CRP on Development and Application of Ion Beam Techniques for Materials Irradiation and Characterization Relevant to Fusion Technology

CRP Code F11023

Guidelines

CRP'S RESEARCH PRIORITIES

TO BE CONSIDERED IN THE PREPARATION

OF RESEARCH PROPOSALS

About the CRP

The CRP F11023 aims at assisting the international Ion-Beam Analysis (IBA) community to coordinate research efforts in understanding aspects of ion-induced radiation damage in materials relevant to fusion energy as well as related analysis and interpretation. The CRP's workplan includes three major activities:

- Work Package 1: Experiments to determine original new nuclear data relevant to the scientific goals of the CRP. These include measurements and/or validation of new/existing reaction cross sections as well as measurements of stopping powers,
- Work Package 2: Round Robin exercise(s) to evaluate the performance of IBA laboratories world-wide for experiments of ion-induced radiation damage in materials relevant to fusion energy, including post irradiation analysis.
- Work Package 3: Development of international good practices and procedures necessary for the standardization of IBA techniques for Materials Irradiation and Characterization Relevant to Fusion Technology.

Research groups interested in participating in the CRP are expected to contribute to at least two of the above listed activities of the CRP. Therefore, the applicants are kindly requested to include in their application a statement on their willingness to participate or not in Work Packages (WPs).

Implementation

The CRP will be implemented in two major phases:

Phase 1:

- Cross section and stopping power measurements
- Experiments relevant to the Round Robin exercise(s)
- Preparation of good practices and procedures, and definition of reference samples for the standardization of the relevant IBA techniques and their implementation through experiments

Phase 2:

- Analysis and inter-comparison of cross-section and stopping-power measurements, interpretation and documenting
- Analysis and inter-comparison of Round Robin results, interpretation and documenting
- Analysis of results obtained through experiments for the standardization of the IBA techniques for Materials Irradiation and Characterization Relevant to Fusion Technology.
- Drafting of international good practices and procedures and the IAEA TECDOC

The detailed program for the implementation of the planned Round Robin exercise(s) and efforts towards Standardization of IBA Techniques as well as the definition of relevant procedures and selection of reference samples will be defined at the first Research Coordination Meeting (1st RCM) of the CRP, expected to be held early in 2021.

The CRP's Work Programme and its priorities

The Ion Beam Analysis (IBA) of materials is a wide research field covering a large mass range and types of materials, which might not have direct relevance to the goals of the CRP. Therefore, research proposals submitted for evaluation, which are not addressing the CRP's work programme priorities will be rejected. Moreover, not all research proposals focusing on the same topic/measurements will be selected, as the CRPs work programme aims at covering all and not part of its task priorities. It is self-explanatory that in all cases the selection criteria will be based solely on scientific merit and technical feasibility.

Annexes I and II, attached to this guide provide some additional information regarding high priority measurements on measurements and/or validation of new/existing reaction cross sections as well as measurements of stopping powers (Annex I) as well as some preliminary proposal for Round Robin targets/samples to be used within the CRP (Annex II). Applicants are advised to submit a research proposal matching the priorities given in these Annexes.

Additional information to be provided in the research proposals

In addition to the research project proposals which the applicants have to fill in the foreseen application form, they should also provide in their submissions some details on:

i) Experimental setup to be used.

ii) Composition of the samples to be employed in the measurements and method(s) to investigate any beam-induced sample deterioration or composition changes. If possible, provide information on the sample's surface roughness and surface purity

iii) Method(s) to apply for the energy calibration of the accelerator as well as expected uncertainties in the energy of the beam and voltage instabilities. It is recommended to consider calibrating the accelerator at three energies separated by at least 1 MeV, via three disjunct methods, namely

- Solving the equation system of RBS and NRA reaction edges
- EBS resonances of known energy (e.g. $^{4}He+^{16}O$)
- PIGE resonances of known energy

iv) Method to apply for the measurement of the beam current and its integration, together with the associated uncertainties. It is recommended to consider measuring the current integral in the same setup via at least the four following different methods:

- Faraday cup and sample current
- Monitor wheel
- Mesh
- RBS reference with known solid angle

v) Method to determine the solid angles necessary for the analysis of the data and with this the Ion dose times detector solid angle (Particle*Sr) value. It is recommended to consider measuring the detector's solid angle in the same setup via four different methods:

- Reference samples
- Geometrical calculation
- Stopping power
- RBS reference layers (e.g. Au)

vi) The detectors to be used and the procedure to follow for the energy calibration of the detectors. It is recommended to calibrate the detector and measure its resolution by several different methods, at least by using NRA and RBS edges and a pulser.

vii) Data Acquisition system to be used. For the any subsequent evaluation and/or inter-comparison of results, settings like ADC parameters may be required.

viii) Technique to apply for dead-time corrections.

ix) Data on stopping powers, reaction cross-sections and software that will be used in data analysis.

x) Procedure and software for the analysis of the spectra.

xi) Expected statistical and systematic uncertainties together with a discussion on their origin.

xii) Willingness to share raw data with other CRP participants, if requested. It is foreseen to organize a raw data repository. The host of the repository will be identified at the first Research Coordination Meeting (1st RCM).

Annex I: New/existing reaction cross sections as well as measurements of stopping powers

- **High priority measurements**

Measurements with the highest priority in the CRP's work programme are listed in Table 1. They refer to ^{3}He-induced reaction cross sections and stopping power measurements. In the former case, measurements should provide results on all (^{3}He, x) reactions, where x = p, d, α, and their excited states in the range up to 15 MeV excitation energy in the produced isotope. Elastic (non-Rutherford) backscattering (EBS) cross-sections should be included where possible.

- **Medium priority measurements**

These also refer to ^{3}He-induced reaction cross sections and stopping power measurements. In the former case, measurements should provide results on all (^{3}He, x) reactions, where x = p, d, α, and their excited states in the range up to 15 MeV excitation energy in the produced isotope. Elastic (non-Rutherford) backscattering (EBS) cross-sections should be included where possible.

- **Low priority measurements**

Existing cross sections of proton induced reactions on the isotopes listed in table 3 should be validated[1] or reviewed. The validation should at least include a comparison of spectra simulated with existing cross-sections with thick target measurements with projectile energies corresponding to the cross-section energy range. If the validation procedure proves that there are no reliable data or significant deviations between reported datasets exist, then new measurements should be performed within the CRP.

TABLE 1: HIGH PRIORITY EXPERIMENTS

<table>
<tr><th colspan="7">Cross section measurements of ^{3}He-induced reactions</th></tr>
<tr><td>Target isotope:</td><td>^{7}Li</td><td>^{9}Be</td><td>^{10}B</td><td>^{11}B</td><td>^{12}C</td><td><b>^{13}C</td></tr>
<tr><td>^{3}He beam energy range and recommended energy step</td><td colspan="6">1 – 6 MeV (Step: ≤ 100 keV);
Caution: consider resonance width, when found</td></tr>
<tr><td>Range of angles to measure</td><td colspan="6">120^O – 175^O</td></tr>
</table>

<table>
<tr><th colspan="6">Stopping Power Measurements</th></tr>
<tr><td colspan="3">Target element:</td><td>W</td><td>Be</td><td>Minimum data points#</td></tr>
<tr><td rowspan="4">Beam</td><td>H</td><td rowspan="4">Beam energy range</td><td colspan="2">20 keV – 2 MeV</td><td>30</td></tr>
<tr><td>He</td><td colspan="2">40 keV – 8 MeV</td><td>25</td></tr>
<tr><td>Cu</td><td colspan="2">1 -25 MeV</td><td>20</td></tr>
<tr><td>I</td><td colspan="2">2 – 40 MeV</td><td>15</td></tr>
<tr><td colspan="3">Target type:</td><td colspan="3">thin film, layer or bulk</td></tr>
</table>

[1] A methodology for benchmark measurements was developed at a Technical Meeting organized by the NDS of IAEA and is described in the report INDC (NDS)-0690; *Benchmarking Experiments for Ion Beam Analysis*, Report of the Technical Meeting, 26-29 May 2015, IAEA, Vienna; https://www-nds.iaea.org/publications/indc/indc-nds-0690/

TABLE 2: MEDIUM PRIORITY EXPERIMENTS

Cross section measurements of ^{3}He-induced reactions				
Target isotope:	**Deuterium** [2)]	**^{14}N**	**^{15}N**	**^{16}O**
^{3}He beam energy range and recommended energy step	1 – 6 MeV (Step: ≤ 100 keV); *Caution:* consider resonance width, when found			
Range of angles to measure	120^{O} – 175^{O}			

Stopping Power Measurements					
		Target element:	**Mo**	**Fe (α phase)**	**Minimum data points#**
Beam	H	**Beam energy range**	20 keV – 2 MeV		30
	He		40 keV – 8 MeV		25
	Cu		1 -25 MeV		20
	I		2 – 40 MeV		15
		Target type:	thin film, layer or bulk		

TABLE 3: LOW PRIORITY EXPERIMENTS

Proton-induced reactions to VALIDATE / REVIEW existing cross sections				
Target isotope:	**^{7}Li**	**^{9}Be**	**^{10}B**	**^{11}B**
Range of angles of interest	120^{O} – 175^{O}			
Range of proton energies (MeV)	0.1 – 4.5			
Thin target (for complementary cross-section measurements)	Yes			
Thick target for validation purposes (*Caution:* Measured yield also depends on stopping power).	Yes			

[2)] For ^{3}He on D, a number of cross section data sets are available, and an evaluation has been published by Bosch and Hale, in Nuclear Fusion 32 (1992) 611); https://iopscience.iop.org/article/10.1088/0029-5515/32/4/I07/pdf and https://iopscience.iop.org/article/10.1088/0029-5515/33/12/513 (corrigendum); Therefore, any proposal on this case should focus on an improved evaluation

Annex II: Preliminary proposal for Round Robin targets/samples to be used within the CRP

The aim of the planned round robin exercise is to establish reproducibility between IBA techniques at different laboratories. For this purpose, following samples are proposed to be provided and employed:

a) Beryllium layer on pure tungsten substrate
b) Deuterium implanted tungsten
c) Deuterium implanted tantalum

Details on the samples recommended for the round robin test, their preparation, surface treatment, concentration in D or Be, quantity to detect etc. are given in table 4.

The Be layer on W target will be used to determine:

a) The areal density of beryllium, and
b) The composition depth profile.

Using the deuterium-implanted targets, the laboratories participating in the round robin should provide:

a) The deuterium depth profile, and
b) The total amount of deuterium.

TABLE 4: REFERENCE SAMPLES FOR ROUND ROBIN

Bulk	**W**	**W**	**W**	**500 nm Be on W**	**Graphite +20µm W**
Detected quantity	D vs depth	D vs depth	D vs depth	Be thickness	Deposits
Preparation	D-implanter 50 kV	D-implanter 120 kV	D-implanter 200 kV	Evaporation	JET
Surface	Polishing	Polishing	Polishing	Polished	Rough
Concentration	≥ 0.1%	≥ 0.1%	≥ 0.1%	> 97% Be	Mixed
Types of Analysis	All	All	All	All	All