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The construction of ITER is starting in Cadarache

The international nuclear fusion experiment ITER will be built in Cadarache, located in the south of France. This was decided in June 2005, following a ministerial meeting in Moscow, where the six ITER-partners – Europe, Japan, China, the Russian Federation, the USA, and South Korea – gathered to make the final choice between the Japanese site Rokkasho and the European site. The decision followed months of intense bilateral talks between the European Union and Japan, after the negotiations had been deadlocked for almost two years. This decision has made the fusion programme definitely change gear. The licensing activities have been launched and the international legal entity will be probably established at the end of the year. In the meantime, India is negotiating its participation, and with this enlargement of the consortium, the ITER partnership would become the largest scientific enterprise ever formed, grouping more than half the world population and three quarters of the world GDP. This is in phase with the ambition of the project: securing the world's future needs for energy with a clean, safe and CO2-free energy source and abundantly available fuel resources. And it is a key test case for large-scale international cooperation in the area of science and technology.

ITER is the main element of the present fusion roadmap. It will integrate the different technologies that have been developed up to now, and assess the control capability of a burning plasma device up to actual ignition. ITER will be the first fusion device to produce thermal energy at the level of an electricity-producing power station. Together with the breeding blanket programme, the material research and the IFMIF testing facility, it will lead the way towards the foreseen demonstration power plant (DEMO). Discussions are now ongoing on a fast track option to provide commercial electricity production at the mid of the century.

The decision on ITER construction questions however the present organisation of the fusion programmes in Europe. It requires specific adaptation inside each associated partner, and SCK•CEN in particular, to evolve from a research driven activity towards a more industrial approach, and to orient the on-going work into a real accompanying effort of the ITER initiative in the following decades.

ITER in Europe will indeed foster a major participation of the European industry to its construction and operation. Due to the high technological content of part of these deliverables, it offers a unique way to build up advanced competencies in view of broader realisations for the future fusion prototype reactors. Research institutes working in fusion technology projects for several decades, such as SCK•CEN, have a key role in this coming industrial participation. This is particularly the case for the design and manufacturing of advanced systems and components and the testing of prototypes under representative environmental conditions, including radiation.

The SCK•CEN involvement in fusion technology

For several years, SCK•CEN articulates its fusion technology contribution towards a crucial question: *"how do materials and equipment behave in severe radiation fields"?* This involves materials for first wall, vessel assembly and blanket, but is also extended to the radiation hardness of instrumentation components used for diagnostics and remote maintenance. This main fusion involvement is complemented by specific studies on environmental issues, in particular related to waste management, and to a few socio-economic aspects of future fusion energy production.

To perform its work, SCK•CEN relies on its core competences and available facilities, usually originated from its main involvement in fission reactor technology: irradiation capabilities, research in radiation effects on materials and instrumentation, on-going programmes in dismantling and waste disposal, and even its involvement in the design of an accelerator-driven spallation-source reactor. The fusion activities are driven by and put in synergy with these strong poles.

The main goal of evaluating the effects of radiation on materials and instrumentation is tackled in a comprehensive way, taking full use of all available facilities: the BR2 materials testing reactor of course, but also a wide range of fully equipped hot-cells, a variety of gamma sources, specialised laboratories for tritium and beryllium handling.

The quality of this involvement is recognised by a co-ordination role played for performance tests of new steels under radiation, and for radiation hardening of instrumentation.

SCK•CEN covers approximately one half of the Belgian contribution to the European fusion programme, in complement to the plasma physics research conducted at KMS/ERM and ULB, and to the industrial contributions of Belgatom through EFET. The SCK•CEN involvement encompasses also the participation of three additional fusion sub-partners: the GRADEL company in Luxemburg (remote handling), the IBA company in Louvain-la-Neuve (IFMIF accelerator) and the KULeuven university (copper corrosion).

Radiation effects on ITER materials: beryllium, tungsten and copper

The vacuum vessel structure and first wall of a fusion reactor has to withstand not only neutrons, but also very high heat fluxes at some locations. Behind the first wall covered by beryllium, tungsten or CFC, an active cooling involves the use of copper ducts. Moreover, behind the blanket modules, attachment parts in inconel are also subject to severe environments. Beryllium is also used in the form of pebbles in the breeding test blanket module, to be installed in ITER. Swelling, creep and reactivity of this material are critical issues to study in order to ensure a high reliability and safety. SCK•CEN helps assessing these materials, in order to guarantee the challenging requirements of ITER by:

- measuring the swelling and creep behaviour of highly irradiated beryllium, coming from our BR2 matrix, as well as the helium release effects when annealed (see also this contribution).
- evaluating the reactivity of new types of beryllium alloys (titanium beryllides);
- studying the effect of both neutron irradiation and thermal shocks on the behaviour of the diverter armour materials: beryllium, tungsten and carbon fibre composites, in close collaboration with FZJ and their JUDITH facility (see also appendix);
- assessing in-situ the mechanical performance and lifetime of copper when subject to the combination of neutron radiation, high temperature and mechanical stress, with a unique in-situ fatigue experiment operated in the BR2 reactor (see also this contribution)

The material for DEMO: EUROFER97

EUROFER97 is the reference steel for the future fusion reactors. It is a reduced activation ferritic martensitic steel with 9% chromium. Assessing its mechanical performance under neutrons and in the presence of liquid metals are critical questions to answer:

- a 2-year irradiation campaign has been completed on EUROFER97 specimens, including also joints and the oxide dispersion strengthened (ODS) version of the steel. The on-going post-irradiation examination will provide the necessary data for the reactor design ;
- a series of corrosion tests for irradiated EUROFER97 in liquid lithium-lead is about to start, after the construction of a dedicated hot cell environment ;
- the modelisation of irradiation effects is crucial to extrapolate the experimental data obtained with fission reactors: the binary alloy Fe-Cr is studied as a model alloy for EUROFER97, both theoretically (down to the atomic scale) and experimentally (see also this contribution)

Radiation effects on diagnostics systems

Diagnostics systems have been developed on existing tokamaks where no radiation constraints are present. ITER sets a particular challenge to these developments by requiring a high radiation tolerance in a severe environment. SCK•CEN has focused its work on four items:

- optical fibres allowing optical diagnostics to become more flexible and performant;
- degradation effects on insulation ceramics;
- radiation tolerance of bolometers and
- radiation effects in mineral insulated cables.

The activities involve:

- optimisation of the hydrogen treatment as a hardening technique for diagnostics fibres with metal coating and large core diameter and evaluating the performance of optical fibres for infra-red thermography ;
- assessment of the radiation degradation of insulators with representative in-reactor high-temperature tests under vacuum ;
- in-situ qualification of radiation hardened bolometers ;
- evaluation of the radiation and thermal effects appearing in mineral insulated cables .

Radiation effects on remote handling sensing systems

The remote maintenance of ITER will require sufficiently long lifetimes for the different components of the handling units to be used inside the vessel. SCK•CEN coordinates the European efforts in this domain, maintains a database of the radiation tolerance information, and sets particular emphasis on multiplexing techniques to alleviate umbilical problems of the handling units. The activities involve:

- the assessment of a radiation-hardened multiplexed electro-optic transmission link for remote handling sensors and the investigation of embarked dosimetry capabilities for remote handling equipment;
- the setting-up of a qualification methodology and quality assurance scheme for the radiation tolerance assessment of the ITER instrumentation.

Fusion waste management

Assessing the behaviour of materials under radiation must be complemented by studies on their management as nuclear waste. The fusion option is particularly attractive for its waste characteristics, but particular problems are to be solved for tritiated waste and special materials such as beryllium. SCK•CEN helps optimising the detritiation techniques in collaboration with FZK and studies specific waste issues such as recycling, disposal criteria and conditioning performance.

- The water detritiation system to be installed for JET can be seen as a prototype for the ITER installation. SCK•CEN evaluates the performance of a catalyst for this installation, studies the water purification requirements, assesses the capabilities to detritiate organic liquids, and conducts a small scale demonstration of the liquid phase catalytic exchange process .
- The fusion waste disposal strategy tends to avoid any deep geological burying. SCK•CEN evaluates the impact of present waste disposal acceptability criteria on this statement, in particular when considering beryllium and tritiated waste. For the particular case of beryllium, conditioning aspects have been studied, with particular attention put on long-term corrosion behaviour in a clay environment.
- Recycling is a critical issue in fusion waste management, especially for high value materials such as beryllium. An orientation study has been performed in collaboration with industrial foundries to evaluate the feasibility of a recycling option in case of highly radioactive metals.

Socio-economic studies

The waste problem touches a sensitive aspect of energy production: its acceptation by the public. Socio-economics aspects are therefore important in this debate, and must be considered with great attention. As part of its social science programme, SCK•CEN is evaluating communication aspects, related to the use of energy model argumentation (see also this contribution).

Organisation of scientific events

A series of fusion related events were organised or co-organised by SCK•CEN, such as

- two workshops on reduced activation steels and on the ethical perspective of fusion in Mol (December 2004)
- the 17th Conference on Optical Fibre Sensors (OFS-17) organised in Bruges (May 2005), and the 12th International Conference on Emerging Nuclear Energy Systems (ICENES) in Brussels (August 2005).
- SCK•CEN sponsored a fusion colloquium (Energy in the 21st Century: From Einstein to Controlled Fusion) in Brussels (March 2005)
- and contributed to an Agoria workshop on ITER in Brussels (December 2005).
- SCK•CEN insured a set of lectures on fusion in Belgian universities and is organising in Mol the interuniversity "Master of Nuclear Engineering" teaching under the framework of the Belgian Nuclear Higher Education Network (BNEN), with fusion is part of the curriculum.
- moreover, in January 2006, a fusion information day especially focused on industrial opportunities of ITER for the Belgian industry will be organised in Mol in collaboration with the Belgian Fusion Association, Belgatom and the federal/regional entities responsible for industrial policy

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