# 4 Fusion Technology Research and Development

Fusion technology tasks were carried out in two fields:

- Neutronic analysis: calculation of the activation and the decay heat of the components - classification of the wastes
- HTS materials for fusion magnets: Transitory states of the superconductor and its properties in the normal conducting state

## 4.1 HTS materials for fusion magnets. Transitory states of the superconductor and its properties in the normal conducting state (EFDA task TW5-TMSF-HTSPER: deliverable 3)

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### Abstract

It is expected that the superconducting coils used in Demo reactor will not be made from $Nb_3Sn$ and NbTi, but from high temperature superconductors. But up to now the available materials, although possessing very high critical parameters are very costly. So the search for cheaper and equally good compounds are still on the way. One of them is magnesium boride. It can not be used in liquid nitrogen temperatures, but is cheap, easy to process and with good critical parameters. In our group we took efforts to produce $MgB_2$ wires and try to evaluate its potential applicability for high field winding.

### Summary

Magnet system is one of most important and most expensive parts of ITER. Although it seemed to be most prepared to be used in reactor, there are still a lot of improvements which can and should be applied there. Especially obvious is the need for the materials less expensive and with at least the same reliability. Discovered already twenty years ago high temperature superconductors were believed to be such compounds. But in spite of the strong efforts by many of physicists and technologists we are still far from the cheap, strong and useful material. Long awaited material with high critical parameters, which can be used in liquid nitrogen temperatures is far for being ready to use in high current applications. So apart of efforts to improve the wires from high temperature superconductors there are carried works to find another alternative. One of them turned out to be magnesium boride, the well known compound discovered to be superconducting only fifteen years ago. It should be used at the temperature of liquid helium or hydrogen, is cheap, has high critical parameters, its easy to be used for wire drawing and its only disadvantage is rather high anisotropy.

### Results

Our work, made in cooperation with the group of Dr. Andrzej Morawski from High Pressure Institute PAS in Warsaw was focusing on following subjects:

- We have made the assessment of the quality and properties of magnesium and boron of high purity obtained from different suppliers (Stark, Strem, Fluka, Riedel de Haen, some Russian suppliers). We have found the best results are obtained for amorphous boron obtained from Russian supplier (magnesium from almost all suppliers was similar and of the same quality). We decided to make in-situ wires.
- After the decision, that we will make wires and tapes with copper jacket we looked for the material for the barrier to avoid reaction of magnesium with copper. We checked niobium, niobium-titanium, graphite and ex-situ $MgB_2$. The best results were obtained for low grain size powder of ex-situ $MgB_2$. (We also tried to use magnesium hydride instead of pure magnesium. Results were encouraging, but there were problems with voids in the wire and with spurious phases degrading properties of the wire.) To increase the critical current we used nanocrystalline

SiC and diamonds. As we had problems with dimonds connected with appearance of some new phases with carbon, which decreases critical temperature and made it difficult to precisely control the composition of the compound, we decided to use SiC.

- To obtain nanometer size grains of the magnesium and boron powders we used ball milling and new, developed by us method, of ultrasonic purifying.
- Our best wires have critical current densities which are above the values known from literature. They are equal to above 36 000 $A/cm^2$ at magnetic field of 12T and above 34 000 $A/cm^2$ for the field of 14T (Fig.1.).
- Our investigation proved that magnesium boride is very promising candidate for substituting NbTi compound for making superconducting winding of magnet systems in Tokamak if these winding will be kept in liquid helium temperature. Critical current densities are superior comparing to NbTi and both starting materials and production procedure is cheaper than for NbTi. Critical temperature of $MgB_2$ is above 35K, much higher than for NbTi , what in temperature of liquid helium gives much wider margin for stable work of the windings. Last studies of anisotropic properties of $MgB_2$ suggest that this material could be used for the fields up to 20T with anisotropy much less than 2. This is additional argument that $MgB_2$ may be treated as the future material for superconducting magnets of Tokamak.

## Main achievements

- We developed new method for cleaning powders of magnesium and boron. It was ultrasonic purifying under high pressure of helium and neon. It results not only in powder without adsorbed oxygen on the surface but also in much finer powder without tendency to agglomerate.
- We obtained $MgB_2$ wires in copper sheath and diameter below 0.8mm with critical current densities higher than known from literature.
- We proved that magnesium boride wires might be successfully used for making magnet systems for Tokamak, what should decrease substantially cost of superconducting windings.

## Conclusions

Our main conclusion is that the superconducting and mechanical properties of the wires made of magnesium boride are, even at this preliminary stage, so promissing, that this material should be seriously consider as the one for preparing superconducting winding for future Demo reactor. Although magnesium boride can not be cooled with liquid nitrogen, the necessity to use liquid helium seems not to be really disadvantaging (for reactor producing a lot of helium). Rather high critical temperature of this compound gives also possibility to use liquid hydrogen for cooling the magnets.

## Collaboration

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## 4.2 Nuclear data: benchmark experiments to validate EFF/EAF data EFDA Technology Task TW5-TTMN-002

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### Abstract

In the present work, based on the previous research and new experiments, activation calculations were benchmarked against validation experiments, for Ta and EUROFER. The work has three parts. Calculation of the neutron induced activity in EUROFER and Ta with the FISPACT inventory code and EAF-2005 activation cross-section data. Comparison of the calculation results to those obtained from the ALARA and IEAF-2001. Comparing of both calculated activities with the measured ones and production of the respective C/E values. Other teams involved in EFDA work program provided the required input data.

Based on the obtained results the following remarks are concluded:

- the role of exact determination of neutron spectrum is crucial for evaluation of the obtained results,
- regarding the experimentally determined activities it would be more precise to compare with calculations the directly measured activities, instead of the values recalculated back to the end of irradiation; the latter approach in cases of complex decay can lead to erroneous experimental results,
- independently of the previous remarks, the results justify our opinion that the EAF2005 data base, however yielding improved results for Ta, still needs improvement

### Summary

The comparison of calculated induced activities in Eurofer sample has revealed satisfactory agreement between the two calculations for half of the detected radionuclides and large discrepancies for some of the others. For Ta the results were not as good. The comparison with experiment for EUROFER has shown no significant results improvement of the FISPACT against the ALARA. In both cases only ~20% of C/E ratios differ by less than 33% from unity. Thus the previous indication (TW3-TTMN-002, Deliverable 9) of the need for updating the relevant cross sections in the IEAF-2001 data library was not effectively fulfilled in the EAF2005 library. However, for Ta, for the 8 nuclides measured, the superiority of FISPACT/EAF2005 results over the ALARA/IEAF2001 ones is clear.

The results for Ta are more optimistic as regards the C/E ratios, however they are too few for detailed analysis and not totally satisfactory. For this element the EAF2005 data base looks much better than IEAF2001.

The importance of accurate knowledge of the neutron spectrum applied in experiment should be stressed. Without this condition fulfilled the comparisons with calculations do not have a solid foundations.

## Conclusions

Comparison of calculations

- for Ta: for 75 % of the 24 compared nuclides, serious discrepancies are observed between FISPACT/EAF2005 and ALARA/IEAF2001 results; only for ~20 % the agreement is relatively good (within 35 %); the differences reach their extremes for $^{180}$Ta, $^{179m}$Hf, $^{180}$Lu, $^{178m}$Hf and $^{178m}$Ta; for these nuclides the ratio of results exceeds $10^3$!; two experimental values point out the FISPACT/EAF2005 results as much more reliable

- for EUROFER, the comparison of FISPACT and ALARA results show a good agreement for ~ 50% of nuclides, while for the others ratios as high as 14.7 ($^{177}$Ta) and 10.2 ($^{52}$Fe) are observed; only in case of $^{59}$Fe both calculations agree, also with experiment

Comparison of calculations and measurements

- for Ta, for the 8 nuclides measured, the superiority of FISPACT/EAF2005 results over the ALARA/IEAF2001 ones is clear

- for EUROFER: no significant improvement in the FISPACT results against the ALARA ones; in both cases only ~20% of C/E ratios differ by less than 33% from unity; still remains the need for improvement of the relevant cross sections in the respective data bases; the only way to produce $^{187}$W is the (n,$\gamma$) reaction from $^{186}$W; the C/E ratio for this nuclide is 5 – 10 times too small (for sample P4 even 10 – 25 times); it may be explained either by still too small share of thermal neutrons or by erroneous cross section values.

Comparison of the two evaluations (1$^{st}$ and 2$^{nd}$) of the neutron spectrum

- for Ta, the tendency in the calculated activity is logically following the partial transfer of fast neutrons to the thermal and epithermal region; therefore, calculated activities of nuclides produced in (n,$\gamma$) reactions, like $^{182}$Ta and its isomers, increased for the 2$^{nd}$ spectrum, while these produced in threshold reactions decreased,

- for EUROFER the application of 2$^{nd}$ spectrum caused: increase for $^{182}$Ta, $^{187}$W and $^{59}$Fe; no change for $^{60}$Co and $^{60m}$Co; decrease of all other nuclides calculated.

## Collaboration

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