TITLE: Metrology for Fusion

Abstract

The proposed research topic is aimed at establishing the metrological basis for the development and the safe operation of fusion power reactors. Measurement challenges range from dimensional measurements under extreme magnetic fields through extreme temperature measurements, to ionising radiation, which needs to be measured reliably and with sufficient accuracy for extremely high particle fluxes and under harsh conditions, e.g. high temperatures and strong magnetic fields. New instruments need to be tested and calibrated under realistic conditions. Cooperation of European metrology groups is needed for bridging the huge gap between the well-established metrology of present reference radiation fields to the needs for future fusion facilities.

Conformity with the Work programme

This Call for JRPs conforms to the EMRP 2008 [1], section on "*Grand Challenges"* related to *Energy* on pages 8, 10, 23 and 30.

Keywords

Metrology, nuclear fusion, energy production, traceable measurements, reference radiation fields, neutrons, photons, charged particles, cross sections, portable 3D-measurement systems

Background to the Metrological Challenges

Energy production by nuclear fusion offers the long-term potential of contributing on a large scale to the global energy supply without greenhouse gas emissions, air pollution or large amounts of radioactive waste. Research and development in the area of nuclear fusion by magnetic confinement is consequently supported by the EC (FP7/EURATOM) with a high priority. The coordination of research is done via the European Fusion Development Agency EFDA. Many activities, aimed at supporting the thermonuclear reactor ITER being built in Cadarache (FR), are predominantly carried out by research groups belonging to the 27 fusion research organisations associated to EFDA. Since NMIs are not partners of EFDA, their metrological competence is not directly included in these research activities. This topic aims to address the metrological challenges associated with fusion on large scale and make the unique competences in metrology of the NMIs/DIs available for the fusion research community.

Instrumentation, even for the current leading fusion device, JET, requires improvement to allow the facility to be used as a test device in preparation for ITER. Instrumentation for the next generation machines will present huge, at present unsolved, problems in reaching the required uncertainty levels, not least due to the intense neutron and gamma fluxes and the harsh conditions (temperature, magnetic field, etc). While many diagnostics systems, developed and tested for plasma parameters in today's machines are principally suited for ITER, the real difference will be the generation of neutrons: neutron heating will be typically 1 MW m^{-3} compared to essentially zero in existing ones. Further challenges are imposed by the test facility IFMIF, to be built in Japan, which is expected to produce very high intensity neutron radiation consisting of a broad energy distribution up to 40 MeV.

Among the many plasma and first wall parameters to be measured at ITER, the neutron emissivity and the fusion power will play an important role for plasma optimisation and for achieving ITER goals, in particular the fusion gain factor Q related to the reactor performance. In very hot plasmas optical information from atoms is unavailable because of the degree of ionisation. At ITER about 200 neutron and gamma detectors have to be installed. The planned calibration strategy includes detector calibration at a Neutron Test Area (NTA), to be built on the ITER site, before installation in the Tokamak complex and *in-situ* calibrations after installation with DD and DT neutron generators and neutron sources which will be moved inside the ITER vacuum vessel.

The IFMIF facility will provide extremely high neutron fluxes to allow testing of material properties for ITER, and also for DEMO, the demonstration power plant which will follow. The high neutron fluxes will be produced with the Li(d,n)-reaction yielding a broad energy spectrum which is different to those observed at fusion plasmas. The characterisation of the beam will to a very large extent rely on calculations, which have to be based on a reliable database of nuclear cross sections. There is a clear lack of data for d-induced reactions (to understand the neutron production) and for n-induced reactions up to 60 MeV (relevant for shielding and radiation damage).

In ITER, DEMO and future fusion power plants, the alpha particles resulting from the fusion reactions must be well confined inside the plasma while slowing down in order to heat the plasma. Techniques and detectors capable of operating in the challenging environment of the ITER first wall (neutron and charged particle flux densities in the order of 10^{15} $cm^{-2}s^{-1}$, plasma radiation: 500 kW m^{-2}) must be developed, tested and calibrated. ITER will include photon spectrometers for measurement of impurities which need to cover energies up to 20 MeV and which need to operate under large neutron fluxes. The calibration strategy needs to be developed for these higher energies.

The proposed research topic is strongly supported by stakeholder groups (ITER planning team on diagnostics, JET diagnostics task force) and by the EURAMET TC-IR. The development of suitable and reliable measurement methods and sensors for different monitoring purposes, able to operate under harsh conditions is challenging. Fibre optic sensors and systems are well suited due to a number of advantages compared to electrical, electronic and other sensor methods.

Narrow manufacturing and assembly tolerances of reactor components necessitate the application of 3D geometric large scale metrology systems with very small uncertainties for which improved calibration procedures need to be developed.

The key elements are heat resistant materials for the first reactor wall to withstand high operating temperatures and ion-bombardment. This requires improved measurement techniques to investigate corrosion and high-temperature behaviour of the most promising materials as well as drift free and ion bombardment-resistant temperature sensors at these operating temperatures and conditions.

To fulfil safety regulations in nuclear power plants the permitted thermal power output is lowered to a value of 2 % below the nominal maximum power to account for the uncertainty of 2 % of the flow rate measurements. Lowering the uncertainty of flow rate measurements to 0.5 % directly enhances the power output by the same amount. Besides, for all types of power plants the uncertainties of flow rate measurements lead to non-perfect steering and control mechanisms.

Scientific and technological objectives

Proposers should aim to address all of the stated objectives. However where this is not feasible (i.e. due to budgetary or scientific / technical constraints) this should be clearly stated in the JRP protocol.

The objectives are based around the PRT submissions. As experts in the field, JRP proposers should establish the current state of the art, which may lead to amendments to the objectives - these should be justified in the JRP proposal.

- Development of techniques and calibration procedures for the neutron spectroscopy as required for ITER neutron test area and IFMIF.
- Measurement and evaluation of nuclear cross sections relevant for material in ITER and IFMIF (neutron energy up to about 40 MeV).
- Development of techniques and calibration procedures to measure fusion alpha particle losses in the conditions expected at ITER.
- Development of techniques and calibration procedures for photon spectrometry for energies up to 20 MeV.
- Development of metrological techniques for the dimensional in-situ measurement on the structure of the reactor.
- Development of measurement techniques the thermal properties of the first wall under ITER conditions
- Development of novel measurement techniques and sensor technologies, exploiting innovative sensing principles, e.g. based on fibre optics, for distributed, on-line and long-term monitoring purposes, able to operate under harsh environments.

Potential impact

Proposals must demonstrate adequate and appropriate participation/links to the "end user" community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the "end user" community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

Detail the impacts of the proposed JRP in accordance with the document "Guidance for writing a JRP"

You should detail how your JRP results are going to:

- Feed into the ITER and IFMIF teams
- Feed into the relevant support teams (recognising the decentralised nature of the ITER contributions and the role of EFDA)
- Contribute to wider appropriate standards activities
- Transfer knowledge to the grid & generation sector

Time-scale

Although first plasma operation at ITER is not expected until 2018 the first irradiations of instruments are expected in 2014 and ITER scientists are already considering the metrology requirements. The problems are severe and establishing the metrological basis needs an immediate start. Research in these area are also relevant for other fusion research facilities, such as the stellarator project Wendelstein 7X, expected to start operation in 2014.

Additional information

[1] European Metrology Research Programme. Outline 2008 Edition - November 2008 http://www.euramet.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/docs/EMRP-outline2008.pdf&t=1248796946&hash=9da9ceb781370f04c322ac48068deca5