERVIEW OF ASSOCIATION EURATOM/LEI

Before its accession to the European Union in May 2004, Lithuania was not associated with EURATOM. However, since then Lithuanian researchers have been active and in 2005 they managed to be successful in three EFDA technology calls for proposals so that they participated in fusion research by means of cost-sharing actions. These involve a safety study, the design and analysis of the inboard rail of the ITER divertor cassette, and the characterisation of W-coatings for fusion applications. Tasks of physics – calculation of the cross-sections of atomic processes useful for plasma diagnostics – were delayed until the start of the new Association.

After negotiations, which started in 2006, between the European Commission and the partners in Lithuania, a Contract of Association was signed. The new Association is comprised of the Lithuanian Energy Institute (LEI) in Kaunas, Lithuania, with the involvement in the Association activities of the Institute of Theoretical Physics and Astronomy of Vilnius University (VU ITPA), Kaunas University of Technology (KTU) and Vytautas Magnus University (VMU). The Contract came into force on January 1, 2007 and Lithuania became a new member of the EURATOM Fusion programme.

The kick-off meeting of EURATOM/LEI association took place at Lithuanian Energy Institute, in Kaunas, Lithuania on November 15, 2006. The representatives of the European Commission Y. Capouet, M. Pipeleers, B. Green, and S. J. Booth participated at the kick-off meeting. The Director Prof. E. Ušpuras signed the Contract of Association and he was designated as the Head of Research Unit.



Meeting of EURATOM-LEI association in the field of thermonuclear synthesis (15 November 2006)

Four Lithuanian organisations – Lithuanian Energy Institute (LEI), Institute of Theoretical Physics and Astronomy of Vilnius University (VU ITPA), Kaunas University of Technology (KTU) and Vytautas Magnus University (VMU) participated at the kick-off meeting. Later formal co-operation agreement was signed between LEI and VU ITPA and currently these organisations comprise the Research Unit. KTU and VMU continued participation in fusion research through the Cost Sharing Actions projects, initiated in 2005.

The Steering Committee of EURATOM/LEI consists of Mr. Y. Capouet (Head of Unit J4 “Contracts of Association” DG Research, European Commission), Mr. S. J. Booth (Unit J3 “Joint Development of Fusion” DG Research, European Commission), Mr. E. Rille (Head of Unit J5 “Administration and finance” DG Research, European Commission), Mr. Z. R. Rudzikas (President of the Lithuanian Academy of Sciences), Mr. L. Pranevičius (Professor of Vytautas Magnus University), Mr. A. Žalys (Director of the Department of Science and Technologies of the Ministry of Education and Science of the Republic of Lithuania). The Steering Committee meeting was held on July 10, 2007 by the videoconference, which was arranged between the premises of Distance Education Centre at Kaunas University of Technology (KTU) and European Commission. At the meeting the ongoing activities and future plans of EURATOM/LEI association were discussed and approved.

In 2007, the co-operation of EURATOM/LEI with EURATOM/IPP was initiated in order to take part in the design of fusion facility W7-X, which is being constructed at Max-Planck-Institut fuer Plasmaphysik in Greifswald, Germany.



In December 4–5, 2007 representatives of EC, Mr. S. Booth and Mr. M. Pipeller visited EURATOM/LEI organizations VU ITPA and LEI to observe the situation and clarify the administrative issues

2 ACCIDENT ANALYSIS AND EVALUATION OF CONSEQUENCES FOR W7-X

The co-operation between LEI and Max-Planck-Institut fuer Plasmaphysik (IPP) started in March 2007 by the visit of Dr. D. Naujoks (IPP) to Lithuania and continued in informal way, where IPP provided technical information on the design of Wendelstein7-X test facility, whereas LEI investigated the received materials. The Collaborative Actions with the Association EURATOM/IPP in the field of thermal-hydraulic analysis and Systems safety analysis for W7-X device and its main components started in the frames of ongoing Contract of Association EURATOM/LEI for 2007.

W7-X (Figure 2.1)) is a large superconducting stellarator project under construction in Greifswald, Germany. W7-X should demonstrate the conceptual reactor qualification of stellarators. W7-X is like ITER based on superconductivity with a complex thermal insulation system and has the goal of steady-state plasma operation necessitating the development of long-pulse plasma heating, exhaust technology, long-pulse plasma control and diagnostic techniques.

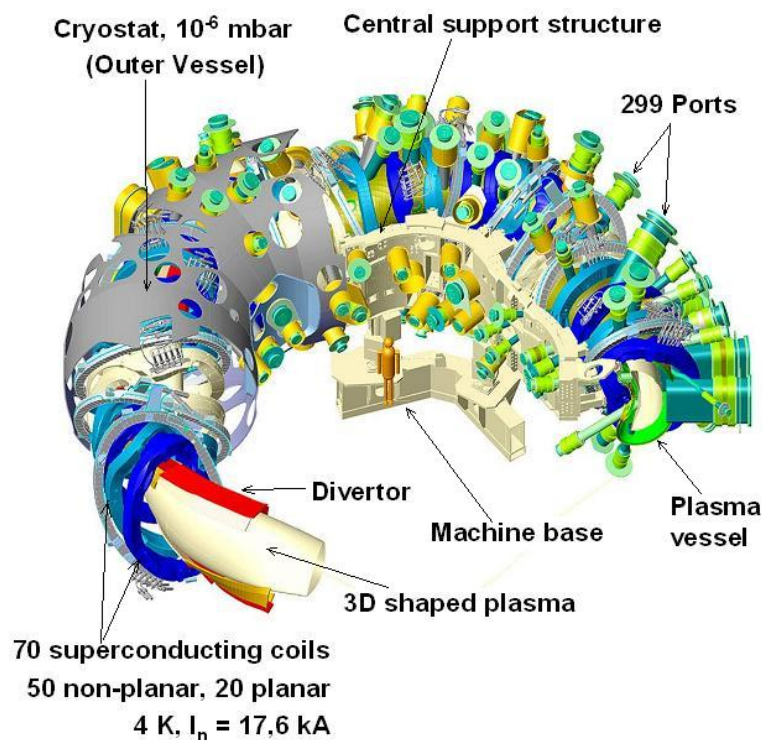


Figure 2.1.
The fragment of a CAD
model of the W7-X system

W7-X is the last large superconducting device built in the European Union before ITER and is, therefore, expected to help maintaining and developing industrial manufacturing and quality assurance capability in a number of technologies required for ITER construction.

In-vessel components, such as protection tiles and actively cooled first wall components have been developed for Tore-Supra and also in the framework of the ITER R&D programme. The production of these components for W7-X will add to the body of industrial manufacturing and Quality Assurance know-how in preparation for ITER construction.

In the area of assembly, the W7-X requirements on dimensional accuracy are a challenge and require the use of modern sophisticated optical metrology techniques. The experience gained for the large and complex W7-X components will be of direct interest to ITER. For more conventional technologies, such as power supplies, cryogenic and vacuum systems, ITER is expected to benefit from the industrial interest and manufacturing capability generated by the W7-X activities.

Failure of one of the coolant pipes providing water to the divertor targets with inner diameter of 40 mm is considered as the most severe accident in terms of the plasma vessel pressurisation [1]. Pressurisation of the Plasma Vessel above 110 kPa must be avoided by means of active (safety valves on coolant pipes) and passive safety devices (burst or rupture disk). The supply valves have to be closed after the detection of an in-vessel water leak to limit the mass of water that could be injected inside the Plasma Vessel. The rupture disk has to be opened at 110 kPa pressure in the PV and relief steam into the torus hall or through an additional exhaust pipe outside the torus hall directly into the atmosphere.

During visit of LEI experts at IPP it was agreed that in the period 2007–2008 LEI could perform Loss-of-Coolant accident (LOCA) analysis including thermal-hydraulic and structural analysis [2].

The analysis of LOCA in W7-X facility is planned to be performed using lumped parameter codes RELAP5 [3], COCOSYS [4] and ASTEC [5].

RELAP5 code will be used for the analysis of the cooling circuit response to the accident and determination of the coolant discharge parameters, i.e. flow rate and specific enthalpy. Later this information will be used in COCOSYS code, which will be used to calculate the pressurisation of the plasma vessel.

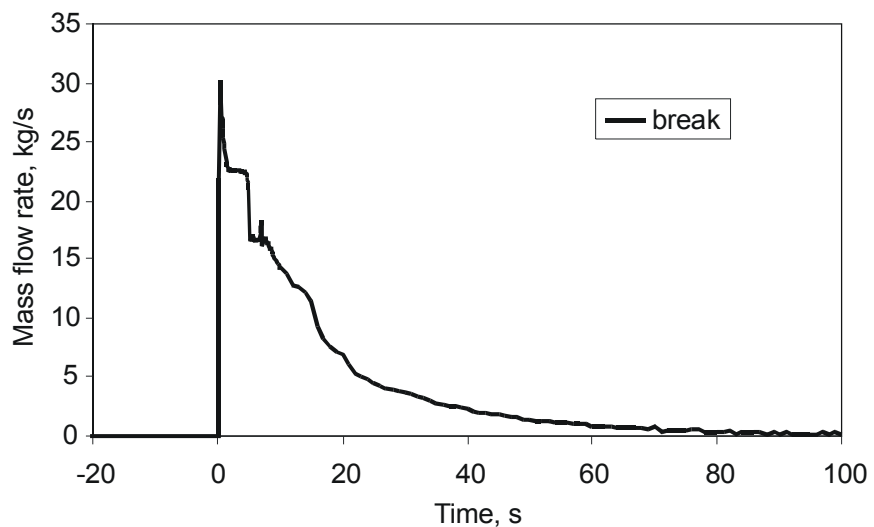


Figure 2.2. Discharge of coolant through the ruptured 40 mm pipe

The integral code ASTEC will be used to perform an integral analysis of W7-X response to LOCA, i.e. cooling circuit response and plasma vessel pressurisation. CESAR and CPA modules of ASTEC code will be involved in the analysis. The results received with ASTEC will be compared with the results received with RELAP5 and COCOSYS codes.

At present the model for RELAP5 code is developed and the first results of the analysis are available. Of course, the developed model will be further improved updating the details on the cooling and baking circuits of W7-X. The first result regarding the flow rate of discharged coolant is presented in Figure 2.2. When the pipe ruptures, the maximum flow rate of the discharged coolant reaches 30 kg/s, but later it decreases quickly. After 80 s the flow rate is less than 1 kg/s.

Later, the results received with RELAP5 will be used by the COCOSYS code to analyse the response of Plasma Vessel and possibly the hall, where the W7-X is installed.

During visit of LEI specialists at IPP, the possibility to use LEI experience for a static and dynamic structural integrity analysis of piping systems, buildings structures and other complex components was discussed as well. It was agreed to search for possibilities to perform such analyses for W7-X using ABAQUS code and other codes available at LEI.

3 THE ACTIVITIES IN THE FIELD OF PHYSICS

The important impurity in tokamak plasma is tungsten, which is most resistant to sputtering, and thus the most suitable as the first wall material, especially in the region of divertor. However, tungsten atoms can migrate into the central plasmas region and exist there in various ionization stages [6]. Such many electron ions radiate intensively giving large radiation losses, thus the concentration of tungsten in the core must not exceed 10^{-4} [7]. On the other hand, the emission of tungsten ions is of interest for plasma diagnostics. The x-ray and VUV spectra of various highly charged ions in tokamak plasma have been investigated experimentally and theoretically in various publications [8–16].

The emission spectrum of tungsten ions, recorded in the ASDEX Upgrade tokamak is dominated by the quasicontinuum band based in extreme ultraviolet spectral range at 4.8–5.4 nm [14, 16]. Contributions from the emission of various ions to this band were investigated using spectra of ions recorded in EBIT for different electron beam energies [14, 15]. It was established that this intensive radiation corresponds to mixed 4d-4p and 4f-4d transitions mainly in ions having open 4d^N shell.

The aim of the work is to continue theoretical investigation and interpretation of these spectra, of their regularities and conditions of generation by using non-relativistic [17] and relativistic Dirac-Fock [18] wave functions in CI (configuration interaction) approximation.

3.1 Energy spectra of tungsten W²⁹⁺–W³⁴⁺

The radiation of tungsten ions joins the total spectrum of the thermonuclear plasma in various regions of wavelengths and it might be kept in mind while performing spectral investigation of such plasmas. The spectral characteristics of tungsten ions are not properly analyzed since production and spectral investigation of such highly ionized atoms demands very high temperatures and complicated experiments. In the framework of ITER project, the task of both theoretical and experimental research of spectral characteristics of various tungsten ions was posed. Diverse experimental methods are applied to investigate different tungsten ions. The detailed description of the performed research is available in [7, 14, 15]. Within the experimental investigations the main attention is paid to the ions of middle ionization degree with intensive radiation in the region from 45Å to 70Å. The spectra of these ions are composed from multitude of resolved lines, which form bright emission bands. It is known that such quasi-continuum emission bands originate from mostly $\Delta n = 0$ electric transitions within the $n = 4$ shell, though $\Delta n = 0$ transitions are also known to create continuum bands. In order to perform the successful interpretation of the obtained experimental results, the theoretical data are necessary. Thus, generation of theoretical data is a very challenging task due to the particularly large number of the levels and even bigger number of possible transitions between the levels.

The purpose of the work to determine of the configurations, which were necessary to investigate so that the transitions between them would correspond to the needed wavelength interval, and obtaining preliminary data on the energy spectra on the ions under investigation by using non-relativistic wave function for CI.

The ground configuration of the investigated ions is $[\text{Ni}]4s^24p^64d^N$, here N (number of d-electrons) is from 9 to 4 depending on the degree of ionization. All configurations with the energy lower than one of the configuration $4s^24p^64d^{N-1}5g$ have been investigated. The obtained energy spectra of tungsten ion W^{30+} are presented in Figure 3.1, as an example. The energy is presented in atomic units. On the left side of the figure there is a group of even configurations, on the right side – the odd ones. As follows from the experimental works [7, 14, 15], the investigated ions radiate most intensively in the region between 4 and 5 nm. These wavelengths correspond to the transitions between the levels energetically distant from each other by ~ 10 a.u. The energy spectra for W^{31+} , W^{32+} , W^{33+} , and W^{34+} can be found in [19].

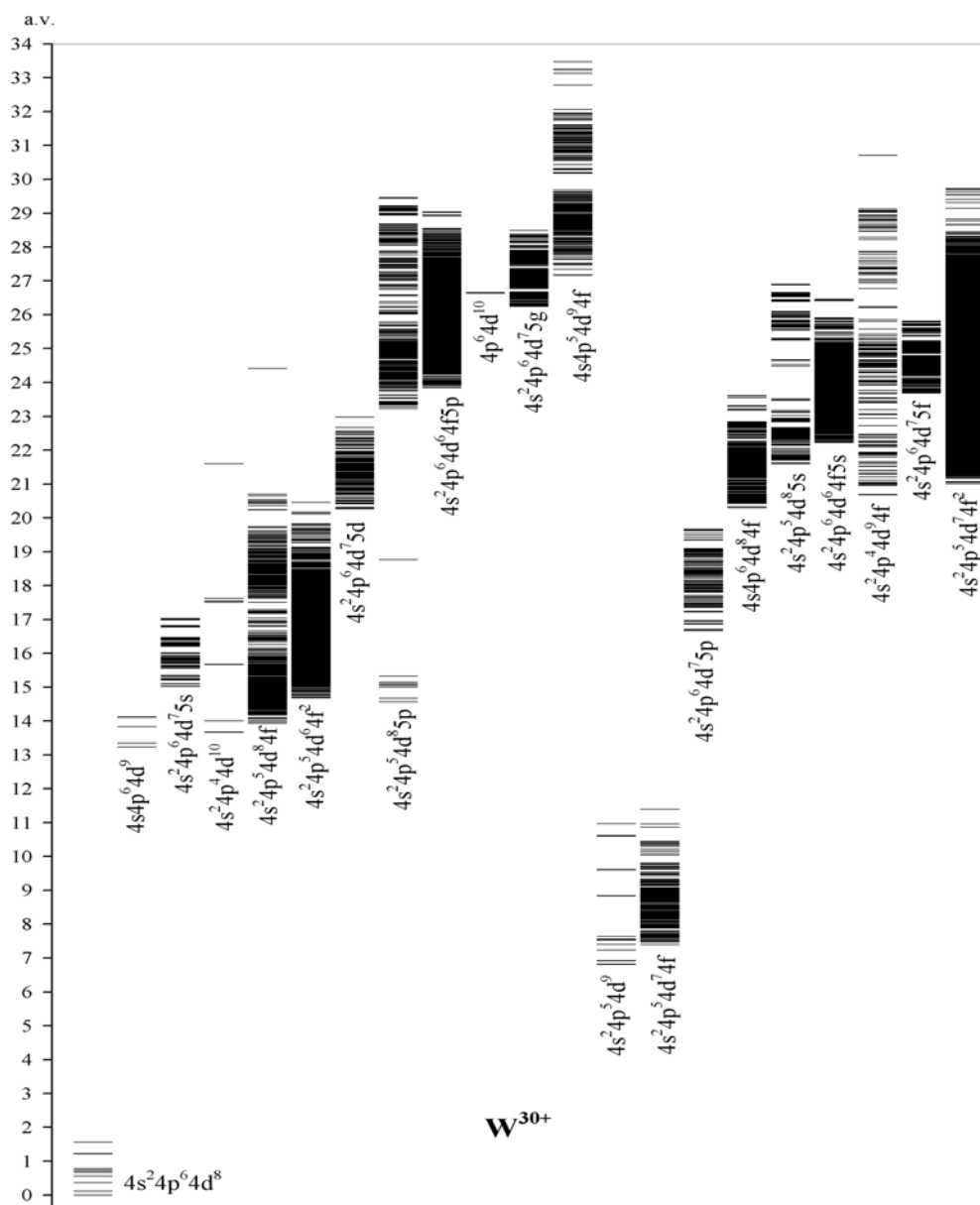


Figure 3.1. Energy spectra of W^{30+}

It is shown in Figure 3.1 that the mentioned wavelength interval corresponds to the resonance transitions from the excited configurations $4s^24p^54d^{N+1}$, $4s^24p^64d^{N-1}4f$ to the ground one. The transitions from the higher configuration group (of the same parity as

the ground configuration) to the mentioned two excited configurations take place. The performed calculations confirm that the energy distance between the excited configurations of the different parity is also ~ 10 a.u.

After performed analysis it can be concluded that the intense emission of tungsten ions W^{q+} with intermediate ionization degrees $q=29-37$ plays an important role in radiative losses of tokamak plasma, Spectra of such ions were registered in EBIT [14] and their main features interpreted [14, 15]. However, some problems concerning the formation of quasicontinuum band and the appearance of the line with almost constant wavelength at 4.5 nm remained.

3.2 Interpretation of the intensive emission of tungsten ions at about 5 nm

The formation of quasicontinuum band at about 5 nm in the highly charged tungsten ions is investigated using relativistic configuration interaction approximation. The formation of this band is related with one of the strongest correlation effects in atoms i.e. the so-called configuration mixing with the symmetric exchange of symmetry $n\ell^{A+1}n(\ell+1)^{N+1} + n\ell^{A+2}n(\ell+1)^{N-1}n(\ell+2)$ (SEOS correlations) [20, 21]. Both these configurations are related through dipole transitions with the same ground configuration $n\ell^{A+2}n(\ell+1)^N$. For this reason SEOS mixing has a very strong effect on the corresponding photoexcitation and emission spectra.

We have shown that under the conditions used in the EBIT experiments the emission spectra of tungsten ions corresponding to the transitions $4p^54d^{N+1} + 4p^64d^{N+1}4f \rightarrow 4p^54d^N$ are mainly determined by excitations from the ground level. This enabled us thereafter to use the ground level model for the investigation of the regularities of emission spectra.

For the ions $W^{29+}-W^{34+}$ at $N = 4-9$ emission spectrum consists of the narrow group of intense lines, which are not resolved experimentally. However, in the ions $W^{35+}-W^{37+}$ at $N = 1-3$ the spectrum changes its character: the intensive lines are distributed in a considerably wider interval [14, 15].

At $N = 4-9$ the $4d_{1/2}^4$ subshell is closed, thus only the excitations $4p_{3/2} \rightarrow 4d_{5/2}$ are possible. Due to the strong mixing of both excited configurations all total line strength is concentrated in the narrow group of several intensive lines near 5 nm, its width does not exceed 0.09 nm, while all interval of weak lines takes up to 3-10 nm. At $q = 35$ and higher ionization stages of tungsten, the $4d_{3/2}^N$ subshell becomes open. Then the excitations to this subshell from $4p_{1/2}^2$ and $4p_{3/2}^4$ subshells are also permitted. Rather strong lines of transitions $4p_{1/2} \rightarrow 4d_{3/2}$ are lying on the small-wavelength side of the transitions 4d-4f and their quenching does not take place. This is the reason for the essential widening of the distribution of the line strength.

The emission spectra of tungsten ions $W^{29+}-W^{34+}$, excited from the ground level, are obtained to be very similar to the excitation spectra from this level. Such similarity appears due to transitions from or to the ground level are more influenced by SEOS correlations than the other transitions.

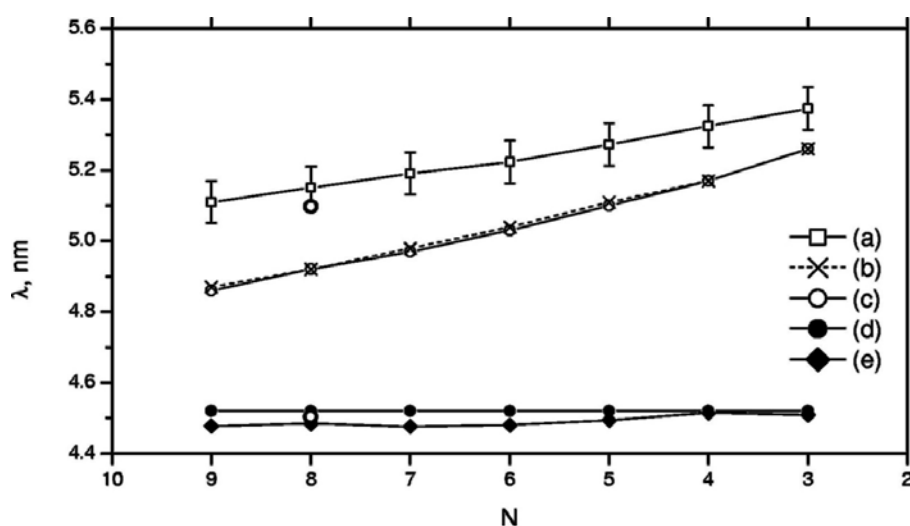
Besides the intensive quasicontinuum band the emission spectra of considered tungsten ions obtained in EBIT also contain the line with almost constant wavelength 4.5 nm. For its interpretation we have performed the CI calculation including additional configurations with one excited 5s electron. The narrow group of lines containing one more intense line with the wavelength very close to 4.5 nm appears indeed in the emission spectra of all ions $W^{29+}-W^{34+}$. The mixing among the configurations with 5s electron and the mixing without 5s electron is rather weak. Thus the lines at 4.5 nm correspond to the subarray of transitions with one spectator 5s electron. These lines are also concentrated in a narrow interval due to the strong mixing of initial

configurations $4p^5 4d^N 5s$ and $4p^6 4d^{N-2} 4f 5s$. One more group of lines appears additionally in the region of 2 nm, it corresponds to the 5s-4p transitions. Such lines are situated beyond the spectral interval which was registered in EBIT experiment.

In order to investigate the influence of other correlations on the considered emission spectra we have performed extended calculations for one of the ions W^{30+} taking into account ten additional configurations. The quasicontinuum band is shifted to the shorter wavelength side, but its shape and width remain very similar to the result obtained for the smaller set of configurations.

The emission spectra obtained on EBIT contain a background and are not well resolved. Thus only the average wavelength of the intensive group of lines can be compared with the position of the quasicontinuum band in the experimental spectrum. Calculated in the ground level approximation the position of this band practically coincides with the result calculated in the collisional-radiative model [14] (Figure 3.2). The average wavelength of the narrow group of satellite lines at 4.5 nm also corresponds well to its experimental values.

In non-relativistic approximation, the calculations of energy spectra of highly charged tungsten ions with filling 4d-shell [19] reveal that the task of obtaining the characteristics of resonant transitions with account of relativistic and correlation effects will not be very complicated since only two excited configurations $4s^2 4p^5 4d^{N+1}$, $4s^2 4p^6 4d^{N-1} 4f$ are strongly interacting. The emission band of the resonant transitions intersects with the multiplex emission lines, which correspond to the transitions from the excited configurations of the same parity as the ground one to the mentioned two configurations. It will be essentially more difficult to obtain the transition characteristics in this case since the initial configurations form the group with very large number of levels. The energies of these levels lie within the narrow interval. This creates extreme correlation effects, which reveal themselves so, that the investigated levels can not be unambiguously assigned to the particular configuration. The precision of the calculation of corresponding matrix elements influences the interaction of the energetically close levels. The correct account of the relativistic effects makes significant differences in the accuracy of the mentioned matrix elements.



Quasicontinuum band: (a) experiment [14] (b) calculation using the collisional-radiative model [14], (c) calculations in the relativistic CI approximation (3). Satellite line: (d) experiment [14], (e) calculations in the relativistic CI approximation. The points near (b) and (d) curves for W^{30+} present the results of the extended calculation with the additional ten configurations.

Figure 3.2. Comparison of the average wavelengths of quasicontinuum band and satellite line in the experimental spectra of tungsten ions with the results of calculations

3.3 Relativistic electron-ion scattering calculation

In order to obtain emission-line spectra or energy losses of plasma impurities, one needs to solve the balance equation, which determines level populations for the ions of the different ionization stages. On its turn, the balance equation requires a detailed knowledge of the accurate atomic parameters, describing atomic structure (energy levels, radiative transition probabilities, and Auger transition rates) and photon or charged particle scattering from ionized atoms.

One of the most accurate and suitable technique to solve the scattering problem is the R-matrix method. However, those calculations are large and extremely time-consuming if performed in the relativistic coupling with the Dirac-Fock R-matrix method employed because the accuracy of results depends on the number of target levels included (which is significantly larger comparing to a non-relativistic *LS*-term case). The methods based on transformation of *S*- and *K*-matrices, calculated in the pure *LS*-coupling, to intermediate coupling can help to overcome the problem because the number of terms is smaller than the number of corresponding levels making these terms.

On the other hand, only the non-relativistic wave functions are used in the *LS*-coupling. This kind of approximation becomes unsuitable and unsustainable when one has to deal with the highly-charged heavy ions, where it is extremely important to use the relativistic wave functions. Therefore, our developed approach based on the analogues of the relativistic integrals enables one to include relativistic wave functions obtained in the Dirac-Fock approximation.

The goal of the research is the assessment of different methods to implement the relativistic R-matrix approach in the calculation of atomic data for electron scattering from the highly-charged tungsten ions and the estimation of the importance of correlation and relativistic effects. The collision strengths and the effective collision strengths for the electron-impact excitation of the relativistic levels of the configurations with the electron in the outer 4p, 4d, 4f, 5s, 5p, 5d, 5f, 5g, 6s, 6p, 6d, 6f, 6g shells from the ground state $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s$ ($J = 1/2$) and from some levels of the $n = 4$ configurations of the W^{45+} ion are being determined by the use of different approaches to include the relativistic effects.

One of the ways to assess the accuracy of the computed wave functions is to compare calculated energy levels with other theoretical data and existing experimental results. In the first phase of the current project, we have compared the energies of the W^{45+} ion levels obtained in our calculations with the existing experimental data and with available theoretical calculations, which employ a different approach. We have performed calculations with well-established and widely recognised relativistic atomic-structure package GRASP using different numbers of configurations in the CI expansion of wave function. Similarly, we have performed calculations with another relativistic code FAC, which employs a different type of radial orbitals. Using above described technique to evaluate the accuracy of our theoretical data, it was established that we have managed to achieve a good agreement with the experimental data, allowing us to make the assumption that our data have the required accuracy. Therefore we can assume that we have established the CI wave function basis to be employed in further calculation of electron-ion scattering data.

To go ahead with the proposed electron-ion scattering calculations, the non-relativistic R-matrix code that uses the relativistic analogues of integrals is extended for the general case, allowing to apply it for the configurations and the ions under consideration. Electron-impact collision strengths are being calculated in the relativistic distorted-wave approximation using FAC suite of codes. This provides us with non-resonant scattering data for further comparison. Furthermore, the relativistic R-matrix calculations employing the regular scattering codes from the DARC program are in

progress. These data will serve as a benchmark point for the comparison with the data, obtained from the non-relativistic R-matrix method based on the multichannel quantum defect theory and intermediate coupling frame transformation with the non-relativistic interaction integrals replaced by their relativistic versions. Based on data comparison, we are going to prepare a research paper discussing the possibilities to calculate electron-impact collision strengths using this newly developed method.

The systematic calculations of the spectra of these tungsten ions [24, 25] have been also performed using the relativistic configuration interaction method. It is shown that spectra calculated taking into account only excitations from the ground level agree fairly well with the results obtained in the collisional-radiative model. The essential change of the width of intensive group of lines on going from W^{35+} to W^{34+} has been explained by the filling up the $4d_{3/2}^N$ subshell. Taking the 4p-5s excitations into account as well as including the configurations with one excited 5s electron to the used configurations basis enable us to interpret the line at 4.5 nm and to predict the other narrow group of lines at 2 nm. It is shown that the inclusion of the interaction with other energetically neighbouring configurations insignificantly influences the distribution of intensity in the spectrum.

4 THE ACTIVITIES UNDER COST SHARING ACTIONS

4.1 Hydrogen deflagration/detonation analyses in ITER HNB (Heating Neutral Beam) and DNB (Diagnostic Neutral Beam) -boxes and cryopumps following a LOVA

The project "Hydrogen deflagration/detonation analyses in ITER HNB (Heating Neutral Beam) and DNB (Diagnostic Neutral Beam) -boxes and cryopumps following a LOVA" (project acronym FU06-CT-2005-00016) was completed by LEI staff in the beginning of 2007. The objective of the project was to perform the analysis of hydrogen distribution and assess the potential safety hazard of hydrogen releases for the complex ITER geometry. The gas mixing in the isolated HNB-/ DNB-boxes and torus cryopumps of ITER in case of loss-of-vacuum accidents is analysed using COCOSYS code. The performed analysis proved that combustible hydrogen-air mixtures can develop in the analysed ITER components during LOVA scenario because the air ingress leads to desorption of hydrogen from the cryo-panels. Explosive hydrogen concentrations could be reached only in case of slow pressurisation accident scenario (pressurisation rate is 1.5 mbar/s). The detonation is possible in each of the analysed ITER component. The calculated maximum detonation pressures and other results are in agreement with the results available from analysis performed by FZK using 3D code GASFLOW. A significant temperature effect on the timing when the hydrogen is well mixed by the inflowing air was observed. Considering the received results it is concluded that it is very important to have the temperatures of gases and structures to be used in the accident analyses specified in the design documentation of ITER. Having these temperatures the calculations should be repeated to assess the possible detonation loads in more detail. More detailed information regarding the results of this project was provided in the presentation under the point 6.1 of the agenda.

The final meeting of this project with EFDA and FZK experts was held on 13 February 2007. As it was pointed in this meeting, for any further possible study, the formal process for associations to contribute to EFDA tasks consists in applying to a call for interest.

4.2 Characterisation of W-Coatings for Fusion Applications

The goal of the research is the fabrication of W films to be used in plasma-facing components in fusion devices, and the understanding of the mechanism of physical phenomena initiating modifications of mechanical properties of W-based thin films on carbon based substrates under high-flux, low-energy H^+ ions irradiation in the range of temperatures up to 1000 °C.

The work has shown that it is possible to produce 3–7 μm -thick tungsten films which adhere well to the stainless steel substrate and demonstrate the improved wear resistance properties. The films were fabricated employing DC magnetron sputtering technique under high-flux, low-energy Ar ion irradiation. The optimum parameters: Ar working gas pressure – 0.4–0.6 Pa, bias voltage – (80–100) V, deposition rate – 6–8 nm/s, substrate temperature – 110 °C, distance target-substrate – 4 cm, magnetron

discharge current – 200 mA, magnetron discharge voltage – 300 V, ratio of fluxes of incident ions to neutrals – 0.2–0.4. An attempt to explain the observed improvements of film mechanical properties has been made. The assumption is made that under high-flux, low-energy ion irradiation when ratio of fluxes of incident ions to neutrals, F_i/F_n , is approximately 0.2–0.4 the dominant processes inducing restructuring of growing film are related to enhancement of relocation of W film surface atoms and their continuous mixing with arriving W atoms. When $F_i/F_n < 0.2$ the role of ion irradiation induced mixing diminishes, and the ion irradiation effects are mainly related to primary ion interaction effects. The work was performed under the Cost-Sharing Actions Contract.

5 THE ACTIVITIES IN THE FIELD OF SOCIO-ECONOMIC STUDIES

This work is intended to contribute to the development of the EFDA word energy model for the evaluation of effectiveness of nuclear fusion plants and evaluation of their economic effectiveness in the Baltic region.

Preliminary discussions with the EFDA experts have shown that the structural changes are needed in the existing EFDA-TIMES module, representing the Former Soviet Union (FSU), and Eastern European Union (EEU) regions. In particular, there is a need for separation of new EU member countries from the TIMES module, representing the Former Soviet Union and their integration into EEU module. Collection of information representing energy sector of the Baltic countries (Estonia, Latvia, and Lithuania), as well as preparation of mathematical model for energy systems of the Baltic countries and evaluation of economic efficiency of fusion power plants for satisfying energy demand of the region was planned to be performed by the LEI experts. These tasks are in line with general objectives of the development and exploitation of the EFDA-TIMES model that are presented below:

- to develop consistent long-term energy scenarios containing fusion as a sustainable energy option and showing the potential benefits of fusion power as an emission free energy source, (LEI can contribute in preparation of energy models for East European countries and countries of FSU)
- to gain visibility, credibility and recognition by contributing with these scenarios to the international scientific energy debate,
- to bring the fusion option into other long-term energy models, by making available the latest technical, economic and environmental dataset on future fusion power plants, (LEI can perform regional studies, e.g. for the Baltic states, Poland, Belarus, Kaliningrad region of Russian Federation and others);
- to explore the conditions that make fusion a successful contributor to sustainable energy systems (LEI can perform this on regional scale);
- to provide domestic and European decision makers, by making use of EFDA-TIMES, with analyses and arguments in support of the potential benefits of ITER and longer term fusion R&D,

During 21–25 January, 2007 under the topic “5.3 Socio-economic studies” Mr. D. Tarvydas visited EFDA-CSU at Max-Planck-Institut fuer Plasmaphysik in Garching, Germany. During this visit Mr. D. Tarvydas took participation in the training on the EFDA-TIMES model.

However, the activity has not started because EFDA postponed research in this field. In the case, the above mentioned activities will become relevant in the future LEI will be expecting the initiative from the project co-ordinators.

6 TRAINING, EDUCATION AND PUBLIC INFORMATION

All information regarding industry possibilities to be involved in the EURATOM Fusion programme is distributed to the Lithuanian industry representatives.

The implementation of QA system is one of the most important topics in the Euratom FUSION programme. Dr. V. Vileiniškis took participation in the QA meeting with Associations in the EFDA CSU Barcelona on 10–13 June 2007.

A series of lectures “International thermonuclear reactor ITER – perspectives for energy” were held for scientists and students at the Institute for Theoretical Physics and Astronomy (VU ITPA) in Vilnius on 26-30 March 2007. The lectures were provided by the scientists of VU ITPA (A. Kupliauskienė, R. Kisielius, P. Serapinas), LEI (S. Rimkevičius, E. Urbonavičius), VDU (L. Pranevičius) and invited foreign lecturers H. Summers (JET, UKAEA), N. Badnell, J. Ongena (Strathclyde University, UK), D. Naujoks (IPP Germany), B.E.J. Pagel (UK), L. Csernai (Sweden).

H. Summers
(JET, UKAEA)



Dr. J. Ongena
(EFDA)

Exhibitions and communication to public

- Physics department of Vytautas Magnus University, Kaunas, Lithuania distributed brochures on ITER in national language to physics teachers of Lithuanian secondary schools.



- 14th March 2007. Brochures on ITER in national language were distributed to students during “Carrier days” at Kaunas University of Technology, Kaunas, Lithuania.



- 4-5th May 2007. In the 5th International Exposition “Kaunas 2007”, Kaunas, Lithuania brochures on ITER in national language were presented for the public.

7 MOBILITY PROGRAM 2007

In the first half of year 2007, the following visits were implemented under the mobility plan:

Dr. Liudas Pranevičius took participation in the 8th meeting of the ITPA Div-SOL TG, which was held on May 7–10, 2007 in Garching, Germany.

Dr. Liudas Pranevičius took participation in the Task Force PWI 2007 General meeting, which was held on October 27–November 2, 2007 in Madrid, Spain.

Two weeks visit of Dr. E. Urbonavičius and Dr. G. Dundulis (LEI) to Max-Planck-Institut fuer Plasmaphysik, Greifswald was implemented on September 3–15, 2007 in order to discuss and detail the scope of the collaborative actions in the field of the thermal-hydraulic analysis. The specific co-operation topics were defined during the visit of LEI researchers at the IPP. It was decided during this meeting to continue the analysis of technical information in co-operation with IPP and prepare for the development of the models for RELAP5 and COCOSYS codes. During year 2007 LEI will agree with IPP on the data required for the development of models of W7-X systems and components. IPP will provide the necessary technical information for LEI in order to prepare for the model development and performance of agreed calculations in 2008.

The co-operation of LEI and IPP in system and functional analysis of the main components of W7-X (risk, hazard and reliability analysis) is also planned and will be discussed in detail during visit of Prof. Juozas Augutis to IPP on 13–15 September, 2007.

These Collaborative Actions are reflected in the “Work plan 2008–2010” within the topic “Fusion Safety Issues”. The following activities are planned within these Collaborative Actions:

- Static and Dynamic Structural integrity analysis of Complex Components of the W7-X device and its main components during normal operation and failure events;
- Thermal-hydraulic analysis during normal operation and failure events;
- Systems safety analysis (incl. complex systems as well as passive and active safety components and their installation).

8 PUBLICATIONS

- 8.1. Bogdanovich P., Rancova O., Adjustment of the quasirelativistic equations for p-electrons // *Phys. Rev. A*, 76, 012507, 2007.
- 8.2. Jonauskas V, Kučas S and Karazija R, On the interpretation of the intensive emission of tungsten ions at about 5 nm // *J. Phys. B: At. Mol. Opt. Phys.* 40 2179, 2007.
- 8.3. Kučas S., Jonauskas V., Karazija R., and Momkauskaitė A., Intensity concentration in the emission spectra of Sb, Sn, and W ions due to the mixing of configurations with symmetric exchange of symmetry // *Lithuanian Journal of Physics*, 40, 249, 2007.
- 8.4. Bogdanovich P., Karpuškieñė R., Theoretical investigation of energy spectra of tungsten ions W²⁹⁺-W³⁴⁺ // *Lithuanian Journal of Physics*, 47, p. 151, 2007.
- 8.5. Pranevičius L., Integration of Lithuanian science to the European Research on FUSION energy, *Lithuanian Journal "Mokslas ir gyvenimas" ("Science and life")*, No. 6, 2007.
- 8.6. "FUSION energy – from dreams to reality by G. Kriščiukaitienė in Lithuanian popular science journal "Mokslas ir technika" ("Science and Technology") ISSN 0134-3165, 2007, No. 5, p. 34.

9 REFERENCES

1. Naujoks D., Initial and Boundary Conditions, 1-NBF-T0008.0, Max-Planck-Institut für Plasma Physik, 2006.
2. Urbonavičius E., Naujoks D., Minutes of Meeting between IPP and LEI, Max-Planck-Institut für Plasmaphysik, LEI-IPP Co-operation, 1-NBF-C0010.0, IPP Greifswald, September 3–14, 2007.
3. Fletcher, C.D., et. al., 1992. RELAP5/MOD3 code manual user's guidelines. Idaho National Engineering Lab., NUREG/CR-5535.
4. Klein-Hessling W. et. al., COCOSYS V1.2 Program Reference Manual, GRS-P-3/2, Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, 2000.
5. ASTEC V1.3 rev0 Users Manuals (modules CESAR, DIVA, ELSA, SOPHAEROS and SYSINT).
6. Krieger K., Geier A., Gong B., Maier H., Neu R., Rohde V., and ASDEX Upgrade Team 2003 *J. Nucl. Mater.* 313-316 327.
7. Pütterich T., Neu R., Dux R., Kallenbach A., Fuchs C., OMullane M., Whiteford A., Summers H. P., and ASDEX Upgrade Team 2004 *31st EPS Conference on Plasma Phys. ECA 28*.
8. Finkenthal M., Huang L. K., Lippmann S., Moos H. W., Mandelbaum P., Schwob J. L., and Klapisch M., 1988 *Phys. Lett. A* 127 255.
9. Mandelbaum P., Schwob J. L., Finkenthal M., and Klapisch M., 1988 *J. Physique* 49 217.
10. Elliott S. R., Beiersdorfer P., MacGowan B. J., and Nilsen J., 1995 *Phys. Rev. A* 52 2689.
11. Fournier K. B., 1998 *At. Data Nucl. Data Tables* 68 1.
12. Neu R., Fournier K. B., Bolshukhin D., and Dux R., 2001 *Physica Scripta* T92 307.
13. Hutton R., Zou Y., Reyna Almandos J., Biedermann C., Radtke R., Greier A., and Neu R., 2003 *Nucl. Instr. and Meth. B* 205 114.
14. Radtke R., Biedermann C., Schwob J. L., Mandelbaum P., and Doron R., 2001 *Phys. Rev. A* 64 012720.
15. Biedermann C., Radtke R., Schwob J. L., Mandelbaum P., Doron R., Fuchs T., and Fußmann G., 2001 *Physica Scripta* T92 85.
16. Pütterich T., Neu R., Biedermann C., Radtke R., and ASDEX Upgrade Team 2005 *J. Phys. B: At. Mol. Opt. Phys* 38 3071.
17. Bogdanovich P., 2004 *Lith. J. Phys.* 44 135.
18. Grant I. P., McKenzie B. J., Norrington P. H., Mayers D. F., and Pyper N. C., 1980 *Comput. Phys. Comm.* 21 207.
19. Bogdanovich P., and Karpuškienė R., 2007 *Lithuan. J. Phys.* 47 151.
20. Beck D. R., and Nicolaidis C. A., 1976 *Int.J. Quantum Chem.* S10 119.
21. Karazija R., 1996 *Introduction to The Theory of X-Ray and Electronic Spectra of Free Atoms* (London , New York: Plenum Press).
22. O'Sullivan G., and Carroll P. K., 1981 *J. Opt. Soc. Am.* 71 227.
23. Bar-Shalom A., Klapisch M., and Oreg J., 2001 *J. Quant. Spectrosc. Radiat. Transfer* 71 169.
24. Jonauskas V., Kučas S., Karazija R., 2007 *J. Phys. B: Atom. Mol. Opt. Phys.* 40 2179.
25. Kučas S., Jonauskas V., Karazija R., and Momkauskaitė A., 2007 *Lithuan. J. Phys.* 47 249.

