3 Fusion Technology

The technology activity includes 9 tasks. The tasks are grouped under the five following sub-headings:

- Tritium inventory and waste recycling. Fusion safety issues
    - In-situ laser detritiation automated by the LIBS diagnostics as a feedback control. Laser diagnostics of in-vessel components and dust generated during detritiation process (JET FT task)
    - Calculation of the activation and the decay heat of the components – classification of the wastes
- Development of material science and advanced materials for DEMO
    - FGM W-Cu composites and W-Cu/W joints fabrication route based on pulse plasma sintering (PPS) method
    - Applications of hydrostatic extrusion for particles and grains size refinement in materials relevant to the fusion technologies
- Contribution to the project W7-X
    - Numerical analysis and evaluation of the structural mechanical behaviour of central support connections under electromagnetic forces for W7-X
    - 10MW neutral beam injection heating system development
    - 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
- Contribution to ITER (former Art. 5.1b contract / present F4E grant)
    - Nuclear data: benchmark experiments to validate EFF/EAF data. Measurements of the tritium production with the use of Thermo-Luminescence Detectors (TLD) in the neutronics HCLL TBM mockup
- Socio-Economic Research (former Art. 5.1b contract)
    - Communication quality and lay understanding of fusion technology: a quasi-experimental study of message formulation effects on attitude change

Tritium inventory and waste recycling. Fusion safety issues

3.1 In-situ laser detritiation automated by the LIBS diagnostics as a feedback control. Laser diagnostics of in-vessel components and dust generated during detritiation process

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Abstract

Development of methods for fuel removal and decomposition of co-deposited layers from plasma-facing components which is an urgent and necessary step to control and mitigate tritium inventory in next-step devices is still not completely solved. To control this process LIBS (Laser Induced Breakdown Spectroscopy) has been proposed as a candidate method. Moreover it has been shown that this method may be used as diagnostics of the wall erosion and composition and dust behavior.

At the IPPLM both laser removal and LIBS have been combined and applied for investigation of graphite and mixed materials samples of tokamak plasma-facing components provided by collaborating associations.

Sumary

In 2008 the experiments were mainly focused on expanding possibilities of spectroscopic measurements. With the new Mechelle 5000 spectrometer there were a series of experiments performed both for in-vessel tokamak components and for non-tokamak metallic and mineral targets. The main subject of analysis consisted limiter samples from TEXTOR covered with a thick co-deposit and mixed material samples from ASDEX which contained thin codeposit on tungsten layers. Together with ion analysis the spectroscopic investigation confirmed ability to detect fuel particles even if they were released in small amounts resulted from thin layers (Figure 1) and its efficiency in characterizing the removal process of thick codeposites from TEXTOR (Figure 2).

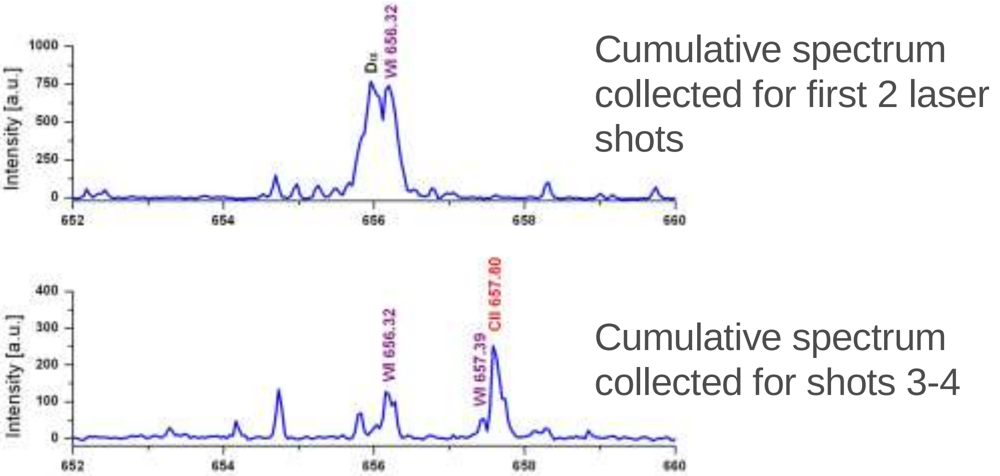

Figure 1 Evolution of spectra of a AUG sample during first 4 laser shots – presence of deuterium line is clearly visible for the first 2 shots.

The measurements not only allowed to measure overall spectra integrated over the whole life-time of laser generated plasma but to trace subsequent stages of plasma formation and quench. In case of TEXTOR sample patterns of the evolution of intensity of deuterium line during subsequent laser shots which corresponded to the amount of fuel particles at depth under investigations have been recorded. The results indicated that most of the fuel inventory was released during first 5-7 shots and after a series of 20-50 shots (depending on the focussing regime) a whole layer of co-deposit could be removed. For ASDEX samples the co-deposited layer appeared to be very thin and were completely removed during first 2 laser shots.

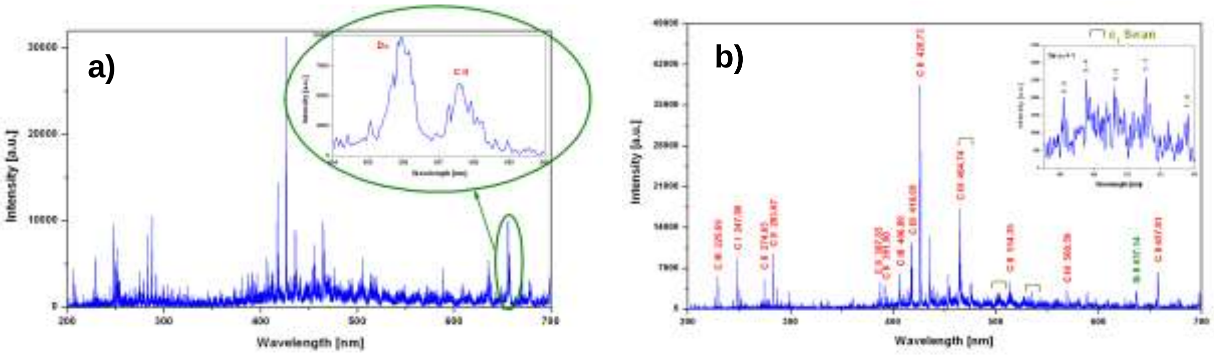

Figure 2 a) a sample spectrum obtained for virgin codeposit with highlighed deuterium line b) a spectrum of a cleaned surface

The results of spectroscopy were confirmed by application of an Electrostatic Ion Energy Analizer (IEA) which allowed to observe the evolution of amounts of deuterium ions. The evolution was consistent with the one observed while doing optical spectroscopy.

The important part of the experiments were aimed on characterization of dust generated during the removal process. Different types of dust catchers have been developed and applied. The collected dust was subjected to the material research analysis at collaborating laboratories. Analysis of macroscopic dust was performed at Alfven Lab by means of NRA method. It detected significant amounts of deuterium in macroscopic dust particles generated from the co-deposit during the experiment at IPPLM; however; the amounts were considerably lover than that which were observed for original co-deposit. Microscopic particles were collected on special grids and were subject to TEM analysis performed at FZJ Juelich. The investigation resulted in characterization the particles as amorphous and semi-crystaline which composition hasn’t show any considerable traces of fuel.

Conclusions

The spectroscopy was confirmed as a convenient diagnostics method for the ablative laser removal as its indications are fully consistent with post-mortem analyses. There are also foreseen experiments which are to check if spectroscopic measures may allow for quantitative analysis of amounts of fuel being released during the process. The analysis of fine deposits on catcher walls proves that some deuterated species released from the target condense on adjacent surfaces.

A fraction of fuel still remains also in dust particles generated by the laser. Precise fuel balance in all products of co-deposit disintegration is still a challenging task to accomplish, but it becomes evident that photonic cleaning may lead to redistribution of fuel to surrounding areas. Thus dust generation and condensation of desorbed fuel species should be taken into account when developing methods for co-deposit and fuel removal from a reactor-class device. Condensation of hydrocarbons may be an issue if carbon-based wall tiles are applied. One may also suggest that dust production accompanying the cleaning process is necessary regardless of the amounts of fuel which it would still contain, because it is easier to release fuel (tritium) from collected dust than to deal with whole tiles of actively-cooled wall components.

Collaboration

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3.2 Calculation of the activation and the decay heat of the components – classification of the wastes

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Abstract

An estimation and characterisation of the life-time induced activity in fusion reactor is the base of classification of the used materials in view of radiotoxicity. The respective quantitative characteristics are: Clearance Index, (CI) deciding of the clearance of materials, the Contact Dose (CD) mainly determining the feasibility of recycling and the Heating Rate (HR) from its radioactive decay responsible for the difficulties of disposal. The present study has laid in evaluation of the above characteristics of DEMO waste, searching, among others their time behaviour and significance of particular nuclides. These calculations of induced activity in the DEMO system brought about valuable results, e.g. indicating sometimes the dominant contribution of very rare reactions or nuclides within hundreds years of decay. Finally, the evolutions of the waste material categorisation and mass balance vs. time are given.

Summary

In view of the problems with social acceptance, limited burial facilities in the EU and foreseeable scarcity of materials an optimum management of those used in fusion installations has to be developed. Importance of this issue is due to the fact that high material inventory and consumption will strongly influence the economy of fusion power. Solution of this problem requires first a reliable estimation and characterisation of the life-time induced activity in fusion reactor that will allow, first of all, for the classification of the used materials from the point of view of their radiotoxicity. The respective quantitative characteristics are: Clearance Index, (CI) deciding of the clearance of materials, the Contact Dose (CD) mainly determining the feasibility of recycling and the Heating Rate (HR) from its radioactive decay responsible for the difficulties of disposal. The above mentioned parameters of DEMO waste: CI, CD and HR have been evaluated in hundreds cells of the DEMO model and their time evolution within time intervals 0 ÷ 100 or sometimes 0 ÷ 1000 years. The evaluations of induced activity in the DEMO system brought about interesting results. Sometimes the contribution of very rare reactions or nuclides proved dominant already within about 100 years. Since the CI is a measure of material activity (that is independent of associated energy) the behaviour of decay heating is not necessarily identical with the one of CI. As a result one can observe rather different trajectories vs. time of the above parameters. The heating within the 30 years interval increases less and after these 30 years drops more (ca. 4 orders of magnitude) than the Clearance Index. The induced activity, obviously, strictly depends also on the operation of the reactor, determined in turn, first of all by availability of the i.e. random failures on one hand and planned interruptions – on the other. Thus, a schedule of breaks in reactor operation has been assumed: once per year but of pertinent length and the time horizon 30 years long reflecting the gradually increasing availability (10%, 33%, 50%) in successive decades.

The performed FISPACT calculations, provided the origin of induced activity, or more exactly - of produced radionuclides i.e. the reactions and/or processes e.g. decays leading to their generation in the system. On that basis one could conclude that in most cases there are few processes (frequently only one dominant reaction, sometimes coupled with a decay) leading to the birth of given radionuclide.

Finally, the evolutions of the waste material categorisation vs. time have been analysed. In this item the significance of trace elements as affecting significantly the proportion between particular categories of waste has been confirmed. Namely the amount of ILW proves larger while that of LLW – lesser.

Then it has been observed that already half century after the reactor closure, there is no High Level Waste whereas after next 50 years the proportions between the LLW and ILW are more than reversed. The ILW nearly disappears the amount of LLW is about to double similarly like the volume cleared. Quantitatively has been estimated that after ca. 70 years the bulk of materials can be rather easily recycled. Already after ca. 50 years well over 13 000 t achieve level 1 and next in short - similar quantity can be qualified to the level 2 whereas only ca 4000 t remain at the level 3 and nothing belongs to the worst 4 category.

The mentioned in the introductory chapters of the present study material recycling (in view of expected reduction in consumption of materials, thus also a cost reduction of fusion) is described as one of key factors in the strategy for the fusion. However, the final concept of material management and respective proceedings would require first a thorough economical analysis. Such studies have to take into consideration the very basic trade-off: higher consumption of fresh materials and such the respective storage after use vs. lesser consumption of fresh materials and then easier storage of the used ones, but at much more difficult and costly dealing with (fabrication: melting, rolling, machining etc.) radioactive materials. This question as lying beyond the scope of the present study was not further discussed here, but certainly requires attention and should be undertaken in future investigations.

The most important is the final material balance. It is presented here in one example of a number of diagrams (Fig. 1) below.

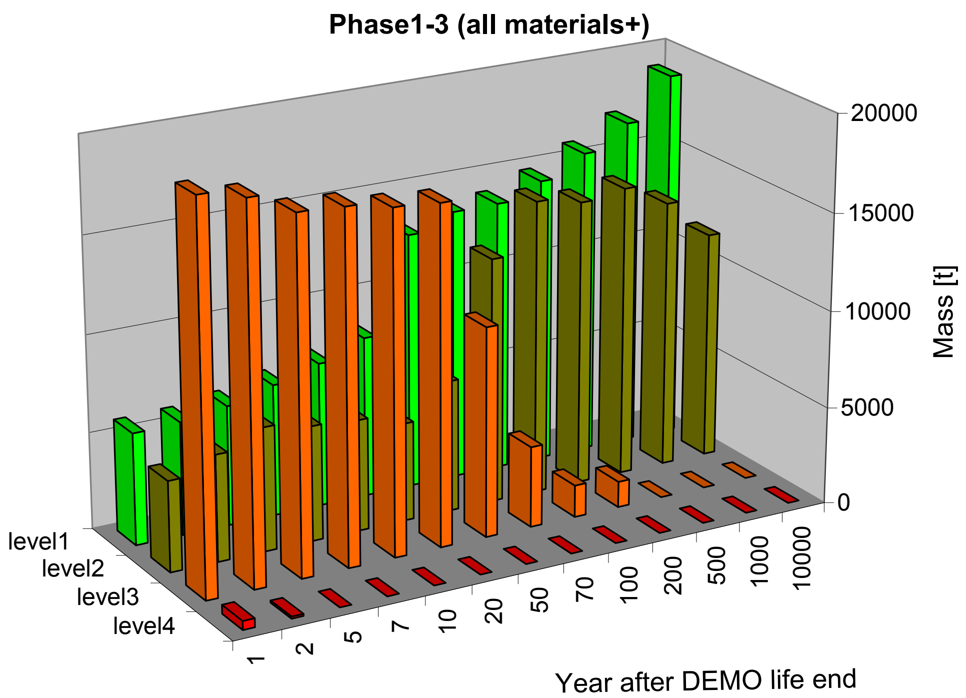

Figure 1. Classification of all materials for recycling vs. time.

Conclusions

In the introduction the material recycling (in view of expected reduction in consumption of materials, thus also a cost reduction of fusion) is described as one of key factors in the strategy for the fusion. However, final concept of material management and respective proceedings would require first a thorough economical analysis. Such studies have to take into consideration the basic trade-off: higher consumption of fresh materials and such the respective storage after use vs. lesser consumption of fresh materials and then easier storage of the used ones, but at much more difficult and costly dealing with (fabrication: melting, rolling, machining etc.) radioactive materials. Yet, this question as lying beyond the scope of the present study was not further discussed here.

Collaboration
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Development of material science and advanced materials for DEMO

3.3 FGM W-Cu composites and W-Cu /W joints fabrication route based on pulse plasma sintering (PPS) method

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Abstract

W/Eurofer steel joints were produced by pulse plasma sintering method. Three different materials were tested as transition layers which are designed to decrease the thermal stresses. The microstructure of joints and interlayers were examined in terms of optimizing the proposed technological route.

Summary

W/Eurofer steel joints were produced by pulse plasma sintering method. Three different materials were tested as a transition layer selected to decrease the thermal stresses. The microstructure of joints and materials used as interlayers were examined. The materials were selected to ensure good wettability of the interlayer materials with tungsten and steel and intermediate value of CTEs (in the comparison to steel and tungsten). The joints were produced using a PPS apparatus, constructed at the Faculty of Materials Science and Engineering, Warsaw University of Technology.

W/W+40vol.%Cu/steel joints

Utilizing the experience gained in the fabrication of the W/WCu joints the conditions for joints production were established. The process parameters are given in Table 1.

Table 1. Process parameters in sintering of the steel/W+Cu/W joints

Process parameters	Stage I	Stage II
Temperature [°C]	150	900
Duration of the individual process stages [s]	120	300
Charging voltage of the capacitors [kV]	2	4
Pulse repetition frequency [Hz]	1	2
Load [MPa]	15	60
Pressure [Pa]	$5 \cdot 10^{-3}$	$5 \cdot 10^{-3}$

The tungsten plate (2.5 mm thick, 12 mm diameter) was sintered with a composite material (40 vol.% of Cu) and steel plate (2.5 mm thick, 12 mm diameter). The SEM examinations of the cross-sections of the joints revealed good bonding between the composite and tungsten plate, free of pores, cracks and delaminations (Fig. 1). The composite material was fully sintered. A delamination was, however, observed at the WCu/steel interface.

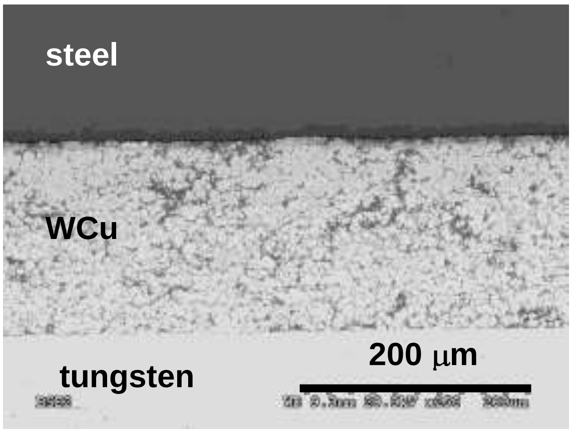

Figure 1. SEM image of the W/W+Cu composite/steel joint cross section

W/W+40vol.%Cu/Ni/steel joints

The microstructure of the W/W+40vol.%Cu/Ni/steel joint is shown in Fig. 2. No porosity was revealed in nickel and WCu interlayers. The transition regions between the individual sublayers (WCu/Ni) and between steel plate and nickel interlayer were free of cracks and delaminations. The delaminations were, however, observed at the WCu composite and tungsten plate interface.

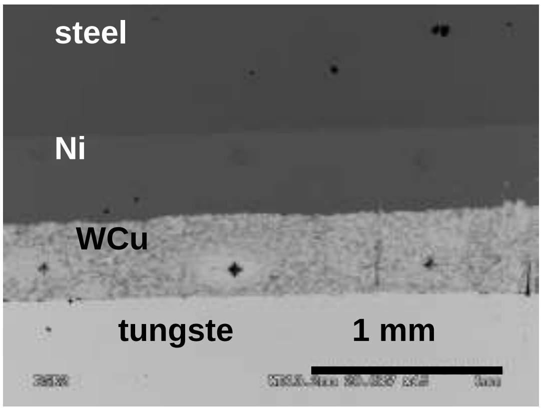

Figure 2. SEM images of the W/WCu composite/Ni/steel joint cross section

W/FeNi/steel joints

The microstructure of the W/FeNi/steel joint is shown in Fig. 3. Te transition regions between steel and FeNi50 as well as tungsten and FeNi50 interlayer were free of cracks, pores and delaminations. The porosity was, however, revealed in the interlayer material.

In order to optimize the sintering process a series of FeNi sinters were fabricated at higher temperature and/or in longer time. The density of the sinters thus produced amounted to 98-99% of the theoretical value (Tab 2).

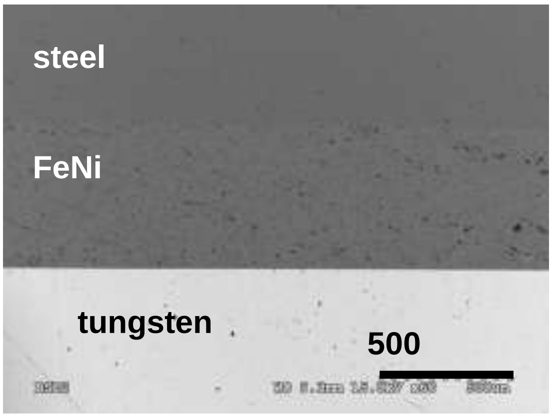

Figure 3. SEM image of the W/FeNi/steel joint cross section

Table 4. Effect of the sintering temperature and time on the density and hardness of the FeNi sinters

	Temperature [°C]	Stage II sintering time [s]	TD [%]	Hardness [HV1]
FeNi (interlayer)	900	300	-	125
FeNi_1	900	600	97.5	174
FeNi_2	950	600	98.1	173
FeNi_3	1000	600	98.6	163

Conclusions

1. The experiments have shown that the PPS can be used for the fabrication of tungsten/steel joints with different interlayers. Three interlayers were employed between steel and tungsten plates in order to decrease the thermal stresses. The joints have been fabricated with: a) W+40vol.% Cu composite, b) W+40vol.% Cu composite and Ni interlayer and c) FeNi interlayer. The W-Cu composite, nickel and FeNi were used to ensure good wettability of the interlayer materials with tungsten and steel. Intermediate value of CTE was also considered (in the comparison to steel and tungsten).

2. All fabricated joints had an acceptable strength and did not disintegrate during the sintering, handling and cutting. In the case of joint with the WCu composite interlayer microscopic observations revealed delaminations at the steel/composite interface. The cracks were also present at the tungsten/WCu transition zone in the joint with WCu+Ni interlayer. In both cases the interlayer materials (WCu composite and nickel) were fully sintered (no porosity in the interlayers was observed).
3. The W/steel joint with FeNi interlayer was characterized by good bonding between the FeNi interlayer and steel and tungsten plates. The interlayer material showed, however, porosity. The optimization of sintering parameters (time or temperature increase) resulted in fully dense interlayer.

3.4 Applications of hydrostatic extrusion for particles and grains size refinement in materials relevant to the fusion technologies

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Abstract

The aim of the present study was to describe the thermal stability of hydrostatically extruded (HE) Eurofer 97 steel and to determine factors shaping mechanical properties of this steel. Samples were hydrostatically extruded in a multi-step process with the total true strain of about 4. The results show that the HE leads to a significant grain refinement from about 400 nm to 86 nm at the same time particle size decreased from 111 nm to 75 nm and their distribution became more uniform. The mechanical behaviour (in tensile tests) of HE processed Eurofer 97 steel over the wide range of temperatures (from -196^{o}C to 600^{o}C) was compared to those of the as-received material. It is clearly visible that the ultimate tensile strength and the yield stress are higher for HE-processed samples in the whole range of temperatures. The results of microhardness measurements of the samples annealed at various temperatures have shown that the highest value of microhardness is achieved for samples annealed at 400°C - 403 HV0.2. The same applies to tensile and yield strength – their values start to decrease after the annealing at 600^{o}C. At the same time elongation increases from 3 to 15%. It can be revealed that annealing after HE at 600 and 800°C significantly improves both strength and ductility. The microstructure of samples annealed at 400°C shows the evidences of intensive recovery, which brings about a lower density of dislocations, whilst the size of grains remains unchanged. A slight increase in the mean equivalent diameter is observed in the samples annealed at 600°C (to 307 nm). After annealing at 800°C, one can observe ferrite grains of few micrometers in diameter which contain laths of martensite.

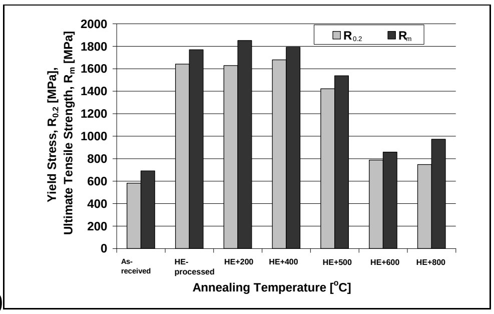
Summary

Reduced activation ferritic-martensitic steel Eurofer 97 is a candidate material for structural applications in ITER reactor. The properties of such a steel strongly depend on its microstructure. This, in particular, applies to the grain size which influences such properties as hardness, flow stress, toughness and creep resistance. The aim of the present work was to determine the possibility of grain size reduction in Eurofer 97 to improve its mechanical properties via processing by hydrostatic extrusion (HE).

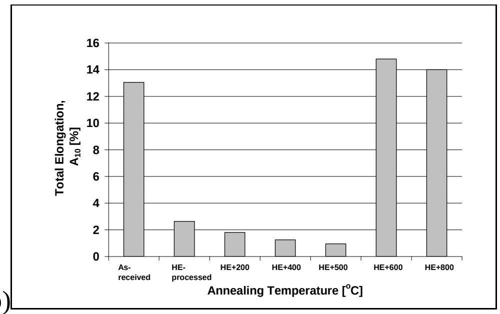
In this project, samples were hydrostatically extruded in a multi-step process with a total true strain of about 4. Microstructural changes induced by HE processing were observed using a light microscope, scanning and transmission electron microscopes. The mechanical properties were determined using an INSTRON 1115 testing machine at a strain rate of $4x10^{-4}s^{-1}$ and Charpy impact test machine. In addition, microhardness was measured under the load of 200 g.

The results show that the HE leads to a significant grain refinement from about 400 nm to 86 nm at the same time particle size decreased from 111 nm to 75 nm and their distribution became more uniform. The mechanical strength of hydrostatically extruded Eurofer 97 steel is higher over the wide range of test temperatures (from -196^{o}C to 600^{o}C) when compared to those of as-received state. However, the ductility of HE processed materials is substantially lower.

In order to determine thermal stability of HE-processed Eurofer 97 steel, the sample were annealed at various temperatures. The results of microhardness measurements have shown that the highest value of microhardness is achieved for samples annealed at 400°C - 403 HV0.2 whereas the lowest for samples annealed at 700°C - 228 HV0.2. The same applies to tensile and yield strength – their values start to decrease after the annealing at 600^{o}C (Figure 2). At the same time elongation increases from 3 to 15%.



a)



b)

Figure 2 Ultimate Tensile Stress R_m Yield Stress $R_{0,2}$ (a), Total Elongation A(b)

Table 3 Statistical parameters of grain size In He-processed Eurofer 97 steel and annealed at various temperatures

State of Eurofer 97 steel	$E(d_2)$ [nm]	$SD(d_2)$ [nm]	$CV(d_2)$	$E(d_{max}/d_2)$
HE	86	31	0,36	1,59
HE+400°C/1h	70	25	0,35	1,48
HE+600°C/1h	307	144	0,47	1,33
HE+800°C/1h	2496	1195	0,48	1,36

E – mean value
SD – standard deviation
CV – coefficient of variation

The mean size of the grains is stable below a temperature of 400°C, which well corresponds to the microhardness measurements. The microstructure of the samples annealed at this temperature reveals the consequence of intensive recovery, which brings about a lower density of dislocations, whilst the size of grains remains unchanged. A slight increase in the mean equivalent diameter (to 307 nm) is observed in the samples annealed at 600°C. After annealing at 800°C, one can observe ferrite grains of few micrometers in diameter which contain laths of martensite.

Summarising results obtained in the present study one should note that nanostructured Eurofer 97 steel obtained by HE exhibits improved strength over its conventional counterpart, however, its ductility is significantly lower. The microstructure of HE processed Eurofer 97 steel is virtually stable up to annealing temperature of 400°C – the grain size remains at a level of 80 nm. An improved combination of strength and ductility over the conventional form of EUROFER 97 steel can be achieved by annealing in the temperature range 600-800°C after HE.

Conclusions

The results obtained in the present work clearly show that Eurofer 97 steel can be processed by HE to improve mechanical properties like the yield stress and the ultimate tensile strength. The microstructure of HE processed EUROFER 97 steel is stable up to a temperature of 400°C with the grain size of 80 nm being retained. At higher temperatures, the yield stress of the nanostructured EUROFER 97 is reduced and the ductility is increased.

An improved combination of strength and ductility over the conventional form of EUROFER 97 steel can be achieved by annealing in the temperature range 600-800°C after HE.

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Contribution to the project W7-X

3.5 Numerical analysis and evaluation of the structural mechanical behaviour of central support connections under electromagnetic forces for W7-X

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Abstract

The objective of the Wendelstein 7-X (W7-X) project is construction of a stellarator which shall demonstrate that this type of reactor can be considered as future devices for energy supply. The design of the detailed coil-support connections has been a critical item for W7-X as even small deviations of the coils ideal shapes or non-symmetric alignments may cause magnetic field perturbations resulting in serious disturbance in operation of the device due to additional magnetic islands, uneven load of the divertor target plates or enhanced particle losses.

W7-X is currently under assembly in Greifswald. The major details of the design had been frozen in accordance with the ongoing component manufacture. Nevertheless, modifications to the design of CSEs are still needed and stem from assembly trials. In 2007 WUT has developed parametric models of several CSEs in order to facilitate quick analyses of possible design modifications and checks. This task has been continued in 2008 and further 5 parametric models have been delivered.

Summary

The following tasks have been performed in the scope of P9 Project in the year 2008:

- Development and testing of semi-parametric model of the Triple Connection
- Development and testing of semi-parametric model of 2 single connections
- Additional corrections and improvements of several CSE models developed in previous years

The major efforts were concentrated on the development and testing of so called semi-parametric models of the 5 CSEs (Triple Connection + 2 single ones). Those semi-parametric models enable an automated analysis of the connection and generate results in a standardized form, thus easy to compare. Each semi-parametric model of a connection consists of the ANSYS compatible database file and several macro files. It is also accompanied by a guiding document describing all macros and listing the parameters that can be altered for a given connection.

The following connections have been prepared as semi-parametric models:

- NPC2-Z2, NPC3-Z2 and NPC4-Z2 as separate connections and Triple Connection submodel
- NPC1Z2 connection
- NPC3Z1 connection

As in every FE analysis the work with semi-parametric models starts with preparation of a geometric and discretesized models of the element to be analysed – a given CSE in this project. For geometry generation a specially prepared model of the connections – so called “basic model” using parametric description of the geometry, contact interfaces behaviour, material properties and loads have been developed.

The following parameters can be altered in the pre-processor phase:

- length of the sleeves and bolts (separately defined)
- all materials properties of the three materials, including σ-ε curves (in functions of temperature)
- contact conditions for the three groups of interfaces (shim, wedges, other): gaps, contact stiffness, friction coefficients (temperature dependent)
- pretension forces in RT (individually defined)

- external forces applied (six components).

In the pre-processor phase the following four macros are used to prepare a connection model for calculations:

1. Scaling_and_Pretension.txt,
2. Change_Materials.txt,
3. Change_Contacts.txt,
4. Loads_and_Steps.txt

After executing the macros of the above list the model is ready for calculations which should be launched manually. Finally, in order to get results in standardized form the following series of macros should be executed in post-processor phase:

1. Bolts_Stress_Forces.txt,
2. Wedges_Stress_Forces.txt,
3. Shim_Displ_Stress_Forces.txt,
4. Path_Wedge_Weld_Stress.txt,
5. Path_Weld_Stress.txt,
6. Global_Results.txt.
7. Plastic_Strain.txt,
8. Wedges_Contacts.txt,

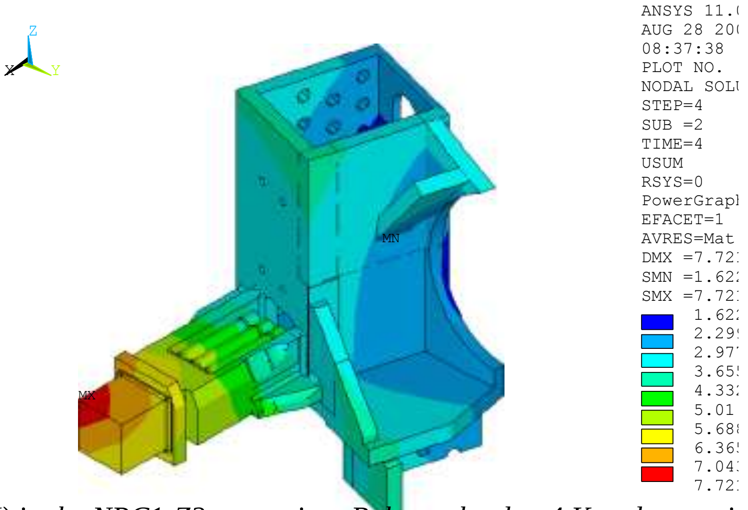
The post-processor macros provide results in standardized form for all important elements of the connections as exemplified in table and figure below.

Table. NPC1-Z2 – Load case LS(55). Bolt forces (in N)

Bolts preload at RT - step 1

BOLT FORCES OF THE NPC1-Z2 CONNECTION

Nu. bol	FX	FY	FZ
1.	489995.4	-70.5	-61.3
2.	489995.4	12.7	-57.2
3.	489995.4	75.2	-57.5
4.	489995.4	-87.7	-4.8
5.	489995.4	-2.9	-5.9
6.	489995.4	88.9	-1.5
7.	489995.4	-86.6	64.4
8.	489995.4	19.7	79.4
9.	489995.4	82.1	45.1



Displacements (USUM) in the NPC1-Z2connection; Bolts preload at 4 K and operational loads - step 4; Load case LS(45)

The semi-parametric models for the connections have been tested. The tests consisted of re-running calculations of a given connection with the same set of input parameters for semi-parametric model as used in past for the "standard" model of the connection analysed in the past. The results of both, the semi parametric and "standard", models were then compared. All 5 semi-parametric models performed well in the tests.

The parametric models of individual connections have been successfully used by IPP Greifswald for the assessment of bolt and sleeve reductions in order to avoid clashes with adjacent components, and of changes of the number and lengths of wedges. The results confirmed that the proposed modifications did not change notably the connection behaviour. Series of non-conformities concerning the planarity of the connections at the CSS back-side have been efficiently analyzed after some adaptation of the models. The obtained results highlighted those connections which required additional surface machining.

The results of this modelling work as well as previously performed tasks in the scope of EURATOM-IPPLM P9 task have been presented at SOFT2008 conference and published in special edition of Fusion Engineering and Design.

Conclusions

A useful tool – the semi-parametric model – for analysis of design changes in the 5 CSEs have been developed. With the semi-parametric models developed in 2007 the IPP Greifswald team disposes now with a complete set of parametric models for semi-automated analyses of all 14 types of connections present in W7-X. This tool have already been used by System Integration team at Greifswald for the assessment of the latest design changes resulting from the assembly trials.

Collaboration

Association EURATOM – IPP, Greifswald, Germany

3.6 10MW neutral beam injection heating system development

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Abstract

The main aim of the project is focused on the preparation of IPJ's team, equipment and premises to the manufacturing of NBI elements: magnets, separation valve, support structure and cooling system.

Summary

Manufacturing of selected elements for Neutral Beam Injectors requires thorough preparation and testing of the technology prior to construction of the items to be used in W7-X stellarator. Each piece of the technology should thus be properly designed, checked and tested using specific methods. The main aim of the project is to prepare IPJ's team, equipment and premises to this task.

The activities in 2008 can be divided into four categories. The first one deals with the preparation of IPj staff to the expected tasks. In the frames of this part of the project five persons have been trained in the use of CATIA 3D CAD system. Paralelly, the personnel become knowledgeable with the NBI design and technologies used.

The next category is related to the IPJ's infrastructure. A dedicated assembly hall has been selected and renewed. The old equipment has been cleared. The design of crane upgrade to 15 tonns has been prepared. Several, dedicated, pieces of the equipment (e.g. magnetoscope, lacking elements of the crane system) have been purchased and measurement methods implemented.

Taking into account that the size or specialized requirements make not possible the production of several parts in IPJ several subcontractors should be selected and approved by W7-X team. Among them the most important ones are: TEPRO company (production of magnet boxes and large parts of the support structures) and Tarnowskie Gory factory (design, production and assembly) of the cooling system). The companies presented their possibilities and machine parks, TEPRO company has been visited by the IPP's team who accepted them as possible subcontractors.

Finally, the most critical technologies should be tested. Among them one can list: vacuum-tight welding of ferritic with austenitic steels and welding of low-permeability steel. It has been agreed, that the first technology will be tested by making a special model chamber which includes all specificities characteristic for magnets. Such a chamber has been designed, manufactured and tested in IPP Garching with positive results. The welds on low-magnetic steels were made revealing slightly higher magnetic permeability than expected (1.07 instead of 1.05). The next attempts are currently in progress aiming the reduction of this value.

In the frames of the preparation to NBI's elements production CAD system has been installed, personnel trained and place for final assembly of NBI's elements has been prepared. Most critical parts of the technology needed were tested. Several pieces of measuring and testing equipment have been purchased.

Conclusions

The work proceeds as expected. Main risks are related to unclear situation of the financement of the next phase of the project.

Collaboration

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TEPRO Company, Koszalin, Poland

3.7 Contribution to the WENDELSTEIN 7-X stellarator assembly process

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Abstract

The Wendelstein 7-X stellarator is now being assembled at Max Planck Institute for Plasma Physic (IPP), Greifswald, Germany. In the year 2008, first of its five modules, module 5, is at the stage of assembly. Two work packages are assigned to the team of engineers and technicians from INP Krakow within the frame of the cooperation agreement: (1) preparation and assembly of so called bus bar system (superconducting cables connecting stellarator coils); (2) design of supporting frames for the outer shell elements and analysis of deformations of those parts during transport and handling. In the year 2008 all supports (holders) for bus bar system in module 5 were installed and aligned and connecting cables were prepared for final installation. Transport frames for outer shell were designed and deformations were analysed for different handling configurations.

Summary

Max Planck Institute for Plasma Physics, Garching, Germany, is constructing the stellarator Wendelstein 7-X (W7-X) at the branch institute in Greifswald. The main aim of that device is to study the behaviour of plasma in steady state conditions close to those necessary for a fusion reaction. A second very important goal of the project is to investigate whether the stellarator principle could be a desirable alternative to a tokamak on the path towards a future fusion reactor. One of the most important requirements for the reactor relevance is to demonstrate stability of the plasma confinement under steady state conditions.

The magnet system of the W7-X is capable of producing a magnetic field of up to 3 Tesla at the plasma axis for 1000 operational cycles. The system comprises 70 superconducting coils producing magnetic field in the inner plasma vessel, arranged periodically around the machine axis into five identical modules. Each individual module includes 14 coils of 7 unique types (five non-planar and two planar) attached to a 72 degree sector of the central supporting ring. The bus bars are made of the NbTi superconductor with an aluminium jacket (243 strands 0,58 mm OD twisted in 81 triplets, an outer shape of rounded square 16x16 mm2), Fig.1, and connect all ten coils of the same type in series and are fed by a current up to 18 kA from dedicated power supplies. A free space inside the Al jacket (about 37%) serves as a liquid helium cooling circuit. The bus bar is covered with multi layer isolation, two layers of kapton foil and three layers of glass fabric impregnated with epoxy resin. The layout of the stellarator coils determines the complex 3D routing of the bus-bars (Fig. 2).

The mounting of all supports/holders, Fig.2, preparation of the bus-bars ends, Fig.3, final assembly of the bus bars on the module 5, Fig.4, were the goals for year 2008.

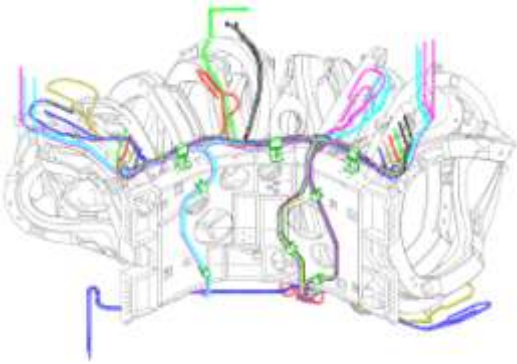

Figure 1 Bus bars on one of the W7-X module

Figure 2 Type I holders mounted on the central ring

Figure 3. Bus bars in the preparation area

Figure 4. Bus bars pre-installed on module 5

Part of the preparation for the assembly process was the design of tools used during handling, assembly and transportation of the outer vessels. Structures called TMV (Transport-und-Montageversteifung) have been designed for the purpose of using them when the lower/upper shells together with domes of modules 1, 2, 3, 4 or 5 have to be lifted with the help of a crane. The TMV structures designed for the module 5 shells were verified, in case of the remaining modules (1, 2, 3, 4) they were re-designed or modified, if necessary. The structure shown in Fig. 5 was designed for the lower shell of module 5. For each module, the deformation of the whole system (TMV and the shells together with the domes) has been checked by use of numerical calculations [1], [2], [3].

Deformation analysis was also performed in cases where the outer shells are transported from Lubmin to Greifswald by a semi-trailer. An example of calculated displacements is shown in Fig.6. Details of the deformation analysis are described in [4].

Figure 5. Lower shell of module 5 mounted on the TMV structure in Lubmin

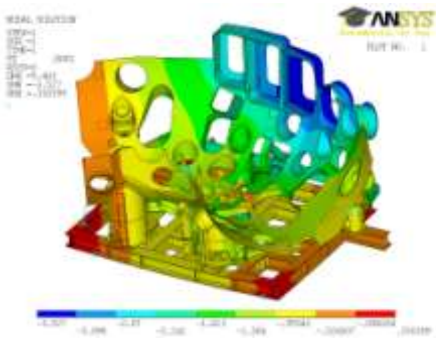

Figure 6. Vertical displacements of the transportation system with a lower shell

Conclusions

The objectives for year 2008 were:

– to become acquainted with basic documents like Working Instructions, QAAPs, qualification procedures;
– installation of the SA holders (coil current leads) on module 5;
– installation of positioning supports and preliminary installation of the bus bars;
– completion of the preparation of bus bars for module 5;
– final assembly of the bus bars on module 5;
– design of tools needed during handling, assembly and transportation of the outer shells of modules 1, 2, 3, 4.

All those objectives for the year 2008 were fulfilled.

Collaboration

Association EURATOM–IPP Greifswald, Germany

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Contribution to ITER
(former Art. 5.1b contract / present F4E grant)

3.8 Nuclear data: benchmark experiments to validate EFF/EAF data. Measurements of the tritium production with the use of Thermo-Luminescence Detectors (TLD) in the neutronics HCLL TBM mockup

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Abstract

Neutronic codes and nuclear data need to be validated in order to assure reliable results when applied in design calculations. Validation of Test Blanket Modules (TBM) design calculations is achieved through integral benchmark experiments where mock-ups are irradiated with 14 MeV neutrons and nuclear responses of interest are measured and compared to calculations, which closely simulate the experimental set-up. Very important one is the tritium production rate (TPR) crucial for the thermonuclear reactor proper functioning. Here the use of the Thermo-Luminescence Detectors (TLD) for T production measurement in the TBM mock-up is proposed. The absolute calibration method of the TLD response against intrinsic tritium activity with the use of the Liquid Scintillation method is proposed and preliminary tested.

Summary

In the frame of the EFDA Work Programme the field of Nuclear Data and Neutronics is embedded as a part of the the neutronic aspects in the design, safety and future operation of the ITER, IFMIF and DEMO including the neutronics tasks for TBM. For the purpose of the further development and upgrade of the European Fusion File (EFF) and the European Activation File (EAF) dedicated neutronics benchmarks experiments are planned. One of them is helium-cooled lithium-lead (HCLL) TBM mock-up serving for design and performance analysis of the DEMO Test Blanket Modules to be inserted in ITER for testing purposes

The objective of the present work is to measure the Tritium production using Thermo-Luminescence Detectors (TLD) in the neutronics HCLL TBM mock-up and to compare experimental results with simulated ones.

In the 2008 the preparative works were continued:

1) The project of the design of the the implementation of Thermo-Luminescence Detectors in the experimental set up has been accepted. TLD detectors holders have been prepared in workshop of the AGH Faculty of Physics and Applied Computer Science (FP&CS) in Krakow from LiPb material supplied by ENEA Frascati. They have been supplied with TLD detectors to ENEA FNG laboratory in Frascati.
2) The way of the conversion of the LiF into liquid form without loss of the generated ^{3}H has been tested and optimised.
3) The method of ^{3}H measurements in the TLD pellets applying LSC technique – was successfully tested and introductory measurements were performed with the use of TLDs irradiated in nuclear reactor in 2 experiments.
4) The linear relation between TLD light output measurements and T activity in TLD detector has been prooved.
5) It was concluded from several LSC and TLD measurements that during one simple readout there is no significant loss of the T from TLD pellet. The T losses during standard detector annealing (1h in 400oC) have been assessed as ca 38%.

6) AGH TLD holders with TLD detectors have been modeled and coupled with the MCNP model prepared in ENEA Frascati. The number of 7. 2x108 source neutrons has been simulated in MCNP5 transport code with the use of FENDL-2.1(ENDF/B-VI) NJOY 99.90 NDS/IAEA Nov 2004) cross section library

Finally detectors have been irradiated in TBM mock-up in ENEA Frascati Neutron Generator Laboratory. During 6 days (end of November 2008) of activation. Total source neutron output reached $5x10^{15}$ value. Samples will be supplied to AGH and analysed in 2009. Complete calibration procedure will be repeated and checked

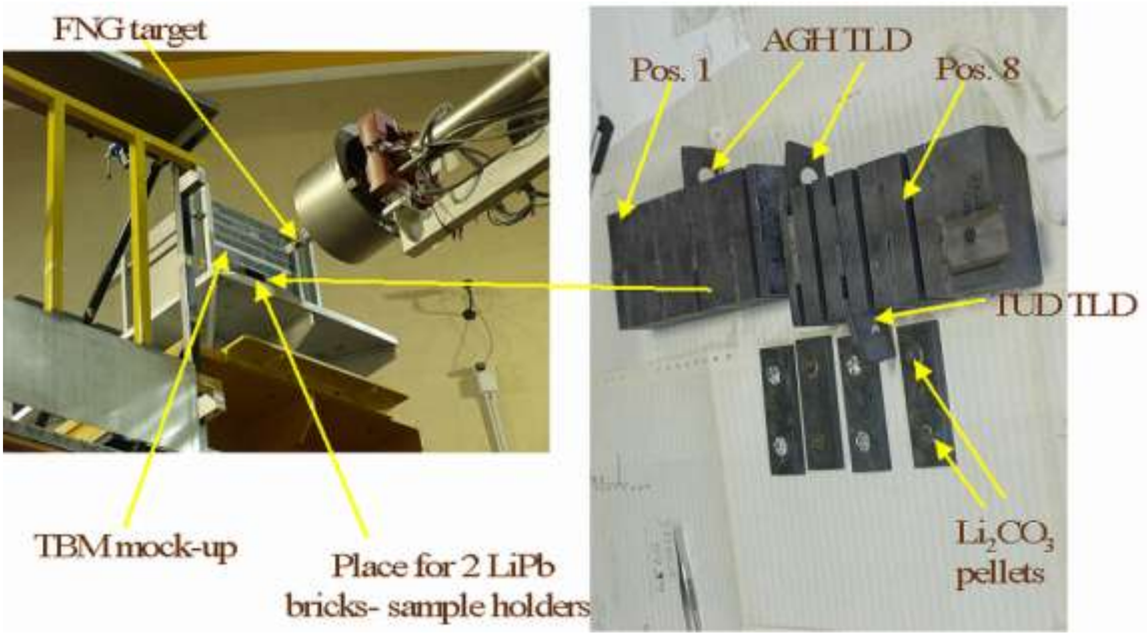

Figure 1. TBM HCLL mock-up in ENEA Frascati FNG Laboratory

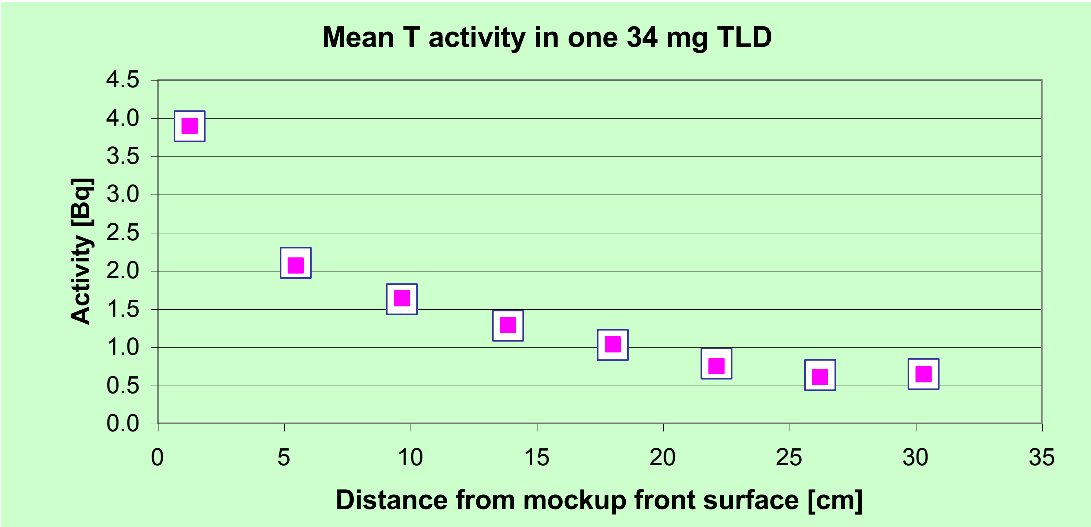

Figure 2. Example of simulation results (in red mean T activity in 3 central TLDs)

Conclusions

During the design and preparation of TBM - HCLL neutronics experiment ^{3}H measurement method with the use of Thermo-Luminescence Detectors has been proposed and implemented in the TBM mock-up construction. The absolute calibration method of the TLD response against intrinsic tritium activity with the use of the Liquid Scintillation method was proposed, optimised and tested with the use two experiments consisting of TLD irradiation in nuclear reactor neutron field.

It has been concluded that during one simple readout and several months storage in ambient temperature there is no significant loss of the T from TLD pellet. Tritium losses during standard TLD annealing procedure has been assessed and adequate modification (shortening) decided. The elaborated calibration procedure will be used in planned experiment.

The TLD detectors holders have been prepared in AGH workshop from LiPb material supplied by ENEA Frascati. Samples have been transported to Frascati Neutron Generator Laboratory, placed in mock-up and irradiated in 6 days experimental campaign. After irradiation in TBM setup the same calibration method will be repeated and checked.

Collaboration

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Socio-Economic Research (former Art. 5.1b contract)

3.9 Communication quality and lay understanding of fusion technology: a quasi-experimental study of message formulation effects on attitude change

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Abstract

The research investigated how scientific information, in confrontation with other factors, shapes lay attitudes towards fusion technology and how specific features of message affect reasoning about fusion.
Five groups of students read five versions of informative material about fusion technology and its application to power generation (prepared by fusion scientists together with this research author) and these groups' knowledge and judgements have been confronted among them and with those of a control group, which has not been taken through a learning process. The parity of six groups under investigation before treatment has been assured. Exposition to scientific information executed a cluster-breaking effect as far as reasoning about fusion is concerned, i.e. the judgements about fusion after being taken through the learning process became more independent each other (less inter-correlated) and less dependent on pre-existent attitudes and dispositions. Also the input of fusion risk perception and fusion benefits perception to the general favourableness towards fusion was different in the control and in the experimental groups. Confrontation of fusion with fission technology executed different impact on understanding than on acceptability of fusion. The exposition to the text presenting scientific community as divided between promoters and opponents of fusion executed different impact on attitudes than the exposition to the text which did not highlighted experts' dispute.

Summary

Favourableness towards fusion technology and various judgements about fusion such as: the evaluation of fusion technology feasibility, its risk and benefits, support for public investment in fusion research and acceptability of a hypothetical thermonuclear plant siting near to one's locality, were strongly interrelated and interacting with being exposed or not to scientific information. While in the lack of knowledge, reasoning about fusion was risk perception-driven, it became benefits perception-driven after being taken through the learning process.

Attitudes towards fusion strongly depended on pre-existent attitudes and dispositions such as the generalised fear level, trust in scientists and "technological optimism".

Presentation of fusion with explicit confrontation with fission technology promoted better understanding but lower acceptance of fusion.

The message presenting scientific uncertainties as dividing scientific community (on the contrary to the message presenting the same uncertainties without painting the picture of experts' controversy), strengthened the links between attitudes towards fusion and the antecedent fear level.

The results demonstrated that attitudes towards technology are composed with cognitive and affective elements and that they are rooted in deeper psychological dispositions (such as generalised feeling or vulnerability or safety), values and worldviews. Scientific information can enhance or weaken these clusters and make public response more reasoned than affective, depending on how the message is crafted, especially, how it relates to mental models and how scientific uncertainties are communicated.

Table 1

Pearson's correlation coefficients between Fusion Risk perception, Benefits perception and other partial attitudes towards fusion technology (all groups: N = 124)

	General favourableness	Support for public investment	Acceptability of siting	Combined Accceptability Indicator IFTAplus°
Risk Perception	-.611**	-.444**	-.653**	-.434**
Benefits Perception	.471*	.342**	.470**	.400**

Table 2

Factors shaping fusion acceptability (Pearson's correlation)

(All groups: N=124)

	Being generally in favour	Fusion =Real solution of Energy problems	Support for public investment increasing	Support for TNP siting near to one's locality	Fusion Benefits perc.	Fusion Risk perc.	Fusion Acceptab. index IFTAplus°	Fusion Acceptab. Index IFTA°°
FUI (Fusion Understanding)	.360**	.188**	.275**	.233**	.190*	-.193*	.355**	.291**
ITO (Technological Optimism)	.238**	.248**	.255**	.298**	.207**	-.262*	.357*	.312**
GRPL (Index of Generalised Fear level)	-.277**	-.181*	-.235**	-.398**	-.239**	.438**	-.263*	-.419**
Trust in scientists	.189*	.245	.226	.161	.230	-.278*	.247**	.313**

Table 3

Mental model-based communication and fusion understanding and acceptability

Pearson's correlation coefficients between being exposed to scientific material confronting fusion with fission technology and the indicators of fusion technology acceptability (IFTA and IFTAplus), risk perception and considering as "true" the statement: "accident in thermonuclear reactor does not lead to chain reaction"

	Right answer to question "accident does not lead to chain reaction"	Fusion Technology Risk Perception	Fusion technology Acceptability: IFTA IFTAplus
"fission story group" (1) versus other four experimental groups (0)	.322**	.243*	-.302** -.211*

Notes:

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

°°IFTA – Index of Fusion Technology Acceptability is the composed indicator based on the combination (sum) of scores obtained from answers to ix questions regarding fusion acceptability and risk and benefits perception

° IFTA plus – is another Index of Fusion technology Acceptability combining scores obtained from agreements to two positive and disagreements to two negative statements about fusion technology

Table 4
Comparison between groups exposed to “experts dispute narrative” and groups exposed to the same information material but with no “dispute narrative”

Pearson’s correlations between Fusion Acceptability indicators, risk perception and generalized fear (GRPL)

	Risk Perception	IFTA	IFTA plus
Control group	.234	-.228	-.276
“Dispute story” group	.648**	-.546**	-.421**
“Non-dispute story” group	.192	-.247	-.023

Conclusions

The project implementation enabled the elaboration of the methodology suitable to taking lay persons through a learning process about fusion technology and examining the effects of this learning process on their way of reasoning and attitudes toward fusion.

The methodology has been applied in a specific field research in Poland.

The results of the field research enabled to analyse lay understanding and acceptability of fusion technology and to to examine

- The relative impacts of scientific information and pre-existent attitudes on lay reasoning about fusion
- Effects of specific features of message on fusion understanding and acceptability

The recommendations to EFDA on this research methodology further applicability and on the design of public information campaigns about fusion technology have been provided (see Final Report to EFDA: “Scientific information and lay public reasoning about fusion technology”).

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