Proposals for an influential role of small tokamaks in mainstream fusion physics and technology research

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Abstract. Small tokamaks may significantly contribute to the better understanding of phenomena in a wide range of fields such as plasma confinement and energy transport; plasma stability in different magnetic configurations; plasma turbulence and its impact on local and global plasma parameters; processes at the plasma edge and plasma-wall interaction; scenarios of additional heating and non-inductive current drive; new methods of plasma profile and parameter control; development of novel plasma diagnostics; benchmarking of new numerical codes and so on. Furthermore, due to the compactness, flexibility, low operation costs and high skill of their personnel small tokamaks are very convenient to develop and test new materials and technologies, which because of the risky nature cannot be done in large machines without preliminary studies. Small tokamaks are suitable and important for broad international cooperation, providing the necessary environment and manpower to conduct dedicated joint research programmes. In addition, the experimental work on small tokamaks is very appropriate for the education of students, scientific activities of post-graduate students and for the training of personnel for large tokamaks. All these tasks are well recognised and reflected in documents and understood by the large tokamak teams. Recent experimental results will be presented of contributions to mainstream fusion physics and technology research on small tokamaks involved in the IAEA Co-ordinated Research Project " Joint Research using small tokamaks", started in 2004.

Keywords: Tokamak, Plasma, Turbulence, Plasma diagnostics, Fusion Technology.
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INTRODUCTION

Much of the world-wide effort on magnetic fusion is devoted to the present and future generations of large tokamaks. In many countries (Brazil, Canada, China, Czech Republic, Egypt, Germany, India, Iran, Italy, Japan, Libya, Mexico, Portugal, Republic of Korea, Russian Federation, Turkey and USA) more than 40 small tokamaks are operational. Research on these tokamaks is mostly on the basis of domestic programmes and only in a few cases also in the frame of an international co-operation.

Because of the compactness, flexibility, low operation costs and high skill of their personnel, the small tokamaks may significantly contribute to the better understanding of phenomena in a wide range of fields such as plasma confinement and energy transport; plasma stability in different magnetic configurations; plasma turbulence and its impact on local and global plasma parameters; processes at the plasma edge and plasma-wall interaction; scenarios of additional heating and non-inductive current drive; new methods of plasma profile and parameter control; development of novel plasma diagnostics; benchmarking of new numerical codes etc. Furthermore, small tokamaks are very convenient to develop and test new materials and technologies, which because of the risky nature cannot be done in large machines without preliminary studies.

Small tokamaks are suitable and important for broad international cooperation, providing the necessary environment and manpower to conduct dedicated joint research programmes. Given the importance of the continuation of joint research on small tokamaks in order to support national fusion programs, international collaboration and the ITER project, a new concept of interactive co-ordinated joint research using small tokamaks was started in 2004 under an IAEA *Co-ordinated Research Project* **(**CRP) [1], in order to better explore the synergies from a network approach on the planning of the research to be conducted.

Specific objectives of this CRP are:

- Direct contribution of small tokamaks to mainstream fusion physics research.
- Small tokamaks as a test-bed of new tools, materials and technologies for large machines.
- Improvement and development of diagnostics.

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- Education&training

Whereas the question of small, medium and large tokamak classification arises one can say that a small tokamak is the versatile device with relatively low operation budget allowing for a significative component of yearly flexible research activities within the major research programme. Their geometrical and plasma parameters are usually one or two smaller than for large devices (Table 1). The classification becomes somewhat more subjective for the medium size devices. The main target of the CRP is to enhance the contribution of small tokamaks to the main stream fusion research, conducted in large devices. It is clear that for maximizing this contribution a close collaboration between small, medium and large tokamaks research activities must always exist at all levels.

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TABLE 1. Comparison between the main parameters of the small tokamak CASTOR and the large tokamak JET.

	CASTOR	JET	magnitude ratio (10^{-n})
Major radius (m)	0.4	3.5	1
Minor radius (m)	0.1	1	1
Toroidal field (T)	1	3.5	0
Plasma current (MA)	0.01	5	2
Pulse length (s)	0.05	30	3
Electron temperature (keV)	0.2	10	2
Ion temperature (keV)	0.05	10	3
Plasma density (m^{-3})	10^{19}	10^{20}	1
Energy confinement time (s)	0.001	1	3
Budget per year (a.u.)	0.5	50	2
Manpower (My)	15	300	1
Edge plasma density (m^{-3})	10^{17} - 10^{18}	10^{18} - 10^{19}	1 - 2
Edge plasma temperature (keV)	0.01 - 0.04	0.2 - 0.5	1 - 2

DIRECT CONTRIBUTION OF SMALL TOKAMAKS TO MAINSTREAM FUSION RESEARCH

Transport Barriers, Electric Fields, Turbulence

The understanding and reduction of turbulent transport in magnetic confinement devices is a matter of practical interest. High confinement and reduced transport is a constraint for the operation of ITER and possible future reactors since it reduces size and cost. Generally speaking, turbulence comes in two classes: electrostatic and magnetic turbulence. Over the last decade, step by step new regimes of plasma operation have been identified, whereby turbulence can be externally controlled, which led to better and better confinement. The physical picture that is generally given is that by spinning up the plasma, it is possible to create flow velocity shear large enough to tear turbulent eddies apart before they can grow, thus suppressing electrostatic turbulence. This turbulence stabilization concept has the universality, needed to explain ion transport barriers at different radii seen in limiter-and divertor tokamaks, stellarators, reversed field pinches and mirror machines with a variety of discharge- and heating conditions and edge biasing schemes.

Although turbulence measurements have been performed on many magnetic confinement devices during the last decades, the additional insight gained from these experiments is relatively limited. This can be attributed to a number of reasons: Firstly, only a very coarse spatial resolution was achieved in many measurements of electric fields and turbulence. Secondly, simultaneous measurements of different fluctuating quantities (temperature, density, electric potential and magnetic field) at the same location, needed for a quantitative estimation of the energy and particle transport due to turbulence were only performed in a very limited number of cases. Thirdly, theoretical models were often only predicting the global level of turbulence as well as the scaling of this level with varying plasma parameters.

The investigation of the correlations between on the one hand the occurrence of transport barriers (TBs) and improved confinement in magnetically confined plasmas, and on the other hand electric fields, modified magnetic shear and electrostatic and magnetic turbulent fluctuations necessitates the use of various *active means to externally control plasma transport*. It also requires to characterize fluctuations of various important plasma parameters inside and outside transport barriers and pedestal regions with high spatial and temporal resolution using *advanced diagnostics*, and to elucidate the role of turbulence driving and damping mechanisms, including the role of the plasma edge properties. The experimental findings have to be compared with advanced theoretical models and numerical simulations. Small tokamaks are particularly suited for these studies since they can make use for instance of dedicated emissive probes and Langmuir probes arrays that can penetrate in the main plasma which otherwise will be damaged in a large device.

On T-10 investigations are conducted to clarify the physical mechanisms behind the observed role of the vicinity of rational q-surfaces (magnetic shear) in the formation and sustainment of electron internal transport barriers (e-ITBs), the correlation between changes of turbulence characteristics, radial electric field and rotation velocity during ITB formation, and the self-organizing nature of the plasma pressure profile (ITBs are a specific feature of this process) and fluctuations [2].

Since the pioneering work on the tokamak CCT, many papers have been devoted to the effect of *electric biasing* in specific machines which in general leads to a strongly varying radial electric field as a function of radius and a resulting sheared E×B flow, giving rise to improved confinement properties [3, and references therein]. A (bias-induced) H-mode can also be triggered externally by imposing an electric field and the resulting ExB rotation in tokamaks like TEXTOR, STOR-M, CASTOR, T-10, ISSTOK [4], TCABR, etc. These electrode biasing experiments have contributed significantly to the understanding of the *H-mode phenomenon (Edge Transport Barrier, ETB)* and of the effects of electric fields on plasma transport.

Emissive electrode biasing experiments have been performed on ISTTOK. In the scrape-off layer (SOL) plasma the turbulent transport was strongly reduced by biasing of both polarities, however, MHD activity was not strongly influenced by the biasing. The radial electric field component E_r is measured by two electron-emissive probes with a radial distance of 3 mm from each other. It turned out that there is always a finite, usually positive (i.e., outward) stationary radial electric field in this region, both for the ohmic and for the biased parts of the discharges. A pronounced minimum of E_r appeared in all cases for $r - a = 0$, where the field also becomes negative. A decrease of the radial field was observed for $r - a \geq 0$ for positive bias. For negative bias, in the same region E_r became larger. For almost all cases, positive and negative biases led to a considerable reduction of the fluctuations of the radial electric field by up to 60%, but positive biasing was more effective over a wider range of radii, whereas a negative bias had almost no effect outside the Last Closed Flux Surface [5].

On CASTOR recently the behaviour of the plasma column at high biasing voltages was studied. These experiments have shown an effective establishment of improved confinement, characterized by the rising of the transport barrier at the edge through steeper density and radial electric field gradients. Critical gradients were periodically achieved and followed by a relaxation at about 10 kHz, associated with a stream of density propagating radially to the wall [6].

Other methods than electrode biasing are utilized to simulate H-modes and TBs. In TCABR the generation of sheared fluxes by Alfvén waves is used to trigger the H-mode and ITBs.The antenna module that is currently installed in TCABR, with the objective of producing plasma heating and current drive, can be configured to favour power deposition at the plasma periphery and production of poloidal fluxes. Pellet injection has been used in TUMAN-3M. Compact Torus Injection (CT) [7] is used in STOR-M to trigger an H-mode. For the CT injection experiments hydrogen CTs can be formed and accelerated between coaxial electrodes with typical densities of the order of 10^{15} cm^{-3}. The measured velocity is approximately 120 to 200 km/s. The inner and outer radii of the CT ring are 1.8 cm and 5 cm respectively. The estimated CT length is 15 cm. The CT mass is in the order of 1 μg, representing 50% the particle inventory in STOR-M.

Improvement & Development of diagnostics, with emphasis on the plasma boundary

During the last decade it became increasingly clear that boundary plasmas play a major role in magnetic fusion experiments, and strongly relate to and even dominate central plasma processes. On the one hand, the conditions of the boundary plasma are crucial to obtain high fusion triple products; on the other hand, plasma-surface interactions, a sufficiently low impurity concentration in the fusion volume, heat removal and helium exhaust which directly relate to the boundary plasma, have emerged as equally important goals, and even more difficult to reach in the state of self-sustained thermonuclear burn. Successful resolution of these issues is critical to establish the viability of the tokamak confinement concept as a fusion power reactor.

All these requirements invoke a complex interplay of core plasma, boundary plasma, and atomic and surface physics. Hence, there is an *ongoing effort regarding plasma diagnostics which is essential to improve our understanding of the tokamak boundary*. The employment of edge diagnostics has to take into account the specific properties of the plasma edge, taken here to be synonymous with the plasma boundary. In magnetic confinement devices the plasma is confined within closed magnetic surfaces, normally generated by a combination of fields due to external conductors and by currents flowing in the plasma.

Probe measurements (one of the earliest approaches in plasma diagnostics) complement spectroscopy by providing detailed profiles of local plasma parameters, as well as quantities like electric fields in the edge plasma which are difficult to determine spectroscopically, and the role of which in plasma confinement and exhaust is now widely recognized. Furthermore, electrostatic turbulence-driven transport, which is generally believed to be the origin of anomalous edge particle transport in tokamaks, can only be fully evaluated with probes. Probe techniques for plasma edge diagnostics in magnetic confinement devices can be broadly divided into two categories: *electrical (active) and surface collection (passive) methods*. With electrical probes real time measurements are obtained as electrical currents drawn from the plasma; they encompass different types of Langmuir probes, and advanced electrical probes such as gridded energy analyzers and mass spectrometers. With collector probes, on the other hand, the deposition of impurities on a collecting target or the implantation of particles within a surface are studied after exposure of the material to one or a number of tokamak discharges.

For the determination of the plasma potential in tokamaks emissive probes and heavy ion beam probes have been used, but these diagnostics are not still used as a routine technique. In practice the floating potential V_{fl} is usually measured by Langmuir probes. The plasma potential Φ_{pl} is estimated from the simple formula of Langmuir probe theory (without magnetic field): $V_{fl} = \Phi_{pl} - T_e \ln(R_i)$, where T_e is the electron temperature in eV. The quantity R_i represents the ratio of the electron and ion saturation currents: $R_i = I^e_{sat} / I^i_{sat}$. The theoretical value of $\ln(R_i)$ in hydrogen plasma is about 2.5. The basic idea of the direct plasma potential measurements with the novel *"ball-pen probe"* (BPP) developed on CASTOR [8] is to adjust R_i equal to one. If this can be achieved the floating potential of the probe is equal to the plasma potential. The probe is designed so that the ratio R can be modified by changing the collecting areas for electrons and ions, taking advantage of the fact that the Larmor radii of electrons and ions are strongly different. The design of the BPP on CASTOR is shown in the schematic picture of Figure1. The probe consists of a conically shaped collector, which is shielded by an insulating tube made of boron nitride. The collector, which is movable inside the tube, is either completely shielded (h<0 in the left panel of Figure 1) or partially exposed (h>0 in the right panel of Figure 1) to the plasma. The probe collector can be biased by a swept voltage to estimate the T_e and the ratio R from the *I-V* characteristics, or can be electrically isolated (floating) to measure the potential *Vprobe* In the ideal case, when the collector is hidden inside the tube, in principle only ions with sufficiently large Larmor radii can reach the collector surface and the collecting area for electrons is zero. Consequently, the ratio $R = 0$.

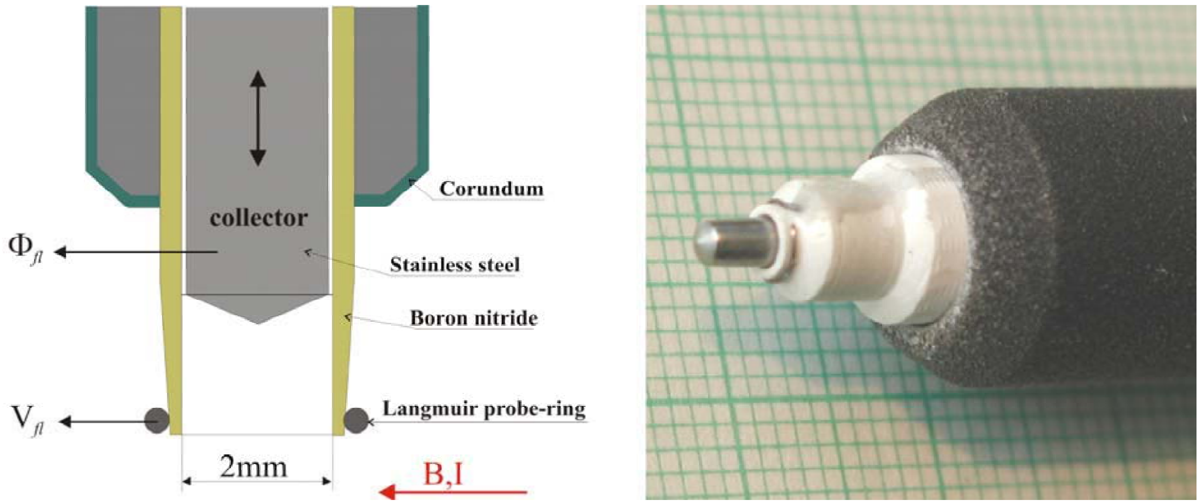

FIGURE 1. Left panel: Schematic of the ball-pen/standard Langmuir probe combination. The conical collector can be moved inside the boron nitride (BN) screening tube that acts as a shield for electrons, h is the position of the collector tip inside the tube relative to the top cross section plane of the shielding BN tube. The Langmuir probe is made of 0.2mm diameter tungsten wire. Right: photograph (fully exposed collector).

Among the various diagnostic tools to measure the edge *electron temperature* T_e in a plasma, probes are the least expensive, simplest and most versatile. Probes can be used in most types of plasma, even in the plasma of medium-size tokamaks, and they allow localised measurements with good spatial resolution. The usual and best known method to determine T_e with a cold probe is to register the current-voltage characteristic and to evaluate the exponential increase of the electron current in the retarding field region. A disadvantage of this method is its low temporal resolution which naturally is limited by the frequency with which the characteristic can be scanned.

A new kind of robust Langmuir probe, the *(segmented) tunnel probe (TP)* has recently been developed for measurements of the electron and ion temperature [9].The probe is shown in Figure 2 and consists of a hollow conducting tunnel (TUN) of 5 mm diameter that is closed at one end by an electrically isolated 5mm diameter conducting back plate (BP). Both conductors are biased negatively to collect ions and repel electrons. The tunnel axis is parallel to the magnetic field B. Plasma flows into the orifice, and the ion flux is distributed between the tunnel and the BP. The ratio $R_c = I_{TUN}/I_{BP}$ between the current to the tunnel (two segments shorted together) and that to the back plate, respectively, is determined by the thickness λ_{MS} of the magnetic sheath (MS) at the concave surface of the tunnel, and is therefore a strong function of T_e. The physics governing the TP is fundamentally different from that of a classical Langmuir probe (LP). The applied voltage on the LP is swept in order to measure a restricted part of the electron distribution function. The TP, on the other hand, is biased to a fixed potential that is sufficiently negative to repel all electrons. *The temperature of the electrons is measured even though none are collected.* The ion current for highly negative voltages is almost perfectly saturated, demonstrating the immunity of concave probes to sheath expansion effects, a problem that has always plagued convex LP applications. The TP can operate in DC mode and therefore provides fast measurements of Te (fluctuations). Moreover, due to the clearly defined tunnel orifice, this probe is not subject to the uncertainties of collecting area from which classical convex probes suffer. The tunnel radius should be roughly twice the thickness of the magnetic sheath. Precise self-consistent, two-dimensional kinetic "particle-in-cell" code XOOPIC is possible because of the simple TP geometry, and is used to determine the theoretical relation between the current ratio $R_c = I_{TUN}/I_{BP}$ and T_e.

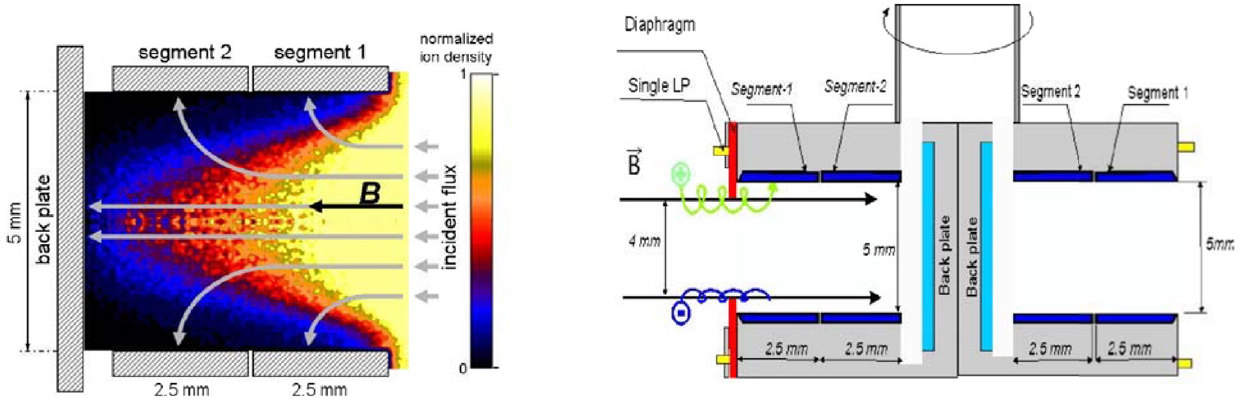

FIGURE 2.. Left panel: schematic of the segmented tunnel probe (TP). The current collected by each of the three electrically insulated conductors is monitored separately. The ion guiding centre trajectories are shown by arrows. Right panel: modified TP; left hand side: ion-sensitive segmented Katsumata TP; right hand side standard segmented TP.

The ion temperature in the tokamak scrape-off layer is notoriously difficult to measure and thus rarely available. The ions that flow into the orifice of the segmented TP (Figure 2) are diverted onto the tunnel surface by the intense radial electric field in the magnetic sheath. The ion distribution along the tunnel decays with a characteristic scale length, which is a function of the ion temperature. Therefore, by splitting the tunnel into two electrically insulated segments, the (parallel) ion temperature T_i can be found from the ratio of ion flux to the first and the second segment, $R_c = I_{seg1}/I_{seg2}$.The advantage is that the TP is operated in DC mode and thus provides fast measurements of T_i as well as of the parallel ion current density $J_{//,i}$. The modified TP shown in the right panel of Figure 2 allows to measure the perpendicular ion temperature. In front of the entrance orifice of the tunnel (left-hand side only) an additional diaphragm is mounted, which transforms it into an ion-sensitive (Katsumata) probe, the *modified Katsumata tunnel probe.* Due to the diaphragm, which protrudes from the tunnel by 0.5mm around the entire circumference, the electrons should in principle not be able to reach the tunnel segments.

An important research topic in the CRP (CASTOR, ISTTOK, STOR-M) is the investigation of the poloidal and toroidal components of the *flow velocity* of the plasma ions in different operating regimes using a *Gundestrup probe*. The Gundestrup probe [10] is an array of collectors around a cylinder. The cylinder is inserted in the plasma with its axis perpendicular to the flux surfaces. Each collector is biased negatively to ion saturation such that polar diagrams of the ion saturation current are obtained as a function of the radial position in the plasma. Using the appropriate model, the poloidal and toroidal Mach numbers can be obtained from the polar diagram such that velocity profiles can be determined.The evolution and modification of these profiles during discharges will be crucial in understanding the physical mechanisms responsible for the generation of the high confinement mode.

In the plasma interior *magnetic fields* can be measured with spectroscopic methods. From magnetic field measurements performed outside the plasma important properties like plasma current, energy content and MHD fluctuations together with their mode structure can be inferred. Such measurements utilize different types of coils. As the discharges became longer, the evaluation of B from its measured time derivative has become increasingly difficult, because the integration needs a precise determination of possible offsets in the preamplifiers. Recently, *Hall probes* have been used on TEXTOR and CASTOR [11] to measure the absolute value of B directly together with its fluctuations in the boundary plasma of tokamaks. The strongest objection against the use of Hall sensors in the reactor type tokamak is their vulnerability to radiation damage (in particular to the high neutron fluxes). This is presently being investigated.

On the spherical tokamak ETE a single-channel optical detection system of the fast neutral lithium beam probe allows measurements of the density and its fluctuations at the edge, with good spatial and temporal resolutions, of the order of 1.5 cm and a few nanoseconds, respectively .

Test-bed for new tools, materials and technologies for large machines

Small tokamaks are very convenient to develop and test new tools, materials and technologies for large machines, which because of the risky nature cannot be done in large machines without preliminary studies**.**

On T-10, analysis of peculiarities of *generation of thin films and dust* during operating regimes and wall conditioning processes, studies on the dependence of film structure on formation conditions, partition of hydrogen isotopes in film and other plasma-surface interaction studies is being performed [12]. Recently an interesting phenomenon has been discovered on wall components of tokamaks such as T-10 and TEXTOR. It concerns the fractal growth of the dust and films (surface layers) which may be a critical issue for the safety of ITER and future fusion reactors, in particular for the tritium inventory. The microstructures are studied using (in-situ) scanning tunnel microscopy, stationary tunnel microscopy and atomic force microscopy. The tritium balance research in JET and particle balance investigations on different tokamaks show the dominant role of deposited films in hydrogen isotope absorption. Different structures of carbon films were observed in T-10, which differ in deuterium fraction. The study of film deposition conditions, film structure, and hydrogen isotope content is one of the priority problems of plasma-surface interaction research on T-10.

It is a well known fact the materials currently used in large size experimental fusion devices are submitted to very high power loads (up to GW/m^2 during off-normal events). As a result of the high erosion levels and thermal stress produced by such power loads, a frequent replacement of the plasma facing components is to be expected in the present approach of the fusion research programme. A further problem is the neutron activation of solid walls. This matter is so critical that the economical viability of the fusion energy production by magnetic confinement could be compromised. One possible way to overcome that issue is linked to the use of *liquid metals as plasma facing components*. The possibility to perform a permanent renewal of liquid surfaces has been pointed out as one adequate solution for both the protection of solid walls and an efficient power exhaustion process from fusion plasmas. Among a set of several liquid metals lithium has, up to now, shown the best compatibility with fusion plasmas, mainly due to its low Z. Nonetheless, another candidate that has good thermal properties, a wider liquid range and lower vapor pressure is gallium.

On T-10, plasma control with lithium gettering , the use of lithium elements as plasma-facingcomponents, and particle transport in the presence of Li are under investigation. ISTTOK will be used to test the behaviour of a liquid Ga jet in the vacuum chamber and its influence on the plasma [13]. Experiments with lithium limiter are carried out on T-11M tokamak and the perspectives of the Lithium Capillary-Pore System for fusion are investigated [14].

Test of *control algorithms* developed for large tokamaks and ITER at low aspect ratio may provide important benchmarking of the developed methods. Here the GUTTA contribution with R/a ~2 may be highly valuable. For these areas of fusion research, the GUTTA tokamak [15] benefits from a flexible poloidal field configuration, good vacuum conditions, excellent availability and good access for diagnostics. On STOR-M an advanced control (e.g., fuzzy logic bases plasma position feedbackcontrol) is being developed, and *Compact Torus Injection* is used for fueling and pressure profile control.

On the ETE tokamak the design and construction of a high-power 6.7 GHz monotron and studies of advanced concepts of corrugated waveguides and cavity resonators were carried out, looking for plasma heating applications in the future.

An alternative method of non-inductive (without use of the central solenoid) plasma *current start-up and sustainment* will be tested on the SUNIST spherical tokamak. The plan is to produce a seed current using ECR (ECRH/EBW assisted breakdown) with electrode discharge assistance and to investigate how to transfer that current into a typical spherical tokamak discharge.

Since a *runaway avalanche* in disruptions is considered a serious problem for ITER, detailed investigation of this process is a relevant fusion-related activity, which can be carried out under controlled conditions in small tokamaks. On TCABR runaway electron phenomena are investigated [16]. There are two mechanisms of runaway electron generation in plasmas with an applied electric field. The Dreicer (primary) process is caused by collisional diffusion of electrons in velocity space to velocities higher than a critical one. The primary mechanism provides a stationary runaway flux. The secondary mechanism pointed out by Sokolov (1979) is caused by close collisions of existing runaway electrons with thermal ones and provides runaway avalanches. At typical values of plasma parameters and electric field, both these processes are rather weak and their role diminishes for reactor conditions. However, it was recognized recently that the avalanche process plays an important role during disruptions, when a high value of the toroidal electric field is generated inductively, triggering the transformation of the plasma current to runaway current. On T-10 the generation of suprathermal electrons is studied during disruption in ECRH/ECCD experiments. Thermal and nonthermal SXR emission in a direction tangential to plasma column is measured using an SXR spectrometer.

Intensive *fusion materials studies* are planned in the newly designed compact (A=2) Kazakhstan Tokamak for material testing (KTM) [17].

Databases and remote participation

The development of tools to bring in close communication the scientists involved in the CRP project is of crucial importance. A web page containing dedicated designed interfaces allows for files upload/download, discussion forums and will integrate a standard interface for remote participation allowing for remote operation, real time video link and database access of any device (the work is in progress). The web-tools under development are being assessed in view of future application to other operating devices. The small tokamak network is being used to test and improve the remote participation tools.

Training, expertise development and capacity building

Several activities are being developed aiming at improving the level of expertise of young students. Joint Experiments and Training Courses at CASTOR were developed in a co-ordinated way and supported through the IAEA and ICTP. The next Joint Experiment is scheduled for September 2006 to take place at tokamak T-10, Moscow. The tokamak ISTTOK is a good example of capacity building through the integration of tokamak research topics in PhD and Master Thesis programmes. On the GUTTA tokamak a laboratory project for undergraduate students on "Plasma equilibrium control in a tokamak" will be introduced as a part of the academic educational programme. The European Master in Nuclear Fusion Science and Engineering Physics (http://www.em-master-fusion.org), starting in the academic year 2006-2007 foresees the participation of candidates in the small tokamaks activities as part of their graduation studies.

The collaboration with other organizations, in particular those operating large facilities, would contribute to enlarge the capacity building potential of the CRP activities.

CONCLUSIONS

The contribution of small tokamaks to the main topics of fusion research can be enhanced through coordinated planning. The activities under the IAEA Coordinated Research Project are already paying visible dividends. Contributions on edge physics transport and turbulence, H-mode like plasmas, heating, wall interaction, diagnostic development and tokamak technology have been reported in refereed scientific journals and were summarized in this paper. By increasing the networking culture among small tokamaks and attracting medium and larger devices to this project would allow to bridge their findings so that the research outputs from small tokamaks can provide complementary insight into basic physical phenomena in fusion plasmas and contribute with input data to large modelling codes.

REFERENCES

1. M. Gryaznevich et al., *Nucl.Fusion* **45,** 1-10 (2005).
2. K.A. Razumova et al., *Nucl.Fusion* **47,** 1-10 (2005)**44,** 1067-1074 (2004).
3. G. Van Oost et al., *Plasma Phys. Contr. Fusion* **45,** 621-643 (2003).
4. C. Silva et al.,*Plasma Phys. Contr. Fusion* **46**, 163 (2004).
5. P. Balan et al., *these Proceedings.*
6. M. Spolaore et al., *Czech.J.Phys.* **55,** 1579-1586 (2005).
7. S. Sen et al. *Phys Rev Lett.* **88**, 185001 (2002).
8. J. Adamek et al. J., *Czech.J.Phys.* **54**, **Suppl. C**, C95 (2004).
9. J.P. Gunn et al., *Rev. Scient.Instr.*7**5**,4328-4330 (2004).
10. J.P.Gunn et al., *Physics of Plasmas* **8**, 1995 (2001).
11. I.Duran et al., *Rev. Scient.Instr.***73**,3482 (2002)
12. L.N. Khimchenko et al., 32nd EPS Conference on Plasma Phys. Contr. Fus., Tarragona, 2005, p. 2.016
13. R.Gomes et al., *these Proceedings.*
14. S.V. Mirnov et al., *these Proceedings.*
15. G.M.Vorobyov, *these Proceedings.*
16. R M O Galvao et al., *Plasma Phys. Contr. Fusion* **43,** 1181 (2003).
17. E.Azizov et al., *these Proceedings.*