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The IAEA Fusion Energy Conference (FEC) is the main fusion conference, held every second year. This year's event marked the 50th anniversary of the 2nd International Conference on Peaceful Uses of Atomic Energy, held in the same premises at the *Palais des Nations* in Geneva, during which magnetic confinement fusion research was declassified.

The 22nd FEC was attended by 761 participants from 42 countries; the contributions included 116 oral presentations and 507 posters.

The two approaches to fusion are traditionally presented at the FEC:

- magnetic confinement (more than 80% of the contributions), which aims at producing hot (10-20 keV) but low density D-T plasmas (1-2 atm.) in large volumes (order 1000 m³) confined by strong magnetic fields; the most successful type of device being the tokamak, now followed by stellarators.
- Inertial confinement, which aims at producing bursts of fusion power by compressing and heating with laser beams (or ion beams) small (sub-cm size) D-T targets to very high pressures (around 10¹¹ atm.). Inertial fusion R&D is driven by defence projects (National Ignition Facility NIF in the US and Laser Mega Joule LMJ in France) accompanied by civilian projects in several countries.

Magnetic Confinement:

It was recalled during the opening talk that the famous Russian physicist L.Artsimovitch said at the 1958 Geneva Conference: "plasma physics is very difficult; worldwide collaboration is needed for progress." And indeed, 50 years later, a most striking feature of the 22nd FEC is the success of international collaboration, which resulted in tremendous scientific and technical progress, from the confirmation of the first success of the tokamak at the end of the 1960's, followed by the doubling of the confinement parameter $n\tau T$ every two years over 3 decades, to the launch of the ITER project with seven parties involved representing more than half of the world's population (China, EU, India, Japan, Korea, Russian Federation, US).

Another striking feature of the conference is that ITER has started providing a powerful drive for physics and technology R&D all over the world. The vast majority of tokamak results presented at the conference aim at supporting ITER design choices, developing modes of plasma operation applicable on ITER or addressing ITER relevant physics issues.

The status of ITER was presented in various talks. ITER aims at demonstrating the scientific feasibility of magnetic confinement fusion in view of future energy production. The main objective is to produce 500 MW or more of fusion power with a gain Q of 10 or more ($Q = \text{fusion power} / \text{external power used to heat the plasma}$). The ITER Organisation was set-up officially in October 2007. The construction is foreseen to last 10 years, with first plasma in 2018 (2 years later than in the original schedule). ITER has undergone a design review in 2007 which results in a fairly optimised design. No information was provided on the cost of the project, while cost increases are in the background since mentioned by *Nature* in June 2008.

Key tests in preparation of ITER construction were reported, among which three are highlighted here: the Nb-Ti and Nb₃-Sn conductors required for the large superconducting coils have been qualified with adequate margins; a world record was obtained with a Japanese gyrotron operating at 170 GHz, 1MW, 800s, reaching ITER specifications except for the pulse duration (3600s); ITER-like antenna concepts are being successfully tested on Tore Supra (France) and JET (EU). Important progress was also reported on prototyping in preparation of the construction of the Divertor, First-Wall, Shielding Blanket, Vacuum Vessel and Cryopump.

Several tokamaks have demonstrated plasmas that meet ITER requirements, although more work is required towards a full set of ITER-like operating conditions. In particular performance with metal walls to reduce erosion and fuel retention looks promising (the first full tungsten wall was recently experienced on ASDEX-Upgrade, Germany), but more work need to be done. The ITER-like wall experiment in preparation at JET (W and Be) is expected to play a crucial role in the next years.

Steady-state operation has seen significant advances, with fully non-inductive operation of tokamaks, but issues remain for long pulse operation, in particular with localized heat/particle handling and heating systems technologies. New superconducting tokamaks have started operation recently, EAST in China (first plasma in September 2006) and KSTAR in Korea (first plasma in June 2008; first tokamak using Nb₃Sn superconducting coils as ITER).

Transport of particles, heat or momentum, remains a key topic related to the performance of magnetic confinement devices. Theory-based models for particle transport have seen progress and experimental validation. Clear evidence of critical temperature gradient has been demonstrated; the evidence of zonal flows reducing turbulent transport is growing. Worldwide work on heat and particle transport confirms former predictions of ITER performance. Significant efforts are now targeting the description of momentum transport in the plasma.

Progress has been achieved to avoid or mitigate transient events, with, in particular, an increased level of confidence for controlling and mitigating such events on ITER, supported by experiments (e.g. DIII-D, US and JET, EU), theoretical analysis and modelling. Real time control of magneto hydro dynamics (MHD) instabilities has seen further advances, which should increase operational margins and allow normalized plasma pressure operation above ITER requirements.

The stellarators research line is also progressing steadily, with the superconducting helical device LHD, Japan, operating in nearly ¼ hour pulses and exploring ways towards high plasma pressure operation. The superconducting stellarator W7X (Germany) construction is on good track, with first plasma foreseen in 2014.

Inertial Confinement

In the US the NIF is almost completed with 4.2 MJ laser obtained in September 2008. The first DT experiments are foreseen in 2010, and high gain $G \sim 10-20$ ($G = \text{fusion energy/laser energy to target}$) experiments foreseen a few years later.

The Fast Ignition Scheme is progressing steadily with several experimental and theoretical work reported; compared to the direct drive technique, this approach drastically reduces the

requirements in terms of laser energy required to bring the target to ignite. “Sub-ignition” experiments will start soon on the facilities in US (OMEGA-EP) and Japan (LFEX). The fast ignition concept will be tested with 10-30 kJ lasers for compression and ~5kJ 10ps lasers for heating. Future high-gain experiments are projected in Japan (FIREX II) and Europe (HIPER).

Challenges ahead

Two key experiments are in preparation in magnetic and inertial fusion: ITER and NIF, which should demonstrate the possibility to achieve burning plasmas in controlled conditions. From these experiments to energy production significant technological and operational challenges are still ahead:

- for magnetic confinement: steady state (or very long pulses, several hours long) operation of high power plasmas will have to be achieved, which puts a challenge on plasma operating modes, heat control and heating and current drive technologies.

- for inertial confinement: the rate of pulses will need to be brought from about one per hour to about ten per second, which represents a challenge in terms of target launch (targets will have to be shot in flight with about 10 μ m accuracy) and high power lasers repetitive rates; laser efficiencies also have to increase significantly. Very little material on these topics was presented at the conference.

- for both magnetic and inertial confinement: materials resisting high fluences (~100 dpa) of 14 MeV neutrons need to be developed as well as in-situ tritium breeding. Significant efforts are conducted on both topics in the field of magnetic fusion research with a number of contributions to the FEC on (1) reduced activation and low activation structural materials and on functional materials, (2) the R&D in preparation of a set of test tritium breeding blanket modules for ITER and (3) the engineering validation and engineering design activities (EVEDA) of IFMIF conducted in the frame of an EU-Japan collaboration (started in June 2007 and foreseen to last 6 years); the project aims at designing an irradiation facility able to mimic the fusion neutron spectrum to qualify materials. All data necessary to decide on construction should be available by the end of the EVEDA; discussions on IFMIF siting and collaboration during the construction and exploitation phase have not started yet.

Conclusion

Steady progress has been reported on fusion R&D. The ITER project provides a strong focus for magnetic confinement research. The reports presented show reasonable optimism that ITER will succeed, with a start of operation foreseen in 2018. On inertial confinement, a key step is the achievement of a multi-mega Joule laser pulse on NIF; DT experiments should follow in 2010. Many challenges are being taken by a broad fusion R&D programme, preparing key scientific demonstrations to be made over the coming two decades.

Conference web site:

<http://www-pub.iaea.org/MTCD/Meetings/Announcements.asp?ConfID=165>