# Joint Research Using Small Tokamaks

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**Abstract.** Small tokamaks have an important role in fusion research. More than 40 small tokamaks are operational. Research on small tokamaks has created a scientific basis for the scaling-up to larger tokamaks. Well-known scientific and engineering schools, which are now determining the main directions of fusion science and technology, have been established through research on small tokamaks. Combined efforts within a network of small and medium size tokamaks will further enhance the contribution of small tokamaks. A new concept of interactive co-ordinated research using small tokamaks in the mainstream fusion science areas, in testing of new diagnostics, materials and technologies as well as in education, training and broadening of the geography of fusion research in the scope of the IAEA Co-ordinated Research Project is presented.

## 1. Introduction.

Much of the world-wide effort on magnetic fusion is devoted to the present and future generations of large tokamaks. At the same time, 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. On these tokamaks, research is carried out mostly on the basis of domestic programmes and only in a few cases also in the frame of an international co-operation.

Small tokamaks have played a very important role in fusion research. They have created a scientific basis for the scaling-up to larger tokamaks and established the well-known scientific and engineering schools, which are now determining the main directions of fusion science and technology.

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 and so on.

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. 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 ITER documents and understood by the large tokamak teams.

In the past, assessment of the output from the small tokamak research programmes has shown the need for stronger links between the small and large tokamaks and better co-ordination of the collaboration between small tokamak research projects [1]. The recent discussion between scientists from many countries during the last sessions of the TM on Research Using Small Fusion Devices (RUSFD) in Vienna in May 2003 has shown the importance of the continuation of joint research on small tokamaks in order to support national fusion programs, international collaboration and the ITER project, under an IAEA **Co-ordinated Research Project** (CRP). This project has started in 2004 and preliminary results of its activities are presented in this paper.

The overall objective of this CRP is to achieve a network of fusion research using the innovative possibilities of small tokamaks. Furthermore, the CRP will result in improving links between small and large experiments and in the deeper integration of small tokamaks in national, regional, and international fusion activities and an increase in the number of the collaborative experiments. This will also help to promote fusion research in developing countries and open wider possibilities for young scientists. Work packages for the different research activities can be carried out under the supervision of the members of the CRP thus providing a clear future perspective for small tokamaks in a co-ordinated approach. This will help to improve the quality of the scientific output from the small tokamak research activities. The output of these activities will be written reports, e.g. IAEA Technical Documents, scientific journal papers and institutional reports and presentations at different national and international conferences and meetings.

The specific objectives of this CRP fall into the following activities:

- Direct contribution of small tokamaks to mainstream fusion research.
- A test-bed of new tools, materials and technologies for large machines.
- Improvement and development of diagnostics.
- Expertise development and capacity building of students, post graduate students and training of personnel, in particular in developing countries. These may be achieved through promotion of mobility, exchange of equipment, joint experiments, training courses, schools etc.

## 2. Small tokamak database.

As one of the first CRP activities, the small tokamak database has been established, Table1. There were several attempts in the past to create a small tokamak database. The most

Table 1.

| | **name** | **organisation** | **R,m** | **a,m** | **elon** | **Ip, kA** | **Bt, T** | **cofiguration** | $t_{pulse}$ **ms, s, h** | **Aux. Heating, MW** | **project start, end, status** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Globus-M | Ioffe, St Petersburg, RF | 0.36 | 0.24 | 1.6/ 2.2 | 350/ 500 | 0.5/ 0.62 | DND, SND,L | 300/ 500 | NB 0.5; ICRH 1 | 2002 |
| 2 | TUMAN-3M | Ioffe, St Petersburg, RF | 0.55 | 0.24 | 1.0 | 180 | 1.0/ 3.0 | L | 150 | NB 0.5; ICRH 0.4/1.0 | 1978 |
| 3 | FT2 | Ioffe, St Petersburg, RF | 0.55 | 0.08 | 1.0 | 22 | 2.5 | L | 60 | LH 0.3 | 1979 |
| 4 | T-11M | TRINITY, Troitsk, RF | 0.7 | 0.2 | 1.0 | 100 | 1 | L | 120 | ICRH | 1996 |
| 5 | GUTTA | St Pet.Univ, St. Petersburg, RF | 0.16 | 0.08 | 2 | 150 | 1 | L | 10 | no | 1984, re-started in 2002 |
| 6 | T-10 | RRC"Kurchatov Inst.", Moscow, RF | 1.5 | 0.36 | 1.0 | 400/ 820 | 2.5/ 5.0 | L | 1 s | ECRH 3.0 | 1975 |
| 7 | CASTOR | IPP Praha, Czech Rep. | 0.4 | 0.085 | 1.0 | 20 | 1.5 | L | 50 | LH | 1985 |
| 8 | ISTTOK | Lisbon, Portugal | 0.46 | 0.085 | 1.0 | 12 | 0.5 | L | 70 | no | |
| 9 | Proto-Sphera /START | Frascati, Italy | 0.18 | 0.14 | | 240 | 0.6 | DND | - | no | Under constr. |
| 10 | COMPASS-D | UKAEA, Culham, UK | 0.557 | 0.232 | 1.66 | 350/ 400 | 2.1 | SND | 1s/ 5s | ECRH 2.0,<br>LH 0.2 | 1992 - 2001 |
| 11 | TRIAM | Kyushu Univ, Fukuoka, Japan | 0.8 | 0.12 | 1.5 | | 8 | | >5h | LH 0.8, ECRH 0.2 | till 2004 |
| 12 | TST-2 | Univ. of Tokyo, Tokyo, Japan | 0.38 | 0.25 | 1.8 | 120/ 200 | 0.3/ 0.4 | DND, L | 200 | EBW 0.2 | 1999 |
| 13 | LATE | Kyoto Univ., Kyoto, Japan | 0.25 | 0.2 | 1.34 | 4 | 0.12 | L | 4.5s | ECRH 0.2 | 2000 |
| 14 | HT-2 | HITACHI Res. Lab., Ibaraki-ken, Japan | 0.41 | 0.11 | | 50 | 2 | | 50 | | |

| | name | organisation | R,m | a,m | elon | Ip, kA | Bt, T | cofiguration | $t_{\text{pulse}}$ ms | Aux. Heating, MW | project start, end |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | HIST | Himeji Inst. of Tech., Himeji, Japan | 0.3 | 0.24 | 2 | 100 | 0.2 | L | 5 | no | 1998 |
| 16 | WT-3 | Kyoto Univ., Kyoto, Japan | 0.65 | 0.2 | 1.0 | 150 | 1.75 | L | 150 | ECRH 0.2<br>LH 0.35 | 1985-2000 |
| 17 | TS4 | Univ. of Tokyo, Tokyo, Japan | 0.55 | 0.45 | 3.0 | 300 | 0.5 | L | 5 | no | 2000 |
| 18 | TS3 | Univ. of Tokyo, Tokyo, Japan | 0.2 | 0.14 | 2.0 | 80 | 0.2 | L | 0.05 | no | 1986 |
| 19 | CSTN-IV | Nagoya Univ., Nagoya, Japan | 0.4 | 0.1 | | 1 | 0.12 | L | 20 | | 1998 |
| 20 | HYBTOK-II | Nagoya Univ., Nagoya, Japan | 0.4 | 0.13 | | | | | | | 1991 |
| 21 | NUCTE-ST | Nihon Univ., Nihon, Japan | 0.062 | 0.052 | 10 | 340 | 0.45 | L | 0.12 | no | 1998 |
| 22 | KT-1 | KAERI, Daejeon, Korea | 0.27 | 0.05 | 1.0 | 15 | 1.5 | L | 20 | | 1988 |
| 23 | KAIST-TOKAMAK | KAIST, Daejeon, Korea | 0.53 | 0.14 | 1.0 | 40 | 0.5 | L | 100 | | 1992 - 2002 |
| 24 | CT-6B | IoP AS, Beijing, China | 0.45 | 0.125 | | 30 | 0.75 | | 30 | | |
| 25 | HT-6M | ACIPP, Hefei, China | 0.65 | 0.2 | 1.0 | 150 | 1.5 | | | | |
| 26 | HT-7 | ACIPP, Hefei, China | 1.22 | 0.35 | 1.0 | 400 | 3 | L | | ICRH 1.0, LHCD 0.4 | |
| 27 | SUNIST | SUNIST Lab., Beijing, China | 0.3 | 0.22 | 1.6 | 50 | 0.08/0.15 | DND, L | 13 | EBW 0.1 | 2003 |
| 28 | HL-1M | SWIP, Chengdu, China | 1.02 | 0.26 | 1.0 | 350 | 3 | | | NBI 1, LHCD 1, ECRH 0.5, ICRH 1 | |
| 29 | HL-2A (ASDEX) | SWIP, Chengdu, China | 1.64 | 0.4 | | 480 | 2.8 | SND | | NBI 1, LHCD 1, ECRH 0.5, ICRH 1 | 2002 |
| 30 | KT-5C | USTC, Hefei, China | 0.325 | 0.095 | | 20 | 0.5 | | | | |
| 31 | ADITYA | IPR, Bhat, India | 0.75 | 0.25 | 1.0 | 30 | 0.5 | L | 30 | no | 1992 |
| 32 | SINP | SAHA, Kolkata, India | 0.3 | 0.075 | | 75 | 2 | | 20 | | 1987 |
| 33 | STPC-EX | TAEA, Ankara, Turkey | 0.084 | 0.056 | 4.0 | 6.5 | 0.12 | L | 9.5 | no | 1992 |
| 34 | KTM | Kazakhstan | 0.9 | 0.45 | 1.7 | 750 | 1 | SND | 4 s | RF 7.0 | Under constr. |
| 35 | TF-2 | IHT RAS Bishkek, Kirgyzstan | 0.225 | 0.041 | 1.0 | 15 | 2 | L | 15 | no | on hold 1998 |
| 36 | DAMAVAND | PPL,Tehran, Iran | 0.36 | 0.07 | 2.8 | 35/40 | 1.0/1.2 | DND | 25/50 | no | 1995 |
| 37 | IR-T1 | PPRS IA University, Teheran, Iran | 0.45 | 0.125 | 1.0 | 40 | 1.2 | L | 10 | no | |
| 38 | Flinders Tokamak | Flinders University, Adelaide, Australia | 0.1 | 0.06 | 2.5 | 17 | 0.024 | L | 5 | RMF 0.4 | 1998-2001 |
| 39 | CDX-U/LTX | PPPL, Princeton, USA | 0.335 | 0.225 | 1.7 | 70 | 0.23 | DND, L | 25 | FW | 1993 |
| 40 | Pegasus | Un. of Wisconsin, Madison, USA | 0.45 | 0.41 | 3.7 | 160/300 | 0.15 | DND, L | 50 | EBW, HHFW | 1996 |
| 41 | ET | UCLA, USA | 5 | 1 | 2.0 | 40/100 | 0.25 | L | 5 s | ICRH 5.0, NB 1.0 | 1999 |
| 42 | HIT-II | Un. Of Washington, Seattle, USA | 0.3 | 0.2 | 1.9 | 370 | 0.6/0.5 | L, SND, DND | 0.06/0.02 | none | 1997 - 2004 |
| 43 | HBT-EP | Columbia University, New York, USA | 0.92 | 0.15 | 1.0 | 30/40 | 0.35/0.5 | L | | ICRF 5.0 | 1993 |
| 44 | ETE | INPE, SP, Brazil | 0.3 | 0.2 | 1.8 | 60/400 | 0.4/0.8 | L | 10.0/25.0 | no | 2000 |
| 45 | TCABR | Univ. of São Paulo, SP, Brazil | 0.61 | 0.18 | 1.0 | 110 | 1.1 | L | 100/120 | Alfven/1.0 | 1999 |
| 46 | NOVA | Univ. of Campinas, SP, Brazil | 0.30 | 0.06 | 1.0 | 10.0 | 0.8/1.5 | L | 12.0 | no | 1998 |
| 47 | NOVILLO Tokamak | ININ, Mexico City, Mexico | 0.23 | 0.06 | 1.0 | 12 | 0.47 | L | 5 | no | |
| 48 | STOR-M | PPL Un. of Saskatchewan, Canada | 0.46 | 0.12 | 1.0 | 30 | 0.7 | L | ac | No | 1984 |
| 49 | EGYPTOR | NRC, AEAEG, Cairo, Egypt | 0.3 | 0.1 | 1.25 | 45/100 | 1.2 | L | 60/45 | no | 2002 |
| 50 | BATORM | PP&VFDep AEAEG, Cairo, Egypt | 0.063 | 0.031 | 1.0 | | | L | | no | 1998 |
| 51 | LIBTOR (TM4-A) | Tajoura Nuclear Reseach Center, Tajoura, Libya | 0.53 | 0.115 | 1.0 | 120 | 4 | L | 20 | no | 1982 |

recent (but far from being full) database with good links to tokamak sites was created by DMOZ ODP, see http://dmoz.org/Science/Physics/Nuclear/Fusion/Magnetic. We are creating a new updated database with 51 presently or recently active small tokamaks and devices under construction in it. The full database with more information and links is available on the IAEA CRP web page and will be continuously upgraded. The selection criteria for the database was chosen not exclusively on the device size, but on the scale of a project in whole, including budget and staff consideration. For example, the small-size Alcator C-Mod was not included in this draft version, but the ET tokamak with 5m major radius and the medium size T-10, HL-2A and HT-7 are included. In other words, we include tokamaks that could more efficiently benefit from the CRP network. However, any small and medium size tokamaks are welcome to join the CRP and to contribute to its activities. This table is far from being complete and only includes information available to the authors. It is one of the objectives of the CRP to complete it and update on a regular basis. Numbers after a slash in the Table give design values if they have not been yet achieved. Blue colour represents closed projects, pink – projects under construction, for devices marked in black information is provisional.

## 3. CRP participants and description of on-going projects.

Nine proposals have been approved in 2004. Table 2 presents a list of the projects.

Table 2

| | Project title | Institution | Chief Scientific Investigator | Tokamak |
|---|---|---|---|---|
| 1 | T-10 activity in frame of Small Tokamak Collaborative Project aimed at solution of fundamental and applied problems of plasma physics. | Kurchatov Institute of Atomic Energy, Moscow, Russia | B Kuteev | T-10 |
| 2 | Educational and Research Programme on Small Tokamak GUTTA | St. Petersburg State University, Zubov Institute of Computational Mathematics and Control Processes, St. Petersburg, Russia | G M Vorobyev | GUTTA |
| 3 | Use of the Tokamak ISTTOK in the framework of the project "Joint Research Using Small Tokamaks" | Instituto Superior Tecnico, Centro Fusao Nuclear, Lisbon, Portugal | Carlos Silva | ISTTOK |
| 4 | ECR plasma current startup with electrode discharge assistance | SUNIST United Laboratory Department of Engineering Physics, Tsinghua University, Beijing P.R.China | Yexi He | SUNIST |
| 5 | Joint Research Using EGYPTOR Tokamak | Atomic Energy Authority Nasr City, Cairo, EGYPT | H Hegasy | EGYPTOR |
| 6 | Study of physical processes of improved plasma confinement, MHD phenomena and runaway avalanche in the TCABR tokamak | Universidade de Sao Paulo, Sao Paolo, Brazil | I C Nascimento | TCABR |
| 7 | Plasma edge studies in the ETE Spherical Tokamak | Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brazil | Gerson Otto Ludwig | ETE |
| 8 | Edge plasma physics and relevant diagnostics development on CASTOR tokamak | Institute of Plasma Physics, Academy of Science of the Czech Republic, Prague, Czech Republic | Martin Hron | CASTOR |
| 9 | Plasma Flow Measurements in the STOR-M Tokamak (Joint Research Using Small Tokamaks) | University of Saskatchewan, Canada | Akira Hirose | STOR-M |

The list consists of well-developed projects which make a direct contribution to mainstream fusion research (T-10, ISTTOK, STOR-M, CASTOR, TCABR) and relatively new tokamaks (GUTTA, SUNIST, ETE, EGYPTOR).

### 3.1. Direct contribution of small tokamaks to mainstream fusion research.

Contribution to mainstream fusion research from CRP participants is foreseen in several areas. On **T-10**, these include: transport barrier investigation, role of the q profile in ITB formation, including role of resonant q surfaces; investigations of plasma turbulence and its impact on local and global plasma parameters using correlation reflectometry; analysis of short wavelength plasma instabilities using ECE scattering and FIR; measurements of stationary and fluctuating electric fields using Heavy Ion Beam probe diagnostics; investigation of energy and particle transport in the vicinity of the Greenwald density limit; investigation of edge plasma behavior; analysis of electron transient transport during auxiliary heating and in transient processes (pellet-injection, ITB formation etc.); particle transport under HF heating and investigation of density pump-out effect and impurity behavior under ECRH.

Enhanced confinement regimes have been identified in several small tokamaks. In **STOR-M** at the Plasma Physics Laboratory of the University of Saskatchewan, H-modes have been triggered using several methods such as plasma biasing and compact torus (CT) injection. Several models to explain the mode switching from L-mode to H-mode invoke the role of plasma flow and its structure in the edge. The proposed research project aims at measuring directly the edge plasma toroidal and poloidal velocities in STOR-M to study its evolution before and after onset of the H-mode thereby identifying the most appropriate model and contributing to the understanding of the processes involved in the switching mechanisms. For the biasing experiments, a voltage is applied, with respect to the vessel chamber, either to a movable electrode inserted into the tokamak edge region (r = 8.2- 10.5 cm) or to a segmented limiter consisting of four segments on each side of a ceramic base. There are small gaps between adjacent segments and each segment could be biased independently. 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 of the order of 1 µg, representing 50% the particle inventory in STOR-M.

Emissive electrode biasing experiments are also planned on the **ISTTOK** tokamak. Two different approaches have been followed in biasing experiments: (i) use of a small limiter, inserted deep inside the main limiter radius and (ii) use of a small emissive electrode made of LaB6. In small tokamaks with relatively low plasma density, the current collected by negative biased standard electrodes is not sufficient to decrease the plasma potential due to the limitation imposed by the ion saturation current. Emissive electrodes produce a much larger current, therefore allowing a more efficient way to control the edge radial electric field. Limiter biasing experiments have already been performed and the results showed that, in spite of the strong perturbation of the discharge introduced by the limiter due to its large area, confinement improvement could be obtained for both polarities. The fast modification of the plasma rotation (induced by biasing experiments) has indicated that the viscosity is dominated by anomalous processes. To clarify the importance of neoclassical effects on viscosity the same experiments will be performed in plasmas with larger magnetic ripple. The larger ripple will be achieved using only 12 of the 24 toroidal field coils.

Studies of physical processes in improved plasma confinement regimes induced using the electrode biasing technique will be performed on the **TCABR** tokamak. Detailed studies will be carried out on physical processes involved in the transport barrier formation at the plasma edge.

Investigation of MHD stability and its control by ECH/ECCD is proposed on T-10. HIBP and reflectometry diagnostics at T-10 together with ECRH/ECCD gives information about the instabilities behaviour.

Experimental and theoretical studies of the ideal kink instabilities and resistive tearing instabilities will be carried out on TCABR, including detailed studies of the disruptive instability.

Studies of plasma and runaway electron parameters in runaway dominated discharges using measurements of hard x-ray emission, magnetic diagnostics, plasma spectroscopy, and reflectometry is a part of the TCABR programme. Studies will be done on the relaxation instability and disruption instability in runaway dominated discharges using measurements of microwave emission from the plasma.

Investigation of generation of suprathermal electrons under ECRH/ECCD, analysis of suprathermal electrons generation during plasma disruption, measurement of thermal and nonthermal SXR spectra using SXR spectrometer will be also carried out on the T-10 tokamak. Non-thermal electrons ($E\sim 40\text{-}100\ keV$) represent one of the most important features of the disruption instability. Recent experiments in tokamaks have indicated that localised beams of non-thermal electrons can be induced during reconnection of the magnetic field lines at the initial stage of disruptions. The beams can affect growth of tearing modes and in some cases can lead to avalanches of the runaway electrons during plasma current collapse. Further experiments are required for studies of the phenomenon. The analysis is complicated by the fact that x-ray emission produced by non-thermal electrons is distributed in a limited forward cone along the electron lines of flight. Measurements of the x-ray intensity in the direction tangential to the plasma column (close to the toroidal direction) are required in order to provide enhanced sensitivity to the suprathermal electrons. A new diagnostic system installed on the T-10 tokamak with orthogonal and tangential views of the plasma column is made on the basis of CdTe detectors. The system will be used for studies of the non-thermal electrons in future experiments.

The fluctuations of the magnetic field will be studied by arrays of magnetic sensors based on the Hall effect in the **CASTOR** tokamak. They will use probe arrays oriented in the poloidal and-or radial direction to measure turbulent structures simultaneously in many space points of the plasma column. The electric fields in the edge plasma of the CASTOR tokamak will be modified by biasing of an electrode immersed into the edge plasma. The resulting changes of turbulent structures will be again measured by probe arrays. Furthermore, transport of impurity ions, injected into the edge plasma from outside under these conditions, will be studied by means of the VUV spectrometer with wavelength and spatial resolution and compared with results of numerical simulations. The probe measurements of density fluctuations will be accompanied by the contactless method – microwave reflectometry.

Systematic measurement and study of plasma edge parameters will be carried out in the **ETE** spherical tokamak. The project includes the implementation and upgrade of diagnostics (Thomson scattering, neutral lithium beam probe, electrostatic probes, spectroscopic and magnetic measurements, ultra soft X-ray photodiode arrays, among others) that will be used to study the plasma boundary properties. Several aspects of the edge physics will be considered, including issues of plasma fuelling and density control, impurity effects and wall conditioning, and power and particle handling. The activities related with the upgrade of the Thomson scattering system, as well as the implementation of a data acquisition system in ETE have been carried out in collaboration with the Centro de Fusão Nuclear (CFN) of the Instituto Superior Técnico (IST) in Lisbon, Portugal, and Ioffe Institute in St. Petersburg, Russia.

### 3.2. Small tokamaks as a test-bed of new tools, materials and technologies.

Small tokamaks are very convenient to develop and test new materials and technologies and can be a good test-bed of new tools, materials and technologies for large machines. On T-10, plasma control under lithium gettering and the use of lithium elements as plasma-facing components is under investigation. 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 will be performed.

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.

Implementation of the liquid metal limiter and evaluation of liquid gallium limiters as a new plasma facing material for fusion applications are carried out on the ISTTOK tokamak.

Effects due to plasma-wall interactions on different materials will be investigated on ETE simultaneously with the development of plasma assisted surface treatment processes.

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, GUTTA tokamak benefits from a flexible poloidal field configuration, good vacuum conditions, excellent availability and good access for diagnostics.

Design studies of Next Step spherical tokamaks (STs) show that the optimum aspect ratio for a Burning ST, ST Component Test Facility or ST Power plant lie between 1.4 and 2. With aspect ratio A = 2, **GUTTA** fills a gap between spherical and conventional aspect ratio tokamaks. Plasma start-up is an important issue in ST research due to reduced space for the central solenoid. Experiments with the ECRH/EBW startup on GUTTA will contribute to this area.

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

### 3.3. Improvement and development of diagnostics.

Development of new plasma diagnostics was traditionally an important part of small tokamak activities and is expected to be a valuable output of the CRP. A new diagnostics system based on the scanning probe microscope (STM-AFM) will be developed and applied for analysis of thin films and dust during operating regime and wall conditioning processes on T-10. On this tokamak, the development of new diagnostics of non-thermal emission in a wide energy range E=3-200 keV is also foreseen.

Development and testing of advanced tools for edge plasma diagnostics is included in the CASTOR proposal. In particular, a so-called tunnel probe for fast measurements of the electron temperature will be used to determine the level of electron temperature fluctuations. Its modifications (the segmented and Katsumata tunnel probe) appeared to be sensitive to the ion temperature. Finally, the “ball pen probe” was designed to take direct measurements of the plasma potential and its fluctuations. The design of an oriented electric probe (the Gundestrup probe) for ion flow measurements has been optimised. The experimental work will be accompanied by numerical simulations in order to interpret correctly the experimental results achieved. Implementation of these advanced probes to the other small tokamaks, which participate in the CRP, is envisaged. The design and fabrication of the Gundestrup probe to measure the poloidal and toroidal components of the velocity of the plasma ions in different operating regimes has also been proposed on STOR-M tokamak.

On ETE, it is proposed to use the fast lithium beam probe to measure the particle influx from gas puff at the boundary. The probe (10kV; 100μA/cm$^2$ equivalent current) has been developed in a continuing collaboration with the lithium beam probe group of the Compact Helical System of the National Institute for Fusion Science (NIFS) in Toki, Japan.

### 3.3. Training, expertise development and capacity building.

A very important goal of small tokamaks is to provide necessary facilities for education of students, scientific activities of post-graduate students and for the training of personnel for large tokamaks. On CASTOR, an annual practical training course on the tokamak operation has been organised and in 2003, the Summer Training course (SUMTRAIC) hosted 12 Hungarian graduate and PhD students. The CASTOR tokamak was completely available for them for one week. The students were divided into 3 experimental groups (Probe diagnostics, fluctuation measurements, and plasma spectroscopy), supervised by Czech and Hungarian supervisors. Students participated in measurements and processed the data in different discharge regimes. The course was concluded by the workshop, where students presented the results achieved. In 2004, the SUMTRAIC has been organised on a more international basis (Hungary, Slovakia, Belgium and Egypt). The next experimental training course on the CASTOR tokamak (SUMTRAIC-III) for graduate and PhD students will be organised in June 2005. Participation at the course will be preferably offered to members of the CRP.

Joint research on the **EGYPTOR** tokamak will help improve links and deeper integration of EGYPTOR in national and international fusion activities. This will promote fusion research in EGYPT and other developing countries and open wider possibilities for young scientists from these countries to participate in fusion research.

On GUTTA, a laboratory project for undergraduate students on "Plasma equilibrium control in a tokamak" will be introduced as a part of the academic educational programme.

### 4. Summary.

In summary, this Co-ordinated Research Project with a duration of five years will be useful to provide co-ordination and guidance for small tokamak projects. The output will also consist of:

(a) an established informational network of small tokamak projects resulting in improvements in communication among small tokamak groups working worldwide;

(b) practical advice and assistance via IAEA on further integration with the national programmes of large tokamaks, ITER and other international projects as well as contribution to mainstream nuclear fusion R&D;

(c) co-ordinated plan of collaboration between small tokamak projects to support and promote a free exchange of scientific and technical personnel, equipment and diagnostics;

(d) joint presentations of the scientific results achieved on small tokamaks under international collaboration.

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[1] ROBINSON D.C. "The present role of small tokamaks". PPCF **35** (1993) B91