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FUSION RESEARCH IN INDIA

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1. Introduction

Research in thermonuclear fusion is of recent origin in India, although plasma physics research has a long history in the country going back to the work of Saha on interstellar plasmas in the late twenties. Much of the early work was in the context of astrophysical plasmas. The early seventies saw the emergence of groups in national laboratories and some universities engaged in research in theoretical and experimental aspects of laboratory plasmas with an emphasis on understanding basic plasma processes. Although this activity continues to this day, in the last few years there has also been an increased involvement of Indian physicists both within the country and abroad in research activities relevant to thermonuclear fusion. The national programme in fusion physics has evolved out of an awareness of this tradition of basic plasma physics research and is strongly motivated by the desire to harness this expertise and experience towards exploiting the vast potentials of this frontier area of science. The programme is still primarily committed to nurture basic plasma physics research in the country. However the emphasis is on experimental and theoretical studies related to both magnetically and inertially confined high temperature plasmas. The programme also has a technological mandate to develop indigeneous expertise - in the construction of experimental devices for hot plasmas and to create an infrastructure within the country that will anticipate. critically evaluate and implement fusion technology if and when it is proven viable. The scientific and technical expertise thus accumulated should also provide ample scope to capitalise on 'spin-offs' and make inroads into other frontiers of applied science. The principal components of the Indian programme are outlined below in terms of institutional contributions.

2. Institute for Plasma Research, Gandhinagar

A major component of the national programme is being carried out at Gandhinagar under the auspices of the Institute for Plasma Research (IPR) which is an autonomous institute funded by the Department of Science & Technology. IPR has a broadbased scientific programme aimed at both fundamental studies and experimental and theoretical investigation of high temperature magnetically confined plasmas. The major experimental programme is based on a tokamak device which has been indigeneously constructed. Other experiments include a toroidal magnetic device (BETA) (with no poloidal field) meant to carry out basic plasma studies and a relativistic electron beam generated compact torus experiment. A double-plasma machine is also operational for nonlinear wave propagation studies and some significant work on ion-acoustic solitons and electrostatic double layers has already been accomplished.

The tokamak at IPR, named ADITYA -(the Sanskrit word for Sun) - is a low field large volume device with $R = 75$ cm, $a = 25$ cm, $B_T = 1.5$ T, $I_p = 250$ kA. The choice of machine parameters has been guided to a large extent by considerations of simplicity, available technology and allowing maximum flexibility to accomodate the various needs of the proposed experiments. One of the prime considerations was to provide ample access for a large number of diagnostics (including beam injection in the future) and have a plasma with reasonable density and temperature values and sufficient size for decent confinement studies. The overall scientific objectives of ADITYA are to carry out a number of investigations related to the basic physics of tokamak plasmas, with a view to extending the successful operating parameter space. Specific experiments are being planned in the following areas:

(a) novel regimes of tokamak operation with current primarily carried by energetic electrons,

(b) stabilization of plasma disruptive instability using feed-back coils

(c) auxiliary plasma heating using Alfven range of frequencies,

(d) studies on detached plasmas.

The principal thrust of theoretical investigations at IPR is in the area of nonlinear phenomena with wide ranging applications e.g. turbulence, rf heating, current drive, parametric instabilities, solitons etc. There is also a strong effort in MHD and resistive MHD theory to understand the linear and nonlinear behaviour of tearing modes and ballooning modes in tokamak plasmas. Much of this work is being complemented by numerical computations. In addition, numerical modelling in the form of simple transport codes are also being utilised to aid in the design of ADITYA and for future help in understanding the discharge behaviour.

3. Saha Institute for Nuclear Physics, Calcutta

Beginning with early work on low density discharge plasmas, the plasma physics group at SINP has substantially increased the scope of their research programme to include high temperature plasma experiments. For this a small research tokamak (R = 30 cms, a = 6.4 cm, B_T = 20 KG) has been bought from Japan. Their major scientific objectives are to carry out studies related to atomic and molecular phenomena in tokamak plasmas, transport processes and RF current drive. There is also a small effort devoted to setting up a linear z-pinch device.

4. Bhabha Atomic Research Centre, Trombay

The BARC programme is primarily devoted to the inertial approach and has a strong accent on technology development. Fusion related work is carried out in a number of different departments in the organisation.

The Laser Division

Laser fusion programme at BARC was started in 1974 when construction of a 50J/5nsec, single beam Neodymium glass laser system was undertaken. This laser was commissioned in 1978 and since then a large number of laser-plasma interaction experiments have been done using it. These include, scattering of laser radiation from coronal plasmas, target ablation, stability of target motion, ablation pressure and mass ablation rate measurements, x-radiation losses from laser-produced plasmas etc. Several diagnostics have also been developed for these studies viz. x-ray detectors, x-ray imaging, x-ray spectrographs, optical interferometry/shadowgraphy, charge collectors and analysers etc. Suitable codes for data interpretation have also been developed. A four beam 1 KJ/1ns glass laser system is under construction at present and is likely to be functional in late 1989.This system will be used for symmetric irradiation and compression of sperical fusion targets. It is also proposed to upgrade the laser to 2 KJoule and frequency up convert it for obtaining high ablation pressures for target implosion.

The Plasma Physics Division

The Plasma Physics Division carries out beam plasma experiments using pulsed electron beams (pulse length of 50 nanoseconds and power in the 10^9 watt range). The group has also successfully developed plasma jet equipment for industrial applications e.g. DC plasma torches for metal cutting/welding and spraying applications. One of their other major involvements has been in the field of MHD power generation and development of associated technology.

The Neutron Physics Division

The Neutron Physics Division has an experimental and theoretical programme based on the plasma focus device. A 500 KJ fast capacitor bank facility capable of delivering of about 10 MA of current is presently under construction. Present studies include impact fusion experiments and development of macro particle accelerators based on an exploding aluminium foil driven electric gun. The group is also engaged in theoretical studies of fusion-fission hybrid reactors to assess their potential prospects for breeding ^{233}U from Thorium and their eventual importance in the power generation scenario.

The Department of Atomic Energy has recently established a Centre for Advanced Technology (CAT) at Indore where much of the future work related to fusion in the inertial approach will be carried out in an integrated fashion.

5. Plasma Research in Universities

Plasma physics activities carried out at a number of university departments constitute an important component of the fusion programme of the country in terms of providing trained scientific manpower, basic research support and infrastructure development. Some of the major centres engaged in this work are at Indian Institute of Technology (IIT), Delhi, University of Rajasthan, Jaipur, Bharatidasan University, Tiruchirapalli, Indian Institute of Science, Bangalore, Ravishanker University, Raipur, University of Hyderabad, Hyderabad, Jadavpur University, Calcutta, Institute of Technology, Varanasi, Institute of Advanced Science and Technology, Guwahati, University of Kalyani, Kalyani, North Bengal University, Darjeeling, University of Delhi, Delhi, Physical Research Laboratory, Ahmedabad, Punjabi University, Patiala and University of Punjab, Chandigarh. Most of these centres have strong theoretical research programmes with major emphasis towards the study of nonlinear phenomena including solitons, double layers and dynamical chaos. Some of the University groups have also begun collaborative research programmes with the national laboratories on fusion oriented tasks. The only significant experimental effort at the University level is at the Indian Institute of Technology, New Delhi - where apart from basic plasma experiments, a major programme on gyrotrons and Free Electron Lasers is under development.

6. Conclusion

In summary, the fusion research programme in the country has two major components - basic studies and research and development related to high temperature plasmas. Basic studies are carried out at a number of universities and some national research institutes. The principal thrust is towards studying nonlinear phenomena with a number of applications in mind. The work is mainly theoretical but a number of small experimental devices are also beginning to function. High temperature plasma studies have been undertaken at three major centres - BARC, IPR and SINP. At BARC the accent is on technology development and pursuing the inertial approach whereas IPR and SINP have programmes centred around the tokamak device. The principal support for research is provided by the Departments of Science and Technology (DST) and Atomic Energy (DAE). At the present time the support is good and plasma physics has been identified as a 'thrust' area - earmarked for rapid development. It is expected that the research programmes will not only contribute towards advancing the frontier areas of plasma physics, but also help establish a powerful scientific and technological infrastructure within the country to enable it to tap the enormous potential benefits of fusion and other spin-off applications.