**DIAG-5** Field test of an activation probe

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| **TG priority:** High | **Start date:**  2012  | **Status:**  On-going | **Personnel exchange:**  Yes |
| **IO priority:**   | **End date:**   | **Motivation:**  Diagnostic concept test  |

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| --- | --- | --- | --- |
| **Device / Association** | **Contact****Person** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2012** | **2013** | **2014** | **2015** |
| AUG  | A. Fenyvesi András ,A. Herrmann | Desirable | Committed | Done | Considering | Analysis |
| KSTAR | S.-H. Hong | Desirable |   |   | Committed | Done |

**Results for 2015**

* a critical review has been completed for the available activation cross section data that are relevant to the activation probe technique,
* trajectory simulations were performed by experts of KSTAR to provide data for the optimum alignment of the activation probe,
* discussions were made on a recent publication of S. Äkäslompolo et al. [8] and on the possibilities of performing plasma physics simulations with the LORBIT code for the activation probe experiment at KSTAR,
* LiF, CaF2 and YVO4 samples with 99.99% chemical purity needed for the activation probe experiment were purchased by MTA Atomki and MTA Wigner RCP,
* a proposal on activation probe measurements was submitted to KSTAR experimental campaign in 2015
* in the 19-30 October 2015 period András Fenyvesi spent 2 weeks at KSTAR and participated in the activation probe experiments,
* on 26 October 2015, for the first time at KSTAR, activation probe experiment was performed using 8 shots of H-mode D-D plasmas (shots: #014138, #014139, #014140, #014141, #014142, #014143, #014145, #014146),
* gamma lines corresponding to detection of neutrons, escaping protons and 3He-ions were identified in the gamma spectrum obtained during on-site counting of the samples,
* the activated samples were sent to Institute for Reference Materials and Measurements (IRMM, Geel, Belgium) for counting them at low and ultra-low background facilities,
* 2 November 2015 is the expected date of starting the counting of the samples at CELLAR facilities,
* in the November - December 2015 period cross section measurements will be performed at the Van de Graaff accelerator of MTA Atomki (Debrecen, Hungary) at particle energies below 5 MeV to obtain new data for the excitation functions of the nuclear activation processes that are most relevant to the activation probe experiment performed at KSTAR.

**Plans for 2016**

* evaluation and interpretation of the results of the activation probe experiment performed at KSTAR during the experimental campaign in 2015,
* simulations with the LORBIT code for the experimental circumstances at KSTAR,
* publication of the results of the experiment performed in 2015,
* further field tests of the activation probe technique at KSTAR during the experimental campaign in 2016.

**Purpose:** The objective of the joint experiment is performing field measurements at tokamaks (ASDEX, KSTAR) with the activation probe technique for measuring escaping alphas and other fast ions. The results will be compared with results of simulations and FILD measurements.

**Motivation:** A fraction of energetic charged particles (p, d, t, 3He and 4He) can escape fusion plasmas. Alpha confinement will be especially important at ITER and measurement of fluxes of lost alphas has to be solved for ITER. The performance and reliability of the standard ion loss measurement techniques based on direct particle detection are questionable as the detectors will have to operate in harsh radiation environment of ITER first wall. The activation technique has been proposed as a potential alternative for ITER.

National Fusion Research Institute (NFRI, Daejon, South Korea) offered opportunity for performing field test of the activation probe technique at KSTAR.

A proposal was submitted to the Program Advisory Committee of the EUFRAT Transnational Access Program of EU DG JRC IRMM-Geel (Geel, Belgium) to obtain access to low and ultra-low background counting facilities of the Collaboration of European Low-level underground LAboRatories (CELLAR collaboration). On 25 September 2015 the PAC of EUFRAT accepted the project and the project has been endorsed to use 1200 hours of total counting time after a successful experiment at KSTAR. The expected date of starting counting of the activated samples is 2 November 2015.

The PAC of the Accelerator Centre of MTA Atomki provided opportunity to perform a cross section measurement program at the Van de Graaff accelerators of the institute.

**Background:** A fraction of energetic charged particles (p, d, t, 3He and 4He) can escape fusion plasmas. Alpha confinement will be especially important at ITER and measurement of fluxes of lost alphas has to be solved for ITER. The performance and reliability of the standard ion loss measurement techniques based on direct particle detection are questionable as the detectors will have to operate in the harsh ITER first wall environment. New and more robust techniques need to be developed in order to minimize risks and increase measurements’ reliability. The activation technique has been proposed as a potential alternative for ITER. It has been shown at JET [1-5] that a technique based on charged particle in-vessel activation is able to generate absolute measurements of fusion proton loss. The same technique might be developed and used for measuring the loss of alpha particles in ITER.

For the first time, at ASDEX Upgrade (AUG) tokamak, a measurement with an activation probe was carried out in January 2013. Fluxes of En = 2.5 MeV and En = 14.1 MeV energy neutrons and flux of Ep = 3.7 MeV energy escaping protons were calculated. Recent ASCOT simulations [7, 8] done by the TEKES Finnish team indicate that the irradiation arrangement at AUG can be improved and more precise fluxes of lost ions can be expected.

The experiments planned for 2014 could not be performed. In 2014 no time was allocated for the experiments at ASDEX. At JET the manipulator needed for the activation probe experiments was broken.

National Fusion Research Institute (NFRI, Daejon, South Korea) offered opportunity for performing activation probe experiments at KSTAR during its experimental campaign in 2015.

**Purpose:** The objective of the joint experiment is to perform new measurements with activation probe for measuring escaping alphas and other fast ions. The experiment with the activation probe should have the following deliverables:

1. Optimized irradiation arrangement
2. Identification of escaping energetic ions by activation technique
3. An absolute value of the escaping energetic ion range
4. The angular or pitch angle range of escaping energetic ions
5. The energy of escaping energetic ions
6. Adequate time span/coverage. In JET, time-integration over several plasma pulses was performed, but on ASDEX single pulses could be measured

Variations in toroidal field and current directions and strengths, along with various shapes are key to the validation of this technique.

**References:**

[1] G. Bonheure et al, Fusion Sci. Technol 53 3 (2008) 806
[2] E. Wieslander et al, Nucl. Instrum. Meth. A. 591 (2008) 383
[3] G. Bonheure et al, Rev.Sci.Instrum 79,1 (2008)
[4] R. Gonzales de Orduna et al, Applied Radiation and Isotope 68 (2010) 1226-1230
[5] G. Bonheure et al, Fusion Eng. Des. 86 (2011) 1298
[6] G. Bonheure et al., *Europhysics Conference Abstracts*, 37D (2013) O5.610
[7] S. Äkäslompolo et al., *Europhysics Conference Abstracts*, 37D (2013) P5.101
[8] S. Äkäslompolo et al., arxiv1504.03073v3

**The next pages are the former reports.**

**They should not be modified.**

**Report for 2014**

**Results for 2014**

* a new activation probe was designed at Wigner RCP (Budapest, Hungary) for the mid-plane manipulator of KSTAR,
* CAD drawings of the components of the probe were sent by Wigner RCP to National Fusion Research Institute (NFRI, Daejon, South Korea) and the components of the probe were fabricated at NFRI,
* the assembled probe was installed on the mid-plane manipulator of KSTAR, and then mechanical testing of the installed probe was started,
* the EXFOR database was searched for the available measured cross section data for the relevant nuclear reactions induced by p, d, 3He- and α-particles on nuclei of isotopes of B, Li, C, O, F, Ca, Y and V,
* a critical review and evaluation of the available measured activation cross section data was started,
* a proposal was prepared for measuring new cross section data for particle energies below 5 MeV at the Van de Graaff accelerator of MTA Atomki (Debrecen, Hungary),
* the proposal was accepted by the PAC of the Accelerator Centre of MTA Atomki.

**Plans for 2015**

* simulations with the LORBIT code for the experimental circumstances at KSTAR,
* field test of the activation probe technique at KSTAR,
* off-site counting of the irradiated samples at gamma counting facilities,
* evaluation and interpretation of the measured gamma spectra,
* comparison with the results obtained from simulations and FILD measurements.

**Purpose:** The objective of the joint experiment is performing field measurements at tokamaks (JET, ASDEX, KSTAR) with the activation probe technique for measuring escaping alphas and other fast ions. The results will be compared with results of simulations and FILD measurements.

**Motivation:** A fraction of energetic charged particles (p, d, t, 3He and 4He) can escape fusion plasmas. Alpha confinement will be especially important at ITER and measurement of fluxes of lost alphas has to be solved for ITER. The performance and reliability of the standard ion loss measurement techniques based on direct particle detection are questionable as the detectors will have to operate in harsh radiation environment of ITER first wall. The activation technique has been proposed as a potential alternative for ITER.

The experiments planned for 2014 could not be performed. In 2014 no time was allocated for the experiments at ASDEX. At JET the manipulator needed for the activation probe experiments was broken. National Fusion Research Institute (NFRI, Daejon, South Korea) offered opportunity for performing the experiments at K-STAR. The experiments can be done during the 2015 experimental campaigne at K-STAR. Preparation for the experiment has been started.

**Background:** A fraction of energetic charged particles (p, d, t, 3He and 4He) can escape fusion plasmas. Alpha confinement will be especially important at ITER and measurement of fluxes of lost alphas has to be solved for ITER. The performance and reliability of the standard ion loss measurement techniques based on direct particle detection are questionable as the detectors will have to operate in the harsh ITER first wall environment. New and more robust techniques need to be developed in order to minimize risks and increase measurements’ reliability. The activation technique has been proposed as a potential alternative for ITER. It has been shown at JET [1-5] that a technique based on charged particle in-vessel activation is able to generate absolute measurements of fusion proton loss. The same technique might be developed and used for measuring the loss of alpha particles in ITER.

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Variations in toroidal field and current directions and strengths, along with various shapes are key to the validation of this technique.

**Report for 2013:**

1. Escaping fast ion measurements were performed at ASDEX Upgrade tokamak (AUG). The activation technique was employed. The geometry was similar to that foreseen for an ITER activation probe [6]. An activation probe was mounted on the manipulator slightly above the tokamak mid-plane. The probe was filled up with 24 pcs of activation detectors made of boron carbide (B4C), calcium fluoride (CaF2) and yttrium ortho-vanadate (YVO4). The detectors were exposed to products of the fusion reactions

D + 3He → p (14.7 MeV) + α (3.7 MeV)

D + D → p (3.0 MeV) + T (1.0 MeV)

D + D → n (2.5 MeV) + 3He (0.8 MeV)

D + T → n (14.1 MeV) + α (3.6 MeV)

of two H-mode deuterium plasmas (Bt =2.5 T, Ip = 106A) with long flat-top phases and high DD fusion yield.

1. After irradiation the radioactivity of the samples was measured at ultra-low background gamma counting facilities. Products of nuclear activation reactions induced by neutrons, protons and 3He ions have been identified in the measured gamma spectra [6].

Products of the neutron induced 46Ca(n,γ)47Ca, 48Ca(n,2n)47Ca, 51V(n,α)48Sc, 89Y(n,2n)88Y and 89Y(n,2n)90mY reactions were present in the samples. The obtained emission of En = 2.5 MeV energy neutrons was 7.0x1015 for the #29226 shot and 1.1x1016 for the #29228 shot.

7Be from the 10B(p,α)7Be reaction induced by Ep = 3.7 MeV protons and 89Zr from the 89Y(p,n)89Zr reaction induced by 14.7 MeV protons were identified in the irradiated detectors with high significance. The obtained fluence of Ep = 3.7 MeV protons was 5.8x108 cm-2 ± 50%.

91mNb from the 3He induced 90Y(3He,n)91mNb reaction was also identified but only with small significance. Further investigations are necessary for confirming this observation.

1. ASCOT simulations have been done for the experiment by the TEKES Finnish team [7]. The difference between the fluxes obtained from measurements and simulations was significant. It has been concluded that further optimization of the irradiation arrangement is necessary and the nuclear activation cross section background of the technique has to be improved, too.
2. Estimation of particle fluences needs good quality excitation function data (cross sections) for the nuclear activation reactions. It has been found that experimental, theoretical and evaluated cross section data are missing or scanty, and the available cross sections are discrepant especially in the Eparticle < 5 MeV energy range. Significant improvement of the cross section data (excitation function data) for the relevant nuclear activation reactions is necessary. The first step should be a critical overview of the relevant libraries of experimental, theoretical and evaluated cross section data. Further cross section measurements, theoretical calculations and evaluations are recommended, too.

**Plans for 2014:**

* Install the activation probe on the mid-plane manipulator of AUG.
* Test of the modified irradiation arrangement.
* Develop optimum operating scenarios on AUG where other diagnostics can be benchmarked: a number of scenarios have been identified (see overall progress above) and simulations are in progress.
* Execute experiments on AUG for Code Benchmark and multi-diagnostic measurements.

**References:**

[1] G. Bonheure et al, Fusion Sci. Technol 53 3 (2008) 806
[2] E. Wieslander et al, Nucl. Instrum. Meth. A. 591 (2008) 383
[3] G. Bonheure et al, Rev.Sci.Instrum 79,1 (2008)
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