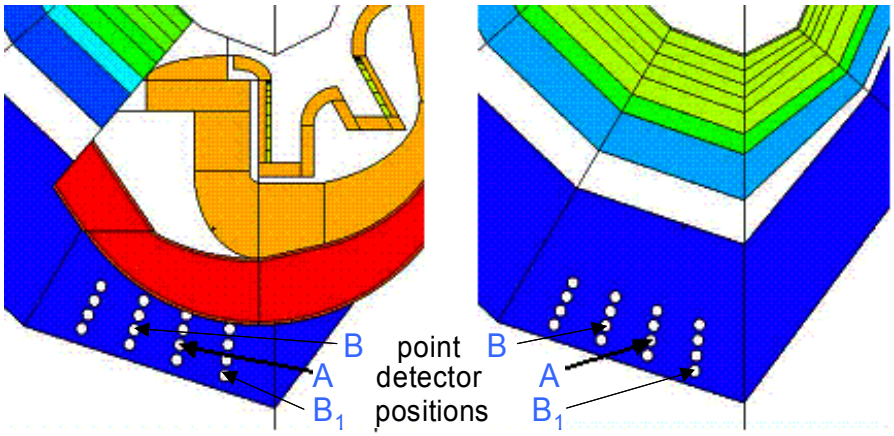
4. Fusion Technology Research and Development

Fusion technology tasks were carried out in three fields:

- Nuclear Data – benchmark experiments to validate EFF/EAF data: Post-analysis of the validation experiments for Ta cross sections up to 55 MeV in an IFMIF – like neutron spectrum
- HTS materials for fusion magnets: Transitory states of the superconductor and its properties in the normal conducting state
- Conceptual design of a HCLL reactor: Activation of the divertor region as a function of different divertor designs and configurations



Selected illustration Divertor region of the HCLL3 plant. Geometry of deep penetration neutron transport heterogeneous system vs. homogenised one (see section 4.3 for details)

4.1. Post-analysis of the validation experiments for Ta cross sections up to 55 MeV in an IFMIF – like neutron spectrum (EFDA task TW5-TTMN-002: deliverable 5)

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Abstract

Simulation of the Eurofer steel activation has been performed with the FISPACT inventory code and EAF-2005 data library. The yields of 32 reaction products were calculated and compared with results measured at NPI Řež and the ALARA/IEAF2001 calculations. The comparison of FISPACT and ALARA calculations show good agreement for about 50% of the 23 nuclides, while for the others ratios even as high as 14.7 (^{177}Ta) and 10.2 (^{52}Fe) are observed. Only in one case (^{59}Fe) both calculations agree with experiment.

Summary

In the frame of the EFDA Work Programme the activation experiment on the Eurofer low activation steel was performed at the cyclotron of the Nuclear Physics Institute (NPI), Řež. The objective was to provide the experimental data base for validating activation cross-section data in the energy range relevant for the International Fusion Material Irradiation Facility (IFMIF). In the same work programme the computational pre-analysis and the post-analysis to check and validate the high-energy cross-section data for neutron activation calculations were performed in Forschungszentrum Karlsruhe.
The objective of the present work, based on the previous research and new experiments performed at NPI, is to benchmark activation calculations against validation experiments, for Ta and EUROFER activation. Two Eurofer samples were irradiated in separate runs. They are named in this report P3 and P4. The work is divided into three parts:

1. Calculation of the neutron induced activation in EUROFER and Ta irradiated in an IFMIF like neutron spectrum using the FISPACT inventory code and EAF-2005 activation cross-section data.
2. Comparison of the calculated activities, with the use of FISPACT and EAF-2005, to those calculated with the ALARA activation code and IEAF-2001 cross-section data.
3. Comparison of the calculated activities with the measured ones and production of the respective C/E values.

The required input data (neutron source spectrum, irradiation history, material sample composition, measured activities) were (or will be) provided by other teams involved in EFDA work programme.

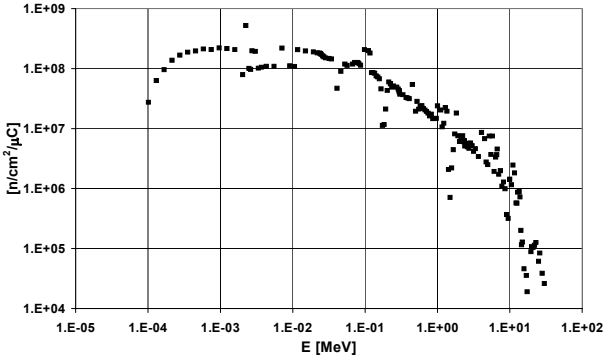

Figure 1 Neutron spectrum used in calculations

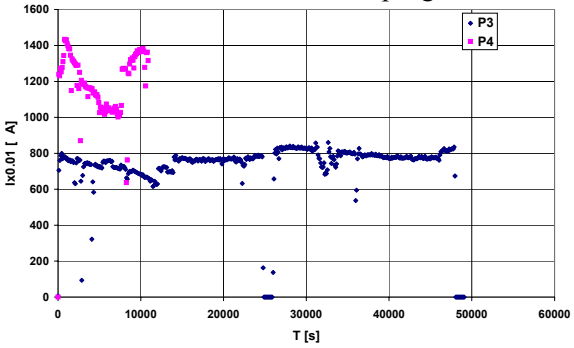

Figure 2 Irradiation time profiles for the Eurofer

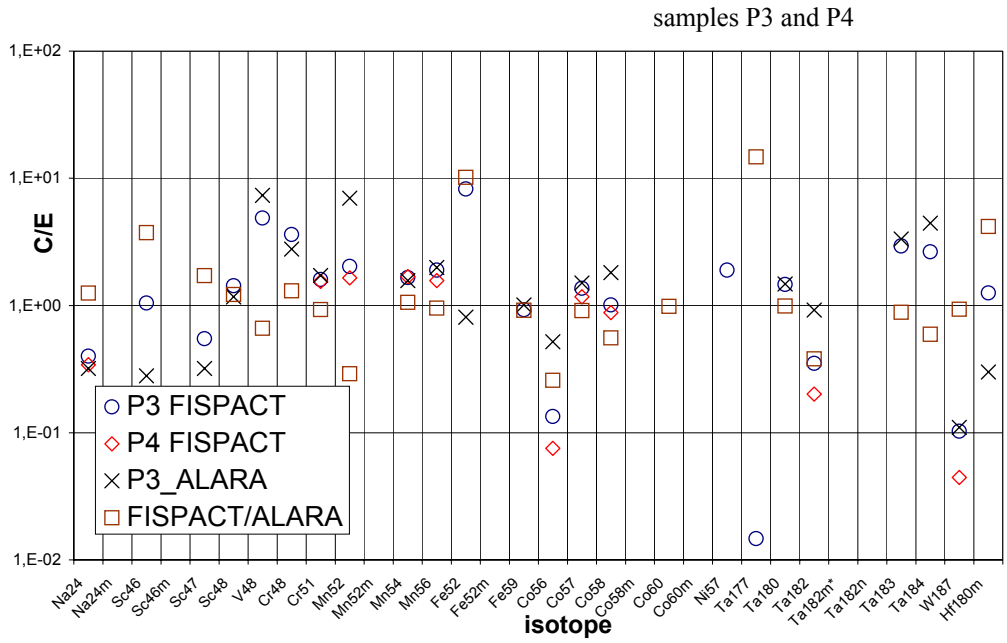

Figure 3 C/E ratios as obtained from the analysis of the Eurofer-97 activation experiment at INP Řež using ALARA/IEAF-2001 and FISPACT/EAF-2005, for samples P3 and P4

Conclusions

For the EUROFER sample only partial agreement (50% of nuclides) was achieved in the results of calculations with the use of ALARA+IEAF-2001 and FISPACT+EAF-2005. In the comparison with experimental results none of the two calculation methods looks satisfactory.

Collaboration

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4.2. 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 already decided, that magnetic system for ITER will be built using conventional NbTi and Nb_3Sn superconductors cooled with helium. But the operational costs would be lower and working parameters of next generation DEMO would be meaningfully improved if magnet winding was made of high temperature superconductors, working in liquid nitrogen. So together with eligibility of new superconductors for magnet windings their reliability and durability should be assessed. Just these properties were studied and tested in our group.

Summary

The main effort within our task at Magnet Structures & Integration during the past year was concentrated on the measurements of the normal state properties of high temperature superconducting tapes supplied by American Superconductors (coated conductors). Their investigation is important to study the consequences for fault conditions of the future DEMO magnet system.

Another our goal was to investigate the critical currents of superconducting strands made of Nb_3Sn, which are used presently for preparing magnet coil system for ITER.

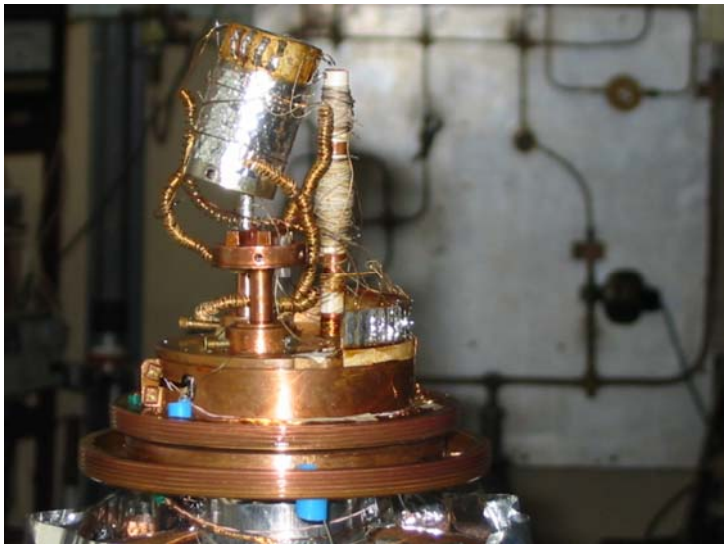

Figure 1 The details of the insert for thermal transport measurements

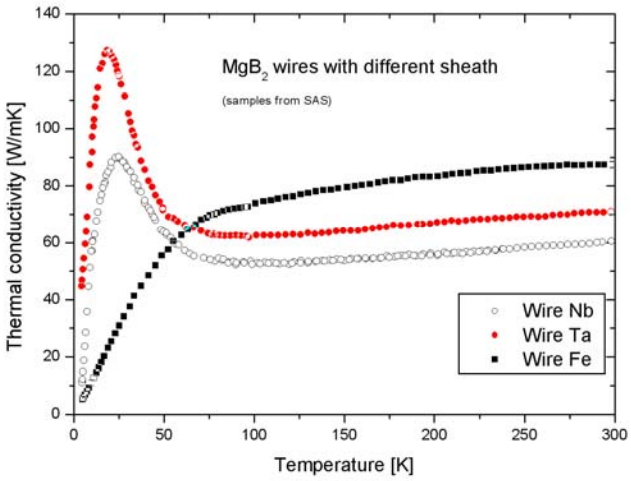

Figure 2 Thermal conductivity of MgB_2 wires with different sheath material

Conclusions

We believe that our studies of thermal conductivity, thermal expansion, and measurements of critical current and AC losses are very important for evaluating the properties of the materials which could be successfully applied for reliable use as superconducting windings of coil system producing magnetic field in tokamaks.

Collaboration

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4.3. Activation of the divertor region as a function of different divertor designs and configurations (Cost-Sharing Action N° FU06-CT-2004-00049)

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Abstract

The Power Plant Conceptual Study has been launched in the framework of the EU fusion programme with the objective to demonstrate the credibility of fusion power plant design and the claims for safety and environmental advantages of fusion power. A set of requirements, addressing in particular safety, operational and economic aspects, has been set out.

In this context the aim of investigations has been to evaluate the activated material produced by the operation of a fusion power station. It can be expected that the induced radioactivity is lower and decays rapidly, orders of magnitude faster than that of the waste from fission power plants. The respective research of the PPCS waste assessment is intended to confirm these findings in updated power plant models.

Several reactor models, using different coolant and breeding materials and having different degrees of extrapolation on both physics and technology have been evaluated. A certain near term model, based on the helium-cooled lithium-lead (HCLL) blanket concept, has been identified and adopted as one of the European designs for the "test blanket modules" to be tested in ITER.

Summary

The aim of present investigations was to evaluate the activation materials in the course of operation of a fusion power plant.

Thus the neutron activation rates and consequent nuclide inventories have been evaluated in divertor region of the fusion power plant with consideration of the geometry of the HCLL reactor concept. 3-D neutron field modelling of the HCLL plant models has been performed with the MCNP and MCNPX codes whereas the nuclide production and evolution of induced activity have been estimated with FISPACT-2003 and EAF-2003 nuclear data libraries.

A number of effects – listed below, have been studied, namely, among others, it has been found that admixtures of impurities even at concentrations apparently negligible can significantly affect the induced activity.

Next, the significance of divertor position with regard to the neutron source has been studied. The performed sensitivity test has lain in calculations of the neutron flux in the divertor for its various positions (several vertical and horizontal shifts of the divertor). The sensitivity of neutron flux, induced activity and other reaction rates to divertor position has proved rather low.

Then, the significance of resonance self-shielding effects in the circumstances of HCLL divertor has been evaluated /ca. 40% overestimation of (n,γ) reactions, on the other hand conservative/, thus proving that these effects are not quite negligible. In conclusion it has been recommended that the neutron cross-sections for calculations pertinent to the induced activity evaluations should be either continuous or when they are group ones, should be strictly problem-dependent and not those for general use.

Finally, it has been shown that homogenisation of real heterogeneous divertor structure results in total neglect of very significant streaming effects. This simplification of the system geometry seems

weakly affect the evaluation of radioactivity in the regions (close to or) directly exposed to 14 MeV neutrons. But the results obtained for deeper layers i.e. more shielded from the fusion neutron source are incomparably more biased. Due to streaming effects the neutron flux, thus the activity, heating etc. cannot be properly evaluated in the homogenised divertor system. Exact knowledge of the detailed structure of principal elements of the divertor is necessary. Only on this condition the streaming effects affecting the neutron flux distribution and spectrum can be properly reflected in neutron transport calculations.

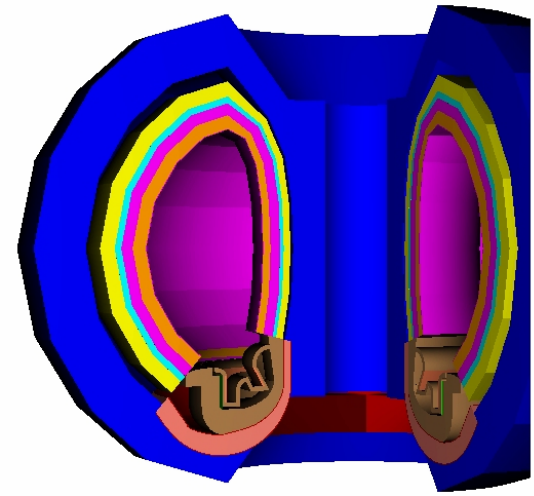

Figure 1 Incorporation of the FZK divertor model into the HCLL3 plant model

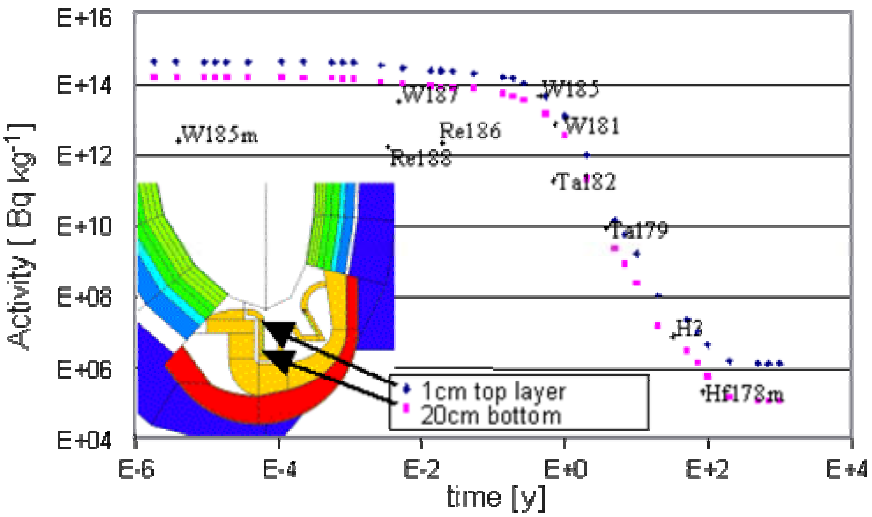

Figure 2 Activity induced in the tungsten layers of the divertor

Conclusions

The main conclusions to be drawn on the basis of performed study include also certain recommendations addressed to decision makers laying out the plans of future respective research. All they can sound as follows:

- The results of evaluation of the induced activity in Cracow and Culham have been in good agreement.
- The share of fast neutrons in the spectra diminishes with penetration of neutrons from the source into deeper layers of the divertor system.
- The neutron transport calculations (thus being all the based upon that evaluations, e.g. of the induced activity) in the zones directly exposed to source neutrons (and adjacent to those) are sufficiently accurate also in homogenised divertor models. With this exception in all the remaining zones of divertor region the homogenisation cannot bring adequate results.
- Due to streaming effects the neutron flux, thus the activity, heating etc. cannot be properly evaluated in the homogenised divertor system. Knowledge of the detailed structure of principal elements of the divertor is necessary. Only on these conditions the streaming effects affecting the neutron flux distribution and spectrum can be properly reflected in transport calculations.
- Not only main components of materials used in the divertor region but also admixtures at concentrations of impurities can significantly affect the induced activity in there. It signifies that the exact knowledge of the material composition is recommended.
- The sensitivity of neutron flux, induced activity and other reaction rates to divertor position has proved rather low.

Since the resonance self-shielding effects are not quite negligible, the neutron cross-sections to be recommended for calculations pertinent to the induced activity evaluations should be either continuous or when they are group ones, should be problem-dependent.

Collaboration

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