PLASMA PHYSICS
NETWORK NEWSLETTER

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA

No. 1 August 1989

INIS-mf--13005

184 pages
CONTENTS

Foreword

Nuclear Fusion Programmes in the Third World

Nuclear Fusion Research in Argentina
Chinese Fusion Efforts
Plasma and Fusion Physics in Egypt
Fusion Research in India
Fusion Research in the Republic of Korea
Fusion Programmes in Malaysia
The Agency's Fusion Programme

Proposal for a Workshop on Computational Plasma Physics
Asian African Association for Plasma Training (AAAPT)
Fusion Research in "Small" Countries
ITER Newsletter
The past several years have witnessed an increasing awareness on the part of the industrialized countries of the fusion research being carried out in a number of developing countries. Prominent scientists in the larger fusion programmes have recognized the fact that scientists in the developing world could make contributions to the mainstream of fusion research and have in fact given consideration as to how they might help in realizing this latent potential.

During this period there has been much discussion on how the International Atomic Energy Agency (IAEA) could address the needs of its developing Member States with regard to fusion. Several interesting ideas have emerged from this process. One of the more useful ones calls for the formation of a group devoted to furthering the interests of fusion scientists in developing countries, and the publication of a Newsletter containing items of interest to these people.

Earlier this year the International Centre for Theoretical Physics (ICTP) organized a "Symposium on Third World Fusion Programmes and South-North Collaboration" which we had the pleasure to attend and at which this question was again discussed. A very positive result of these discussions was the decision to form an organization which is called the "Third World Network", and that a quarterly Newsletter be published. The latter is to be known as the "Plasma Physics Network Newsletter". What you are reading now is the Foreword to the first Newsletter.

We would like to discuss briefly what the purpose of the activities is, and in doing so we will take the liberty of addressing these issues in a frank manner.
The needs of the developing fusion countries in fusion are simple to state; they need more money, more technical help from their counterparts in those countries with major fusion programmes, and more support from their own governments. The satisfaction of these needs is however not nearly as simple a matter. To bring about such a happy state of affairs requires much thought and much effort, if it can be achieved at all. Above all, it requires the combined efforts of all the small fusion countries acting in concert rather than as individuals.

In our view, the most important purpose served by the Network and its Newsletter is to start the process of unifying the developing country fusion community into some type of a cohesive entity and to bring the efforts of the developing countries in the plasma physics research area to the attention of the world fusion community at large. I grant the point that the needs of individual laboratories within these countries differ widely. Some are just on the threshold of starting a fusion programme within their country, while others have an existing and well developed ones. Nevertheless, we are convinced that the potential existing within the donor fusion countries to assist their poorer counterparts will not be fully realized until the latter can speak with essentially a single voice to the former.

Some readers of this foreword are familiar with an initiative made by one of the four world largest fusion programmes to establish a system whereby the transfer of fusion technology between the "have" and "have not" countries could take place. In order to start this process a meeting was arranged one evening during the 1988 International Conference on Plasma Physics and Controlled Nuclear Fusion Research in Nice. This presented an excellent opportunity for the leaders of the large fusion programmes to meet their counterparts from the smaller ones. To make a long story short, the meeting was a failure because of the inability of the participants to express the needs of the fusion community of which they are a part. Instead, there were some requests for specific items of immediate use to a hopeful recipient. The net result of this was the loss of an opportunity to organize the major fusion countries in the effort to help the smaller ones.
This brings me to the major points we wish to make, namely, that this Newsletter which serves the ostensible (and important) function of disseminating information to the developing world fusion community, also represents the first communal effort on the part of this community. Hopefully this will mark the beginning of a process culminating in a situation where the leaders of the industrialized fusion world can talk to representatives of the developing fusion world to the mutual benefit of each.

My second point is simply this. Regardless of whether you believe that the Newsletter can be instrumental in achieving such ambitions a goal as described above, or even if you do not believe that such a goal can be reached at all, you, individually, must decide whether or not the Newsletter is a worthwhile venture. If you believe that it is, then you must assist in making it a success. Although the Agency can probably compile sufficient information every 4 months to justify mailing a Newsletter, the major contents should be information received from the laboratories in the developing countries. In this regard we would urge you not to be diffident in the type of information you submit for publication. Certainly the major aspects of your programme and its status are of interest. Equally important is a realistic assessment of the needs of the programme and how to meet them, also in a realistic way. However, anything and everything of relevance to fusion should be included. The more information that is available to the community at large the more possible it will be to unify that community. Do not forget also that the Newsletter is in its embryonic stage. Your suggestions on how to improve it will be very important.

There is no doubt that the most important organizations contributing to the scientific activities of the developing world are the International Centre for Theoretical Physics and the Third World Academy of Sciences. Furthermore, this situation is unlikely to change in the near future. Nevertheless, the IAEA can play a significant role in this area. A brief description of the Agency's fusion programme is included in this Newsletter. The Agency's fusion activities most important to the developing world are described in more detail below.
The Fellowship Programme provides training in a relevant subject for one or two years, and occasionally for a longer period. In the past, fusion scientists from developing Member States have spent a year or more at a large fusion laboratory in order to acquire skills relevant to their work at home, or at universities working towards an advanced degree. Also within the Fellowship Programme are the so-called Scientific Visits. These consist of a 6 to 8 week tour of several laboratories engaged in programmes that the traveller wishes to establish in his home laboratory.

These Fellowships are available to workers in developing Member States, and qualified scientists are urged to consider the usefulness of applying for inclusion in the programme.

Under the Technical Co-operation Programme the Agency provides assistance to laboratories in developing Member States to develop or expand scientific projects. This assistance can include the purchase of equipment, training, travel, and the provision of expert help. Typical amounts for a Technical Co-operation Project are $30,000 - $40,000 per year.

As might be expected, the criteria for the award of such assistance are more exacting than in the case of the Fellowships. The proposals must be well thought out and realistic. They must in addition, show their connection to the country's overall scientific programme, and they must be viable in terms of the existing expertise in the recipient laboratory.

A variation of this programme which has proven to be effective are the Coordinated Regional or Interregional Programmes.

The programmes are designed to address the problems of a specific geographical region or of several such regions and entail a collaborative effort in solving these problems. A goal of this approach is to establish a level of scientific independence in the particular scientific area under investigation. A typical result of this approach can be the establishment in a region of several centres of excellence in specific areas. Such a scheme seems particularly interesting for the developing fusion world and deserves further investigation.
The Research Contract Programme is designed to provide "seed money" for laboratories in starting projects. These are limited to approximately $5000 per year and last for 3 years. The major expense of the project is thus borne by the home laboratory. Nevertheless, this programme has, for various reasons, proven useful to many institutions. Often, the existence of an Agency grant, although small, provides the leverage to obtain additional support from local authorities. As in the case of Technical Projects, Coordinated Research Programmes, wherein a number of different laboratories work on different aspects of a problem are a useful variation of Research Contract Programme. It should be noted that application for a contract under these programmes requires not only the signature of a laboratory director; they need not be submitted to the Agency via governmental authorities.

Finally, we would like to draw attention to the items included in this Newsletter from Malaysia and Australia. These describe fusion/plasma physics activities that result in useful physics and are performed with equipment that is relatively inexpensive. It is worthwhile for smaller laboratories who are in the process of either establishing a fusion programme or enhancing an existing one to consider these approaches. The process of building on the success of a programme using small and cheap devices may be easier in the long run than trying to assemble the resources needed to operate a small tokamak.

Manfred Leiser
Head, Physics Section
Department of Research and Isotopes
International Atomic Energy Agency
NUCLEAR FUSION PROGRAMMES IN THE THIRD WORLD

A. Names and addresses of institutes with fusion programmes

B. Countries and institutions with fusion activities
   B.1 List of countries
   B.2 Distribution of countries by region
   B.3 Distribution of institutes by region
   B.4 Distribution of institutes with experimental facilities by region

C. Experimental facilities
   C.1 Fusion experiments in the Third World
   C.2 Tokamaks in the Third World

D. Division of countries according to strength of fusion programmes

E. Priorities and future concepts

F. Enhancing fusion research in the Third World
   F.1 Requirements and Modalities
   F.2 Proposal
A. Names and addresses of Third World institutes with fusion programmes

**ARGENTINA**

Comision Nacional de Energia Atomica (CNEA)
Avenida del Libertador 8250
1429 Buenos Aires

PRIFIP, Consejo Nacional de Investigaciones Cientificas y Tecnicas
Universidad de Buenos Aires
Pabellon 1
Ciudad Universitaria
1428 Buenos Aires

**ARGENTINA**

PROFET, Universidad Nacional de Centro de la Provincia de Buenos Aires
Pinto 399
7000 Tandil

**BANGLADESH**

Department of Physics
Jahangirnagar University
Savar
Dhaka

**BANGLADESH**

Institute of Nuclear Science and Technology
Atomic Energy Research Establishment
Ganak Bari
Savar
P.O. Box 3787
Dhaka

**BRAZIL**

Instituto de Estudios Avanzados
Centro Tecnico Aerospatial
Rodovia dos Tamoios
KM 5.5
CEP 12200
São José dos Campos

**BRAZIL**

Instituto de Fisica
Universidad Federal do Rio Grande do Sul
Av. Prof. Luiz Englert s/nº
90000 Porto Alegre
Rio Grande do Sul

**BRAZIL**

Instituto de Fisica
Universidade de São Paulo
Cidade Universitaria
Caixa Postal 20516
01498 São Paulo

**BRAZIL**

Instituto de Fisica
Universidade Federal Fluminense
Outeiro de São João Batista
Niteroi 24 210
Rio de Janeiro

BRAZIL
Instituto de Pesquisas Espaciais
Caixa Postal 515
Av. dos Astronautas No. 1758
12200 São José dos Campos
São Paulo

BRAZIL
Universidade Estadual de Campinas
Caixa Postal 1170
13 100 Campinas
São Paulo

CHILE
Facultad de Fisica
Pontificia Universidad Catolica de Chile
Casilla 6117
Santiago

CHINA
Department of Electrical Engineering
Tsinghua (Quinghua) University
Beijing

CHINA
Department of Physics and Institute of Modern Physics
Fudan University
Shanghai

CHINA
Institute of Atomic Energy
P.O. Box 275
Beijing

CHINA
Institute of Mechanics
Academia Sinica
Beijing

CHINA
Institute of Physics
Academia Sinica
Beijing

CHINA
Institute of Plasma Physics
Academia Sinica
P.O. Box 26
Anhui Province
Hefei

CHINA
Peking University
Institute of Theoretical Physics
Beijing

CHINA
Southwestern Institute of Physics
P.O. Box 15
Leshan
Sichuan
CHINA
University of Science and Technology
24 Jinzhai Road
Anhui
Hefei

COLOMBIA
Universidad de Antioquia
Apdo Aereo 1226
Ciudad Universitaria
Antioquia
Medellin

CUBA
Instituto de Investigacion Tecnica Fundamental
Calle O No. 8
La Habana

EGYPT
Nuclear Research Centre
Atomic Energy Authority
P.O. Box 13759
Cairo

EGYPT
Physics Department
Al Azhar University
Nasr City
Cairo

INDIA
Bhabha Atomic Research Centre
Neutron Physics Division
Trombay
Bombay 400 085

INDIA
Centre for Advanced Technology
Department of Atomic Energy
Post C.A.T. Rajendra Nagar
Indore 451 012

INDIA
Department of Physics
University Science Instrumentation Centre
University of Rajasthan
Jaipur

INDIA
Indian Institute of Technology
New Delhi 110 016

INDIA
Institute of Plasma Research
Navarangpura
Ahmedabad 380 009

INDIA
Mathematics Department
University of Roorkee
Roorkee
Uttar Pradesh

INDIA
Saha Institute of Nuclear Physics
Sector I, Block 'AF' Bidhan Nagar
Calcutta 700 064
INDONESIA
Yogyakarta Nuclear Research Centre
National Atomic Energy Agency
Yogyakarta

IRAN
Nuclear Research Centre
Atomic Energy Organization of Iran
P.O. Box 11365-8486
Tehran

KENYA
Physics Department
University of Nairobi
Nairobi

KOREA, REP.
Department of Nuclear Engineering
Seoul National University
Shinrim-dong
Kwanak-gu, 151
Seoul

KOREA, REP.
Hanyang University
17 Haengdang-dong
Sungdong-gu 133
Seoul

KOREA, REP.
Korea Advanced Energy Research Institute (KAERI)
P.O. Box 7
Chongryang 131
Seoul

KOREA, REP.
Korea Advanced Institute of Science and Technology (KAIST)
P.O. Box 131
Chongryang
Seoul

KOREA, REP.
Korea Institute of Technology
Seoul

KOREA, REP.
Kyungpook National University
1370 Sanyuk-dong
Buk-gu 635
Taegu

LIBYA
Tajura Nuclear Research Centre
P.O. Box 30878
Tajura

MALAYSIA
Physics Department
University of Malaya
22-11 Kuala Lumpur

MALAYSIA
Physics Department
University of Technology of Malaysia
Kuala Lumpur
MEXICO
Centro de Estudios Nucleares
Universidad Nacional Autonoma de Mexico
A.P. 70-543
Deleg. Coyoacan
04510 Mexico

MEXICO
Instituto Nacional de Investigaciones Nucleares
Insurgentes sur 1079
Cal Nochebuena
03720 Mexico City

NEPAL
Department of Physics
Tribhuvan University
P.O. Box 3757
Tripureswar
Kathmandu

NIGERIA
Department of Physics
University of Ilorin
P.M.B. 1515
Ilorin

NIGERIA
Physics Department
Rivers State University of Science and Technology
Port Harcourt

PAKISTAN
Physics Department
Quaid-i-Azam University
P.O. Box 1090
Islamabad

PHILIPPINES
National Institute of Physics
University of the Philippines
Quezon City 3004
Manila

SENEGAL
Laboratoire de Physique Fondamentale et d'Etudes Energetiques
University Cheikh Anta Diop
Dakar-Fann

SIERRA LEONE
Department of Physics
Njala University College
Private Mail Bag
Freetown

SINGAPORE
Mathematics and Science Centre
Ngee Ann Polytechnic
Singapore

SUDAN
University of Khartoum
P.O. Box 321
Khartoum
<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYRIA</td>
<td>Department of Physics</td>
<td>University of Damascus Damascus</td>
</tr>
<tr>
<td>THAILAND</td>
<td>Physics Department</td>
<td>Prince of Songkla University Hatyai</td>
</tr>
<tr>
<td>TURKEY</td>
<td>Ankara Research and Training Centre</td>
<td>Besevler Ankara</td>
</tr>
<tr>
<td>TURKEY</td>
<td>Cekmece Nuclear Research and Training Centre</td>
<td>P.K. 1 Havaalani Istanbul</td>
</tr>
<tr>
<td>UNITED ARAB EMIRATES</td>
<td>Physics Department</td>
<td>United Arab Emirates University P.O. Box 15551 Al'Ayn</td>
</tr>
<tr>
<td>VENEZUELA</td>
<td>Universidad de los Andes</td>
<td>Avda 3 Independencia Edif. Rectorado 5101 Merida</td>
</tr>
<tr>
<td>VENEZUELA</td>
<td>Universidad Simon Bolivar</td>
<td>Apdo 80659 Prados del Este 1080 Caracas</td>
</tr>
</tbody>
</table>
### B. Countries and institutions with fusion activities

#### B.1 List of countries

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of Institutes with Fusion Programmes</th>
<th>No. of Institutes with Experimental Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Chile</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>China</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Colombia</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cuba</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>India</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Iran</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Libya</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Korea, Rep.</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Malaysia</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Nepal</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Nigeria</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Philippines</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Senegal</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Singapore</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sudan</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Syria</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Turkey</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>United Arab E.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Totals: 29

|                           | 62 | 37 |

18 with experimental facilities
## B.2 Distribution of countries by region

<table>
<thead>
<tr>
<th>Africa</th>
<th>Asia</th>
<th>Latin America</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt</td>
<td>Bangladesh</td>
<td>Argentina</td>
</tr>
<tr>
<td>Kenya</td>
<td>China</td>
<td>Brazil</td>
</tr>
<tr>
<td>Libya</td>
<td>India</td>
<td>Chile</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Indonesia</td>
<td>Colombia</td>
</tr>
<tr>
<td>Senegal</td>
<td>Iran</td>
<td>Cuba</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>Korea, Rep.</td>
<td>Mexico</td>
</tr>
<tr>
<td>Sudan</td>
<td>Malaysia</td>
<td>Venezuela</td>
</tr>
<tr>
<td></td>
<td>Nepal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Philippines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Singapore</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Syria</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Turkey</td>
<td></td>
</tr>
<tr>
<td></td>
<td>United Arab Emirates</td>
<td></td>
</tr>
</tbody>
</table>

| Totals: 7       | 15                          | 7                |
B.3 Distribution of institutes by region

- 28.28% of institutes are in Africa.
- 14.14% of institutes are in Asia.
- 57.58% of institutes are in Latin America.

B.4 Distribution of institutes with experimental facilities by region

- 32.43% of institutes with experimental facilities are in Africa.
- 13.51% of institutes with experimental facilities are in Asia.
- 54.05% of institutes with experimental facilities are in Latin America.
C. Experimental facilities
C.1 Fusion experiments in the Third World

I. LATIN AMERICA

(1) Argentina

<table>
<thead>
<tr>
<th>Institution</th>
<th>Field Reversed Pinch</th>
<th>Plasma Focus</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) CNEA</td>
<td>• Fast Linear field reversed θ-Pinch (1982)</td>
<td></td>
<td>• Formation and stability of RC of FRC</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>• $R = 8 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• $L = 30 \text{ - } 60 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• $B = 1.0 \text{ T}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) PRIFIP</td>
<td></td>
<td>• PFI Mather (1973)</td>
<td>• Breakdown phase and current sheath structure in Plasma Focus</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td></td>
<td>• 0.95, 2.7, 10 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 20kV, 1.4 kJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• PFII Mather (1980)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 1.9, 3.5, 50 cm</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 35kV, 20 kJ</td>
<td></td>
</tr>
<tr>
<td>c) PROFET</td>
<td></td>
<td>• PACO Mather (1984)</td>
<td>• Heating &amp; Radiation</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td></td>
<td>• 2, 5, 5 cm</td>
<td>• Plasma-solid interaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 31 kV, 1.8 kJ</td>
<td>• Laser-plasma interaction</td>
</tr>
<tr>
<td>Institution</td>
<td>Tokamak</td>
<td>Pinches</td>
<td>Others</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------------------------------------</td>
<td>-----------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>a) UNICAMP Campinas</td>
<td></td>
<td>• TUPA linear θ-pinch (82)</td>
<td>• FRC Equilibrium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 15, \text{cm}$, $L = 100, \text{cm}$, $B = 1, \text{T}$</td>
<td>• Stability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Field reversed θ-pinch (85)</td>
<td>• ICH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R = 16, \text{cm}$, $L = 80, \text{cm}$, $B = 0.7, \text{T}$</td>
<td>• Transport</td>
</tr>
<tr>
<td>b) IFUSP São Paulo</td>
<td>• TBR-1 Tokamak (80)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R = 30, \text{cm}$</td>
<td>$a = 11, \text{cm}$, $B_I = 0.5, \text{T}$</td>
<td>• Tokamak confinement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Field reversed θ-pinch (85)</td>
<td>• Diagnostics &amp; data acquisition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R = 16, \text{cm}$, $L = 80, \text{cm}$, $B = 0.7, \text{T}$</td>
<td>• TBR = 2 design</td>
</tr>
<tr>
<td>c) UFF Niteroi</td>
<td></td>
<td>• Linear Magnetic Mirror (1983)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 8.5, \text{cm}$, $L = 255, \text{cm}$, $B_0 = 0.1, \text{T}$</td>
<td>• Waves</td>
</tr>
<tr>
<td>d) INPE São José dos</td>
<td></td>
<td>• Gyrotron high power microwave generation</td>
<td></td>
</tr>
<tr>
<td>Campos</td>
<td></td>
<td>• Multimagnetic dipole discharge (1980)</td>
<td>• Electrostatic propulsion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Plasma centrifuge (1984)</td>
<td>• IA waves &amp; solitons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Vacuum chamber test facility</td>
<td>• Double layers</td>
</tr>
<tr>
<td>e) IEAV, São José dos</td>
<td></td>
<td>• Carbon dioxide Laser</td>
<td></td>
</tr>
<tr>
<td>campos</td>
<td></td>
<td>10J, 20 ns</td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Facilities</th>
<th>Research Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3) Chile</td>
<td>PUC Santiago</td>
<td>• Pseudo-spark discharge (1985)</td>
<td>• Electron and ion beam generation in discharge</td>
</tr>
<tr>
<td>(4) Mexico</td>
<td>ININ Mexico City</td>
<td>• Tokamak (1986)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( R = 23 \text{ cm}, a = 8 \text{ cm}, B_x = 0.47T )</td>
<td></td>
</tr>
<tr>
<td>(5) Venezuela</td>
<td>USB Caracas</td>
<td>• Duo-plasma device (1983)</td>
<td>• Basic plasma parameters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( D = 50 \text{ cm}, L = 100 \text{ cm} )</td>
<td>• Waves</td>
</tr>
</tbody>
</table>
## China

<table>
<thead>
<tr>
<th>Institution</th>
<th>Tokamak</th>
<th>Field Reversed Pinch</th>
<th>Mirrors</th>
<th>Others</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Institute of Physics (AS)</td>
<td>• CT-6B (1974)</td>
<td></td>
<td>• FRPI (1984)</td>
<td></td>
<td>- Stability</td>
</tr>
<tr>
<td>Beijing</td>
<td>$R = 45 \text{ cm}$</td>
<td></td>
<td>$R = 6.5 \text{ cm}$</td>
<td></td>
<td>- Transport</td>
</tr>
<tr>
<td></td>
<td>$a = 10 \text{ cm}$</td>
<td></td>
<td>$L = 55.5 \text{ cm}$</td>
<td></td>
<td>- ECRH</td>
</tr>
<tr>
<td></td>
<td>$B_T = 1.3 \text{ T}$</td>
<td></td>
<td>$B = 0.8 \text{ T}$</td>
<td></td>
<td>- FRC formation &amp; heating</td>
</tr>
<tr>
<td>(b) Institute of Plasma Physics (AS)</td>
<td>• HT-6B (1982)</td>
<td></td>
<td>• OEX simple mirror (1987)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hefei</td>
<td>$R = 45 \text{ cm}$</td>
<td></td>
<td>$a = 15 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 12.5 \text{ cm}$</td>
<td></td>
<td>$L = 50 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 1.2 \text{ T}$</td>
<td></td>
<td>$B_0 = 0.8 \text{ T}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 20 \text{ cm}$</td>
<td></td>
<td>Ratio: 4 - 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 1.5 \text{ T}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R = 65 \text{ cm}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 20 \text{ cm}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 1.5 \text{ T}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$MPT$-X</td>
<td></td>
<td>• HER-Simple Mirror (1983)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R = 40 \text{ cm}$</td>
<td></td>
<td>$a = 12.5 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 8 \text{ cm}$</td>
<td></td>
<td>$L = 38 \text{ cm}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 1 \text{ T}$</td>
<td></td>
<td>$B_0 = 0.45 \text{ T}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 35 \text{ cm}$</td>
<td></td>
<td>Ratio: 2 - 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 3 \text{ T}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$R = 125 \text{ cm}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a = 35 \text{ cm}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$B_T = 3 \text{ T}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Field Reversed Pinch*:
- **OEX simple mirror (1987)**
  - $a = 15 \text{ cm}$
  - $L = 50 \text{ cm}$
  - $B_0 = 0.8 \text{ T}$
  - Ratio: 4 - 6

*Others*:
- **HT-U (under construction)**
  - $R = 125 \text{ cm}$
  - $a = 35 \text{ cm}$
  - $B_T = 3 \text{ T}$

*Topics*:
- Stability
- Transport
- ECRH
- FRC formation & heating
- Tokamak reactor design
- Equilibrium and transport
- MHD instabilities
- Wall conditioning
- Impurity transport
<table>
<thead>
<tr>
<th>Institution</th>
<th>Tokamak</th>
<th>Field Reversed Pinch</th>
<th>Mirrors</th>
<th>Others</th>
<th>Topics</th>
</tr>
</thead>
</table>
| (c) Institute of Physics Leshan | • HL-1 (1985)  
  \( R = 102 \text{ cm}, a = 20 \text{ cm} \)  
  \( B_T = 5 \) | • CF - II  
  \( R = 10 \text{ cm} \)  
  \( L = 185 \text{ cm} \)  
  \( B = 0.5 \) | • MM-1 Simple Mirror (1975)  
  \( a = 11 \text{ cm} \)  
  \( L = 48 \text{ cm} \)  
  \( B_0 = 2.1T \)  
  \( \text{Ratio: 1.75} \) | • Double Plasma Device | • Equilibrium & transport  
 • Wave heating |
| (d) University of Science & Technology Hefei | • KT - 5B  
  \( R = 30 \text{ cm} \)  
  \( a = 6 \text{ cm} \)  
  \( B_T = 0.5 \text{ T} \) | | • MM-2 Minimum B Mirror (1972)  
  \( a = 11 \text{ cm} \)  
  \( L = 56 \text{ cm} \)  
  \( B_0 = 0.6T \)  
  \( \text{Ratio: 2} \) | | • Plasma-wave  
 • Diagnostics  
 • IBW heating  
 • Alfvén wave heating |
| (e) Tsinghue University Beijing | | | | | |
| (f) Institute of Atomic Energy, Beijing | | | | | |

- **Topics**
  - Equilibrium & transport
  - Wave heating
  - Plasma-wave
  - Diagnostics
  - IBW heating
  - Alfvén wave heating

- **Others**
  - Double Plasma Device
  - Particle Beam
<table>
<thead>
<tr>
<th>Institution</th>
<th>Tokamak</th>
<th>Compact Torus</th>
<th>Others</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) IPR Ahmedabad</td>
<td>• ADITYA (1987) R = 75 cm a = 25 cm B(_T) = 1.5T B(_p) = 0.2T</td>
<td>• CT formed by REB (1984) R = 20 cm L = 150 cm B = 0.05 T</td>
<td>• BETA-Torus R = 45 cm a = 15 cm B(_p) = 0.5 T • Double plasma machine (1976) D = 50 cm L = 150 cm</td>
<td>• Waves and instabilities • Relativistic electron Beam • Scrape off layer • RF plasma interaction</td>
</tr>
<tr>
<td>(b) IITD Delhi</td>
<td></td>
<td>• Uniformly magnetized linear device (1985) D = 15 cm L = 250 cm B = 0.1 T • Beam-plasma system (under construction) D = 10 cm L = 150 cm</td>
<td></td>
<td>• Microwave interaction • ECH • Non-linear interaction</td>
</tr>
<tr>
<td>(c) SINP Calcutta</td>
<td>• Tokamak (from Japan)</td>
<td>• Stabilized Z-pinch D = 12.5 cm L = 50 cm B = 0.2 T</td>
<td></td>
<td>• MHD instabilities • Transport • Plasma wall interactions • RF heating • RF current drive</td>
</tr>
</tbody>
</table>
### OTHER ASIAN COUNTRIES

<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Tokamak</th>
<th>Plasma Focus</th>
<th>Other</th>
<th>Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3) Iran</td>
<td>Nuclear Research Centre, Tehran</td>
<td>• ALVANDIIC</td>
<td></td>
<td></td>
<td>• Diagnostics</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R = 45.5 , cm$</td>
<td>$a = 12.6 , cm$</td>
<td>$B_T = 1.2 , T$</td>
<td>• Transport</td>
</tr>
<tr>
<td>(4) Indonesia</td>
<td>Yogyakarta Nuclear Research Centre</td>
<td></td>
<td>• Mathers type</td>
<td></td>
<td>• Glow discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$1, 3, 16 , cm$</td>
<td>$20 , kV, 6 , kJ$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Korea, Rep.</td>
<td>(a) Seoul National University</td>
<td>• SNUT-79 (1985)</td>
<td>• PF-1 Mather</td>
<td>• OH Experiments</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R = 65 , cm$</td>
<td>$2.1, 4.6, 14 , cm$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 15 , cm$</td>
<td>$20 , kV, 50 , kJ$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) KAERI, Seoul</td>
<td>• KAERIT Tokamak</td>
<td></td>
<td>• OH Discharge</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R = 27 , cm$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 5 , cm$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(c) Kyungpook University</td>
<td></td>
<td>• KUTAM Tandem Mirror</td>
<td>• Basic experiments</td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Institution</td>
<td>Tokamak</td>
<td>Plasma Focus</td>
<td>Others</td>
<td>Topics</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>---------</td>
<td>--------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>(6) Malaysia</td>
<td>University of Malaya, Kuala Lumpur</td>
<td>Tokamak (1984) R = 25 cm a = 5 cm (B_T = 0.5 , T)</td>
<td>UMDPF1 Mather (1973) 1.3, 4.3, 15.5 cm 40kV, 12 kJ</td>
<td>Electromagnetic Shock Tube</td>
<td>Plasma Focus diagnostics and fusion neutrons</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UNU/ICTP Device 15kV, 10kJ</td>
<td>Vacuum Spark</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td>(7) Pakistan</td>
<td>Quaid-i-Azam University, Physics Dept., Islamabad</td>
<td>PF (1987)</td>
<td>UNU/ICTP Device 15kV, 10kJ</td>
<td>Glow discharge</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UNU/ICTP Device 15kV, 10kJ</td>
<td>Pinch</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(1987) (as above; but multiple polodial B)</td>
<td>Compact Torus Magnetized T-Tube</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SK/ITT-1 (1984)</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 10 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 8 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 0.075 , T)</td>
<td>and probe measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(R_I = 25 , cm)</td>
<td>Current stepping in pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(H = 22 , cm)</td>
<td>Toroidal pinch-discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Compact Torus Magnetized T-Tube</td>
<td>(B = 1.5 , T)</td>
<td>and probe measurements</td>
</tr>
</tbody>
</table>

- **Tokamak**:
  - **Tokamak (1984)** R = 25 cm a = 5 cm \(B_T = 0.5 \, T\)
  - **UMDPF1 Mather (1973)** 1.3, 4.3, 15.5 cm 40kV, 12 kJ
  - **UNU/ICTP Device** 15kV, 10kJ

- **Plasma Focus**:
  - **UMDPF1 Mather (1973)** 1.3, 4.3, 15.5 cm 40kV, 12 kJ
  - **UNU/ICTP Device** 15kV, 10kJ

- **Others**:
  - **Electromagnetic Shock Tube**
  - **Vacuum Spark**
  - **Glow discharge**
  - **Rotamak**
  - **Pinch**
  - **Laser systems**

- **Topics**:
  - **Plasma Focus diagnostics and fusion neutrons**
  - **Toroidal pinch-discharge**
  - **and probe measurements**
  - **Current stepping in pinch**
  - **Toroidal pinch-discharge**
  - **and probe measurements**
  - **Current stepping in pinch**
  - **Ion acoustic wave study**
  - **Plasma-wave interaction**
<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Plasma Focus</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Egypt</td>
<td>(a) Atomic Energy Authority Energy, Cairo</td>
<td>• Plasma Focus - Mather</td>
<td>• Linear θ - pinch (1983)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 1.6 \text{ cm}$</td>
<td>$L = 80 \text{ cm}$, $a = 8 \text{ cm}$, $B = 1.8 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$b = 3.3 \text{ cm}$</td>
<td>• Linear θ - pinch (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 31.5 \text{ cm}$</td>
<td>$L = 350 \text{ cm}$, $a = 8 \text{ cm}$, $B = 2.5 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$18 \text{ kV}, 10\text{ kJ}$</td>
<td>• Pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Shock Tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Lasers</td>
</tr>
<tr>
<td></td>
<td>(b) Al Azhar University, Cairo</td>
<td>• UNU/ICTP Plasma Fusion Device</td>
<td>• Linear θ - pinch (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 1.0 \text{ cm}$</td>
<td>$L = 350 \text{ cm}$, $a = 8 \text{ cm}$, $B = 2.5 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$b = 3.2 \text{ cm}$</td>
<td>• Pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 16 \text{ cm}$</td>
<td>• Shock Tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15 \text{ kV}, 3.3 \text{ kJ}$</td>
<td>• Lasers</td>
</tr>
<tr>
<td>(2) Libya</td>
<td>Tajura Nuclear Research Centre</td>
<td>• UNU/ICTP Plasma Fusion Device</td>
<td>• Linear θ - pinch (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 1.0 \text{ cm}$</td>
<td>$L = 350 \text{ cm}$, $a = 8 \text{ cm}$, $B = 2.5 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$b = 3.2 \text{ cm}$</td>
<td>• Pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 16 \text{ cm}$</td>
<td>• Shock Tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15 \text{ kV}, 3.3 \text{ kJ}$</td>
<td>• Lasers</td>
</tr>
<tr>
<td>(3) Nigeria</td>
<td>Rivers State University of Science and Technology, Port Hartcourt</td>
<td>• UNU/ICTP Plasma Fusion Device</td>
<td>• Linear θ - pinch (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 1.0 \text{ cm}$</td>
<td>$L = 350 \text{ cm}$, $a = 8 \text{ cm}$, $B = 2.5 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$b = 3.2 \text{ cm}$</td>
<td>• Pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 16 \text{ cm}$</td>
<td>• Shock Tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15 \text{ kV}, 3.3 \text{ kJ}$</td>
<td>• Lasers</td>
</tr>
<tr>
<td>(4) Sierra Leone</td>
<td>Njala University College</td>
<td>• UNU/ICTP Plasma Fusion Device</td>
<td>• Linear θ - pinch (1984)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$a = 1.0 \text{ cm}$</td>
<td>$L = 350 \text{ cm}$, $a = 8 \text{ cm}$, $B = 2.5 \text{ T}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$b = 3.2 \text{ cm}$</td>
<td>• Pinch</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L = 16 \text{ cm}$</td>
<td>• Shock Tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$15 \text{ kV}, 3.3 \text{ kJ}$</td>
<td>• Lasers</td>
</tr>
</tbody>
</table>
### C.2 Tokamaks in the Third World

<table>
<thead>
<tr>
<th>Country</th>
<th>Device</th>
<th>$R$ (cm)</th>
<th>$a$ (cm)</th>
<th>$B_t$ (y)</th>
<th>$I_r$ (KA)</th>
<th>$t_E$ (ms)</th>
<th>$N_e$ ($10^{19}$ m$^{-3}$)</th>
<th>$T_e$ (kV)</th>
<th>$T_i$ (kV)</th>
<th>$\beta_i$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>TBR-1</td>
<td>30</td>
<td>11</td>
<td>0.5</td>
<td>12</td>
<td>1</td>
<td>1.0</td>
<td>0.20</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>China</td>
<td>CT-6B</td>
<td>45</td>
<td>10</td>
<td>1.3</td>
<td>30</td>
<td>1-2</td>
<td>1-4</td>
<td>0.3</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>HT-6B</td>
<td>45</td>
<td>12.5</td>
<td>1.2</td>
<td>40</td>
<td>1-3</td>
<td>3</td>
<td>0.25</td>
<td>0.08</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>HT-6M</td>
<td>65</td>
<td>20</td>
<td>1.5</td>
<td>120</td>
<td>10</td>
<td>7</td>
<td>0.6</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MPT-X</td>
<td>40</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.1</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HT-U</td>
<td>125</td>
<td>35</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>7.2</td>
<td>1.8</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HL-I</td>
<td>102</td>
<td>20</td>
<td>3-4</td>
<td>225</td>
<td>16-18</td>
<td>7.2</td>
<td>1.8</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KT-5B</td>
<td>30</td>
<td>6</td>
<td>0.5</td>
<td>15</td>
<td>2</td>
<td>1</td>
<td>0.1</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>ADITYA</td>
<td>75</td>
<td>25</td>
<td>1.5</td>
<td>250</td>
<td>6</td>
<td>1</td>
<td>0.5</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SINP</td>
<td>30</td>
<td>7.5</td>
<td>2</td>
<td>75</td>
<td>20</td>
<td>3</td>
<td>0.4</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Iran</td>
<td>ALVAND</td>
<td>45.5</td>
<td>12.6</td>
<td>0.8</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Korea, Rep.</td>
<td>SNUT-79</td>
<td>65</td>
<td>15</td>
<td>3</td>
<td>120</td>
<td>50</td>
<td>10</td>
<td>0.5</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KAERIT</td>
<td>27</td>
<td>5</td>
<td>4.2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Libya</td>
<td>LIBTER</td>
<td>53</td>
<td>11.5</td>
<td>4</td>
<td>120</td>
<td>1</td>
<td>5</td>
<td>0.75</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>Tokamak</td>
<td>25</td>
<td>5</td>
<td>0.5</td>
<td>40</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Mexico</td>
<td>NOVILLO</td>
<td>23</td>
<td>8</td>
<td>0.47</td>
<td>12</td>
<td>0.15</td>
<td>2</td>
<td>0.15</td>
<td>0.05</td>
<td>1</td>
</tr>
</tbody>
</table>
D. Division of countries according to strength of fusion programme

<table>
<thead>
<tr>
<th>Strong</th>
<th>Reasonable (critical mass achieved)</th>
<th>Weak (mainly theory, subcritical mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Chile</td>
<td>Bangladesh</td>
</tr>
<tr>
<td>Brazil</td>
<td>Egypt</td>
<td>Colombia</td>
</tr>
<tr>
<td>China</td>
<td>Iran</td>
<td>Cuba</td>
</tr>
<tr>
<td>India</td>
<td>Libya</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Korea, Rep.</td>
<td>Mexico</td>
<td>Kenya</td>
</tr>
<tr>
<td>Malaysia</td>
<td>Pakistan</td>
<td>Nepal</td>
</tr>
<tr>
<td></td>
<td>Turkey</td>
<td>Philippines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Senegal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Singapore</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sierra Leone</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sudan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Syria</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thailand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>United Arab Emirates</td>
</tr>
</tbody>
</table>

E. Priorities and future concepts

- Development of medium-size Tokamaks with specific objectives
- Development of alternative concepts (e.g. field reversed pinch, plasm focus and Rotamak)
- Development of related technologies (plasma torches, radiation generators, plasma centrifuge, particle beams, vacuum techniques, pulsed power technology)
- Intensive training to reach critical mass
F. Enhancing fusion research in the Third World

F.1 Requirements and Modalities

(1) Improvement of Research Facilities:

- Research Grants for purchasing or locally designing equipment (TWAS)
- Donation of Books and Journals (ICTP/TWAS)
- Donation of Equipment (Fusion Labs in Advanced Countries)

(2) South-South Collaboration:

- TWAS South-South Fellowship Programme
- UNU/ICTP Programme
- Latin American Plasma Programme
- Asian African Association for Plasma Training

(3) North-South Collaboration:

- Bilateral agreements and exchange of visits
- Long-term visits to BIG Fusion Projects in the North (e.g. JET, TF JT-60, T-15)
- Participation in International Fusion Programmes such as INTOF and ITER
- Participation in International Conferences (ICTP, IAEA)
Establish a "Third World Fusion Research Network (TWFRN)" involving leading fusion centres in the Third World.

Specific objectives of the network:

- Provide opportunities for intensive cooperation and collaboration between members of the network;
- Undertake common projects;
- Arrange workshops, seminars, symposia and training courses on various topics of common interest;
- Publish a joint newsletter giving information about national, regional and international fusion activities.

A committee of 5-7 leading fusion scientists should supervise the activities of the network.
NUCLEAR FUSION RESEARCH IN ARGENTINA

Adolfo B. Rodrigo
Comisión Nacional de Energía Atómica
Dirección de Investigación y Desarrollo
Av. del Libertador 8250, (1429) Buenos Aires,
Argentina

1.- INTRODUCCION

Following early short lived attempts to fusion research in Argentina, the first continued activity in this field was established at the University of Buenos Aires (UBA), approximately in 1968. This group, which belongs to the Physics Department of the Faculty of Exact and Natural Sciences of the UBA, started initially theoretical work in fundamental plasma physics under the direction of Fausto Gratton, who had completed his Ph.D. in Frascati in the early 60's. Later on, under the scientific tutelage of Winston Bostick, experimental activities were started in plasma focus. The first UBA facility, PF-I, was a 1 kJ plasma focus donated by the Stevens Institute of Technology to the UBA near 1970, and this line of research has continued as the group's main experimental activity up to the present.

In 1975, the Argentine National Atomic Energy Commission (CNEA) started a prospective study on fusion energy, as a result of which it decided to create its own research group in 1976. CNEA's Nuclear Fusion Division belongs to the Commission's Research and Development Management area and its line of work, both theoretically and experimentally, is field reversed configurations (FRC). The FRCs are produced using a field reversed theta pinch, which started operation in 1982.

Finally, in 1983, a part of the UBA group, headed by Roberto Gratton, moved to the newly created National University in Tandil city, some 300 km SW of Buenos Aires. This group also took the plasma focus as their main experimental research line, in which they had experience from their previous work at the UBA. Since 1988, this group extended its activities to the University of Mar del Plata, located 150 km SE of Tandil, where a small z-pinch started operation in 1989 and a repetitive plasma focus is under construction.
All three groups active at the moment in fusion oriented research in Argentina operate independently and a national fusion program is considered at the moment. In all cases, the major source of funding is the Argentine government, complemented by contributions from international funding organizations. In addition, important donations of equipment have been received from the U.S. (UBA - Stevens Institute of Technology) and the F.R.G. (CNEA, Mar del Plata - KFA Jülich).

2. - DESCRIPTION OF RESEARCH ACTIVITIES IN PROGRESS

2.1. - University of Buenos Aires

- Staff: 10 permanent scientific members, Ph.D. level
  3 permanent scientific members, M.S. level
  2 non-permanent scientific collaborators, Ph.D. level
  6 graduate students
  2 technicians

- Typical annual operating budget: U.S. $ 30,000 (excludes salaries)

- Experimental facilities

| Type: Plasma Focus, Mather type |
| Name: PF I (modified version) |
| Name: PF II |
| Capacitor bank energy: 0.005 - 1 kJ |
| Capacitor bank energy: 17 kJ (variable) |
| Capacitor bank voltage: 15-30 kV |
| Capacitor bank voltage: 50 kV (variable) |
| Peak current: - |
| Peak current: 300 kA |
| Neutron production (D-D): - |
| Neutron production (D-D): 2x10^8 |
| Electron density: - |
| Electron density: 10^{18} cm^{-3} |
| Operating since: 1984 |
| Operating since: 1983 (modified version) |
| Diagnostics: framing photography, neutron diagnostics x-ray diagnostics, ion spectrometry, magnetic probes |
- Research activities

Experimental: - sheath physics during the processes leading to the formation of the plasma focus

Theoretical: - fundamental processes
- ICF (heavy ion beam) heating models
- ICF (laser) implosion dynamics models
- magnetic ion confinement

- International cooperation activities

- Stevens Institute of Technology, U.S.A. (Vlasov plasmas, plasma focus theory)

- Technische Universität Graz and Institut für Weltraumforschung of the Austrian Academy of Sciences (dissipative MHD and nuclear fusion physics)

- Centre de Physique Théorique, Ecole Polytechnique, France (non-linear plasma physics)

- Universidad de Antioquia, Colombia (statistical mechanisms of dense plasmas)

- Pontificia Universidad Católica de Chile (plasma focus and dense z-pinch experiments)

2.2. - CNEA's Nuclear Fusion Division

- Staff: 4 permanent scientific members, Ph.D. level
  3 permanent scientific members, M.S. level
  2 permanent engineering support members
  3 students
  3 technicians

- Typical annual operations budget: U.S.$ 30,000 (excludes salaries)
- Experimental facilities

Type: Field reversed theta pinch
Peak bias magnetic field: 0.06 T
Peak external magnetic field: 1.0 T (non-crowbarred)
Ionization and preheating: RF + ringing theta discharge
Coil length: 50 cm
Coil inner diameter: 8.5 cm
Discharge chamber inner radius: 6.7 cm
Diagnostics: optical spectroscopy, magnetic probes, compensated diamagnetic loops, streak photography

- Research activities

Experimental: - FRC formation physics
Theoretical: - FRC equilibrium, stability and transport
- FRC equilibrium models

- International cooperation activities

- University of Maryland, U.S.A: (transport and microinstabilities)
- University of Washington, U.S.A. (FRC experiments)
- University of Campinas, Brazil (FRC theory and experiments)

2.3.- National University of Central Province of Buenos Aires (Tandil)**

- Staff: 2 permanent scientific members, Ph.D. level
  2 permanent scientific members, M.S. level
  2 students
  2 technicians
- Typical annual operating budget: U.S.$ 1,000 (excludes salaries)

- Experimental facilities

  Type: plasma focus, Mather type
  Name: PACO
  Capacitor bank energy: 1.9 kJ
  Capacitor bank voltage: 31 kV
  Neutron production (D-D): $2 \times 10^6$
  Operating since: 1984
  Diagnostics: Visual diagnostics (framing and schlieren photography)

- Research activities

  Experimental: Correlation of sheath dynamics and structure with neutron yield
  Theoretical: Support studies for experimental work

2.4.- University of Mar del Plata

  - Staff: 3 permanent scientific members, Ph.D. level
    9 permanent scientific members, M.S. level
    1 non-permanent scientific associate
    3 students
    3 technicians

  (*) 2 scientific members of this group are also listed in the Tandil group

  - Typical operating budget: U.S.$ 3,000 (excludes salaries)
- Experimental facilities

Type: gas-puff dense z-pinch
Name: NOVA
Capacitor bank energy: 2 kJ
Capacitor bank voltage: 10 kV
Peak current: 250 kA
Operating since: 1989
Diagnostics: framing photography

Type: repetitive plasma focus, Mather type
Name: PULSAR
Capacitor bank energy: 23 kJ
Capacitor bank voltage: 40 kV
Peak current: 600 kA
Repetition rate: 5 PPS
Neutron production (D-D): $10^{16}$ (expected)
Operation: 1991 (expected)

- Research activities

Experimental: - edge plasma properties and plasma-wall interaction in a dense z-pinch
- effects of operating conditions on shock wave dynamics and final plasma parameters
- material studies for fusion reactors using a repetitive plasma focus
- plasma focus scaling and optimization
- use of a plasma focus as a pellet implosion driver

Theoretical: - support studies for experimental work
3. - TRENDS AND PROSPECTS

One way of assessing the evolution of fusion research in Argentina is in terms of the number of annual scientific publications in international journals and conferences with well established refereeing standards produced by the groups discussed in the previous section, as illustrated in Fig.1.

The same analysis in terms of the evolution of permanent scientific personnel and of operating budget, however, does not indicate a significative growth during the past ten years. These facts lead to the general conclusion that in spite of economic limitations, the groups active in fusion oriented research in Argentina have matured and improved considerably their scientific standing during the last decade. This observation is also confirmed by the growth of international cooperation activities established in the same time period. Alternative indicators of recent progress are the addition of four new operating experimental facilities and the creation of two new research groups in this period.

The present level of economic support of fusion research in Argentina amounts to a small fraction of a percent of the government's total investment in energy research and development. This support is definitely inadequate to allow for the growth of fusion activities much beyond and their present level and, for this reason, the question of establishing a more significative fusion research effort has been under
review at the CNEA lately. Considering that this institution is directly responsible for nuclear policies and activities at a national level, it is clear that it is the natural entity for promoting and funding a meaningful fusion research program in Argentina.

In conclusion, the development of fusion research in Argentina has shown definite progress in the last decade in terms of new experimental facilities, of the creation of new research groups and, particularly, in terms of the scientific maturity and consolidation of the existing groups. Further progress beyond the present situation will depend strongly on fusion policy decisions by government nuclear authorities.

REFERENCES

1. J. GRATTON, private communication
2. J. POUZO, private communication
FIG. 1 - Number of publications in journals and international conferences with strict refereeing standards
CHINESE FUSION EFFORTS

I. The goals of Chinese Fusion Research:

1. The long term aim is for the preparation of the Fusion Energy in next century. China has more than 1 billion population, it is impossible to import all of the power stations. Fusion energy, as the clean and unexhausable energy source, should be more significant for the future of China.

2. The limited Uranium resources make people to find some ways to produce the fission fuel artificially in the first half of next century. The Fission-fusion hybrid reactor is one of the promising candidate.

3. Fusion Research is the synthesis of many high technologies, pulsed power, high power microwave, ion beam, telemetering, data acquisition and handling and so on. Therefore Fusion research of suitable scale could push forward the development of hightech in developing country. There are a lot of very important applications which could be developed based on Fusion technology.


II. Fusion Laboratories in China:

There are two major Institutes for Fusion Study:

* The Southwestern Institute of Physics in Leshan. It is supported by
the Ministry of Energy. It has Tokamak HL-1 with ECRH of 50-100 kw, mainly for studying the plasma-wall interaction, LH current drive and pump-limiter. There is a simple mirror MM2, stabilized by Hot Electron ring produced by ECRH.

* The Institute of Plasma Physics, Academia Sinica, in Hefei. There are two Tokamaks:

HT-6B is a small one, it has been mainly used for MHD study by Resonant Helical Field and controlling the disruption.

HT-6M is for high power ICRH heating. Now 1 MW ICRF system, 200 KW NB system and 50 KW ECRH are available.

It has a rather big workshop, which could design and manufacture middle size fusion device. Recently it has fabricated the vacuum chamble and some coils for TEXT-upgrade, Texas, U.S.A.

There is a Plasma Physics Division in Institute of Physics, Academia Sinica, in Beijing. It has a small Tokamak CT-1 mainly for transport studies and ECRH heating (50-100 KW).

There is a sub-department of Plasma Physics in University of Science and Technology of China. They have a rather small Tokamak (Table size) KT-5 and a Theta pinch (100 KJ) for education. Each year there are 10-20 undergraduate students graduate.

There are several Theoretical groups in Beijing University, Qinghua University, Fudan University, etc.

III. Installation:
The Chinese efforts on Magnetic Confinement Fusion mainly concentrated on Tokamak approach. There are four main devices with different programs.

HL-1 in Leshan: \( R=1.02\,\text{m}, \, a=0.2\,\text{m}, \, \) circular cross-section, \( B_t=3\,\text{T}, \, I_p=200\,\text{kA}, \) Iron-transformer with Copper-shell, \( n=5 \times 10^{13}\,\text{cm}^{-3}, \, T_e=1\,\text{keV}. \) The plasma-wall interaction, edge plasma and MHD activities with copper shell have been studied. 70kW ECRH has been available. Conventional diagonostics for \( T_e \) (profile), \( n_e \) (profile), \( T_i \), impurities, ... . The 500kW, 2.45GHz low-hybrid wave system, pellet injection and pump limiter are in construction.

CT-6B in Beijing: \( R=45\,\text{cm}, \, a=12\,\text{cm}, \, B_t=2\,\text{T}, \, I_p=30-50\,\text{kA}, \, n_e=5 \times 10^{13}\,\text{cm}^{-3}, \, T_e=300\,\text{eV}, \, T_i=100\,\text{eV}, \) Iron-transformer without conductive shell. It was the first well operated Tokamak in China. Feedback controlling of \( I_p \) and displacement, slow compression in minor radius and ECRH non-resonant heating have been tested. A 80 kW ECRH systems available. There are conventional diagonostics without spatial resolution.

HT-6B in Hefei: \( R=45\,\text{cm}, \, a=12.5\,\text{cm}, \, B_t=1\,\text{T}, \, I_p=40\,\text{kA}, \, T_e=250\,\text{eV}, \, T_i=80\,\text{eV}, \, n_e=3 \times 10^{13}\,\text{cm}^{-3}, \) air-core transformer without conductive shell, position feedback control, conventional diagonostics emphasized MHD observation. There are two helical winding \( (l=2 \) and \( l=3) \) on vacuum chamber. The MHD mode structure has been studied by helical fields which have been taken as external disturbences. It has been observed that, RHF could amplify the sawteeth and even improve the confinement. Thus a program to study the mechanism of improvement of plasma confinement on HT-6B and HT-6M is carrying out. 50 kw ECRH and 100 kw LHCD will be available at the end of this year.
HT-6M in Hefei: R=65cm, a=20cm, Bt=1.5T, Ip=150kA, Te=700eV, Ti=200eV, ne=3*10**13 cm-3, air-core transformer with position feedback control. It has been mainly emphasized the accessibility and can simultaneously accept near 3 MW ICRH, 100 KW ECRH, 500 KW LHCD, 100 KW NBI and near all conventional diagnostics with spatial resolution. Now 1 MW ICRH, 50 KW ECRH, 100 KW NBI are available, and another 1 MW ICRH, 500 KW LHCD are in preparation. The main physical problem which would be studied on HT-6M is the properties of Tokamak Plasma interacted with high power Microwave (ICRH and LHCD).

There are still two small Tokamak for testing and education: KT-5 in University of Science and Technology of China in Hefei. FY-1 in Leshan.

So, China has rather broad Tokamak projects, including MHD studies, transport and confinement, plasma heating and current drive, particle cycling and impurity control, ...

There are two small simple mirror stabilized by hot electron ring: HER in Hefei, and MM2 in Leshan.

There are two plasma Focus devices in Qinghua University, Beijing.

IV. National Hybrid Reactor Program:

From 1988 we have carried out a program for the feasibility study of Fission-fusion Hybrid Reactor in China, which is funded and controled directly by National Commission of Science and Technology.

V. Chinese fusion research has very close relation with the world-wide fusion resea
1. We have good information and personal exchange with nearly all main fusion research centres in the world, including preprint exchange, visiting of scientists, taking part the main international conference and workshop, private connection and so on.

2. Since 1978, more than 130 Chinese fusion scientists or engineers have worked or are working in different fusion laboratories abroad for two years. They worked, learnt and got lots of experiences, and now some of them are already the key persons of different branches. There are nearly 30 graduate students studying abroad.

3. We have collaborated with different fusion laboratories in the world. The Leshan Institute collaborated with Frascati Fusion Department of Italy for development the diagonostics. The Hefei Institute has collaborated with Fusion Research Centre in Austin, Texas for construction and further experiments of Text-Upgrade, and also collaborated with Julich IPP on Textor. China has a formal collaboration agreement with US DOE, and European Copmmonity sent some very important equipment to China.

4. We have very activily taken part the activities of ICTP and TWAS on Plasma Physics and Fusion. The World Laboratory led by Prof. Zichichi also has a project to support Institute of Plasma Physics in Hefei to develop the advanced diagonostics and computer system.
PLASMA AND FUSION PHYSICS IN EGYPT

BY

T.A. EL-KHALAFAWY

PLASMA PHYSICS DEPARTMENT
NUCLEAR RESEARCH CENTER
ATOMIC ENERGY AUTHORITY
CAIRO - EGYPT

1. INTRODUCTION:

1.1 Nuclear Fusion and Developing Countries:

The energy needs of the world in the future are so great that all sources of energy should be seriously studied. The present understanding is, however, that only nuclear energy - Fission and Fusion - can meet the long term needs of the world. Fusion research has been a growing field of activity for more than 30 years and the advantage of fusion is seen mainly in a comparison with fission. Fusion offers the possibility of several long-term advantages and it seems worthwhile to pursue it vigorously, in spite of some technological difficulties. The main objective has always been the generation of useful and economic power by fusion and during last few years the studies of reactor systems have been undertaken in detail. In fact these studies are complex and expensive and need high technology. Doubtless, fusion is needed, and assuming it will be in due course form the basis of economic reactor, then came the usual question: how developing countries - like Egypt - should respond to these advances in fusion programmes? The answer, of course, depend mainly on the estimated long term energy requirements, taking into account conservation and estimates of the potential of the different energy sources in these countries. But it is agreeable that the most important objective for a developing country is to be able to make a continuous, reliable and objective assessment of the progress and likely outcome of fusion
research in major centres in advanced countries(*). This objective can be achieved by developing sufficient experience in fusion to make an independent judgment, which can be done by attaching scientists to fusion programmes elsewhere or developing a national programme based on small-scale experiments for plasma physics. Also, by employing experts from advanced centres.

In addition, it is known that fusion research is closely related to the basic science of plasma physics, which in turn related to gas discharge physics and astrophysics. Therefore, in developing countries, these fields have to be a desirable fields of study and research for scientific and training purposes.

Now, it will be of interest to give some light on the research fields and main results obtained by both the experimental and theoretical groups—during the last 10 years—at the plasma physics Units, Nuclear Research Center, Atomic Energy Authority, Cairo, Egypt.

1.2 Plasma Physics Activities at The Atomic Energy Authority in Egypt:

Plasma Physics Research Group Now:

Group Leader: Prof. Dr. T.A. El-Khalafawy.

Head of The Experimental Group: Prof. Dr. M.M. Masoud.

Head of The Theoretical Group: Assist. Prof. Dr. W.H. Amein

Members of Experimental Group:

Dr. Eng. M. Bourham (Assistant Professor)
Dr. A.B. Beshara (Lecturer)
Dr. H.M. Soliman (Lecturer)

(*) H.A.B. BODIN; Int. Conf. on Nuclear Energy Technology in Developing Countries, Grado Conf. Centre, Italy, Oct., 1981.
The plasma physics laboratory was created in Nuclear Physics Department, 1962 after my return from Plasma Physics K.F.A. Jülich. The research program was planned to establish mainly two experiments, magnetic compression theta pinches, shock tubes, plasma diagnostics such as magnetic and electric probe, rogowski coils, microwave, spectroscopy, high speed photography and X-ray, and theoretical plasma physics. Preparation of needed trained manpower started by giving courses in theoretical and experimental plasma physics, gas discharge and all related topics in cooperation with University Staff Members.

Cooperation between the plasma physics group and International Laboratory started since 1966 with exchange of scientists for long and short period. Scientists from USSR joined us for long period under the umbrella of bilateral agreement between the Soviet Atomic Energy and The Egyptian Atomic Energy Establishment.

UKAEA, Culham Laboratory U.K. donated the group a 3.5-meter θ-pinche which is now in operation. The bilateral agreement between International Bero K.F.A. Jülich, W. Germany and A.E.A. Egypt 1981 gave a chance of developing the laser diagnostics training the group as well as supplying with some components to improve and upgrade the
diagnostics and technology of the plasma machines. I.A.E.A. supplied us with parts of data acquisition system and some help in the up to date diagnostics.

Also we have a Federation Agreement with the International Centre for Theoretical Physics (ICTP, TRIESTA, ITALY). According to this agreement, two scientists of the theoretical group visit the Centre every year and participating in the activities held in the centre and related to plasma and fusion research.

The cooperation with advanced countries and international societies is of great importance for any developing countries to overcome the sophisticated technology and financial problems.

In present the plasma group consists of 16 permanent physicists, 10 experimentalist and 6 theoreticalists besides 12 technicians, mechanics, electronic, vacuum and optical workshop.

One of main task of the group is to encourage the university staff to go for plasma physics fields. About 25 staff members are attached to the group from different universities, as well as several experiments are running.

High lights on the experiments carried out and the main problem investigated and results obtained by both the experimental and theoretical group follow.

2. EXPERIMENTAL RESEARCH:

The plasma physics research work in N.R.C. of Egyptian A.E.A. started 1962 with two major experiments. The first was theta-pinčh, the second was shock waves. During the 25 years of research some experiments were shutdown, others build up according to scientific personnel presence, apparatus available, scientific and technological development, financial support and cooperation with international laboratory interest.

Current plasma experiments consist of three main experiments, small linear θ-Pinch 4KJ, 10 KJ Plasma Focus, and 3.5 meter θ-Pinch 60 KJ.
The 4 K.J. O-Pinch is in operation since 1973 and continue. The Plasma Focus experiment started with 3 KJ system and developed in 1983 to 10 KJ bank. A new focus device is under construction with bank energy of 40 KJ.

The 3.5 meter $\Theta$-Pinch can be used as O-Pinch, screw pinch, or $Z$-Pinch. It is in operation since 1985 with main $\Theta$-Pinch bank of 60 K.J.

The developments of the diagnostics tools started with laser. A home made nitrogen pumped dye laser is in operation successfully, some modification in the $N_2$ laser and mode selection is in progress. $H\cdot C\cdot N.$ laser and flash lamp pumped dye laser are in the testing phase.

In present year the program are concentrated on several plasma diagnostics and data acquisition system for 35 meter O-Pinch, and 40 KTJ Plasma Focus and Plasma wall interaction. Also it is undertaken to achieve a spheromak configuration by using the coaxial discharge with toroidal and poloidal magnetic field.

Our ultimate goal for the future plan after that will be a small toroidal system with all additional control and diagnostics similar to the existing tokamak system.

2.1 Shot Down Experiments and Its Main Results:

The development of these experiments; configuration, parameters, diagnostics, main problem studied are shown in tables.

2.1.1 Development of $\Theta$-Pinch 1965-1976 (Table I).
2.1.2 Development of shock tubes 1965- (Table II).
2.1.3 Development of Plasma Focus 1974- (Table III).

2.2 Current Experiments:

2.2.1 The Straight $\Theta$-Pinch (Thetatron) Discharge 1984 Till Now:

This work is mainly concerned with the investigation
of heating mechanism and its relation to plasma dynamics and magnetic stability.

Experimental Set-Up:

The thetation discharge arrangement consists of a condenser bank 9uF, producing 129 KA at charging voltage of 16 KV. The compression coils used consists of 14 parts paralellly connected length 50 cm around the ceramic tube of inner diameter 7 cm, its length 100 cm, filled with hydrogen press ranging between 10⁻³ to 10⁻⁵ torr. The gas was preionized by glow discharge, has a maximum value of election temperature 55 eV at tube radius 1.25 cm and density 1.6 x 10⁻¹ cm⁻³.

Diagnostic methods used are electric probe (double floating probe) Rogowski coil, magnetic probes and microwave probe.

Experimental Results:

Radial election temperature distribution shows its maximum value near tube axis R-0.5 cm and drop to lower values at R - 1 cm. The increase of the electron temperature near the axis may be due to energetic particles diffused from plasma sheath and shock waves approaching the axis. But radial density distribution reaches its maximum value at R - 1 cm where n = 13.5 x 10¹² Cm⁻³ and lower value near the tube axes. This can be attributed to the existence of the trapped magnetic field at the axis of the discharge tube.

Study of the microwave radiation emission indicates that it originates from electron oscillations depending on charging voltage for λ ≤ 4 mm

λ ≤ 8 mm according to σ_{rad} = A λ^{1/4} I_{dis}

σ = radiation density, A is a constant, I discharge current, also it was found that the peak value of emitted radiation occurs at Po ≈ 8 x 10⁻³ torr for λ ≤ 4 mm and for 4 mm ≤ λ ≤ 8 mm radiation intensity increase linearly with increasing initial pressure to Po = 8 x 10⁻² torr.
Also it propagate at right angle to the direction of axial magnetic field, predicting that it is due to longitudinal oscillation which leads to the generation of electromagnetic radiation. The microwave radiation frequency bar 8 and 4 mm was \(4.7 \times 10^{11}\) sec\(^{-1}\) 2.36 \(\times 10^{11}\) sec\(^{-1}\) and corresponding value for cyclotron frequency \(W_{ce} \approx 4.93 \times 10^{10}\) sec\(^{-1}\) and 2.92 \(\times 10^{10}\) sec\(^{-1}\) and calculated value for \(W_{Pe}\) is 7.98 \(\times 10^{10}\) sec. This result show that:

\[W_r = nW_{ce} < W_{Pe}\]

Where \(n = 8\) in case of \(\lambda = 8\) mm, \(n = 10\) in case of \(\lambda = 4\) mm, Fig. 4.17, 4.18.

The electromagnetic radiation has also relation to the upper hybrid frequency as:

\[W_r = nW_{nl}\]

Where \(n = 3\) in case 8 mm, \(n = 5\) for 4 mm indicating the possibility of longitudinal oscillation to be transformed into electromagnetic radiation.

Magnetic Field distribution in both axial and radial directions show trapped magnetic field depending on initial gas pressure and has peak value at \(P_0 = 8 \times 10^{-3}\) torr which coincide with maximum of microwave radiation \(\lambda \leq 4\) mm. This predicts that the change of magnetic flux during the tearing and reconnection will cause an accelerating electron beam. This electron beam will give rise to the excitation and emission of microwave radiation.

Recent Published Papers


2.2.2 3.5 Meter Θ-Pinch (1985 – Now):

The machine is the ex-culham 3.5' M Θ-Pinch which is re-installed at the plasma laboratory and modified to suit the rearrangement conditions. Capacitor bank of 60 KJ stored energy is allowed to discharge through 7 turns Θ-coils in order to deliver 400 KA discharge current of 7 μsec rise time. Bias magnetic field is created by the discharge of a 4.8 KJ condenser bank triggered before the main bank by means of a delay system. A z-pinch discharge is used for preionization and preheating before applying the main bank. The discharge takes place between two metallic electrodes placed at the ends of the discharge chamber (4.2 m separation). The z-pinch bank has an energy of ≈ 1 KJ with rise time of 1.9 μs.
Main Problems Studied and Results:

The plasma dynamics for both z-pinch and 9-pinches was investigated. The effect of the bias magnetic field on the stability of the sheath was obtained. The density and temperature of the plasma sheath was estimated. Trapped magnetic field and microwave radiation was measured. A complete analysis of the results is in progress. 3 Reports about the pinch behaviour were published.

Future Plan:

Since the machine banks is triggered by air switches which are noisy, a pressurized switches where designed and under construction to be fixed to the machine. Heating mechanisms and instabilities of the plasma sheath and pinch will be the main course of study in the coming year as well as wake excitation in the microwave region.

Published Works:


M.Sc. Thesis of A. Mansour (to be published).

2.2.3 Coaxial Plasma Focus:

The plasma focus devices, consist of a coaxial electrodes of Mather geometry have been used. The first one has an outer and inner electrodes radii of 3.3 and 1.6 cm respectively and a length of 31.5 cm, and the second one has an outer and inner electrodes radii of 0.5 cm and 5 cm respectively and length of 7 cm.

The experiments were conducted with a 150 KA peak discharge current, with rise time of 10 μ sec, which delivered from a 10 KJ capacitor bank for charging voltage of 15 K.V.
The investigations are carried out in Hydrogen gas with base pressure ranging from 0.2 to 1 mmHg. The discharge was triggered by a two pressurized three electrodes spark gap trigitation type.

Diagnostics used are, miniature rogawiski coil, magnetic and electric probes, high speed camera spectroscopy, X-ray detector, gridded faraday cup, retarding field analyzer.

**Experimental Results:**

a. For the first device (a = 1.6 cm, b = 3.3 cm, z = 31.5 cm).

The most important results are; the current sheath is formed near the breech of the coaxial electrodes and move with velocity \( V \propto Z^{0.4} \), where \( \rho \) is the gas density and \( Z \) is the distance from breech. It rotates around the central electrode at \( Z = 15 \) and the rotating current increases with sheath motion as \( I_0 \propto Z^{3.4} \) until it reaches a value of 20% of the radial current. Applying a magnetic field 0.6 T along the coaxial electrodes, the sheath current rotates near the breech and increases as \( I_0 \propto Z^4 \) until it approaches the value of radial current.

Increasing the discharge current up to 150 KA results of an emission of intensive X-ray accompanied by a low divergence energetic electron beam at one side on the axis and energetic ions burst the other side. Plasma focus density and temperature was estimated to be \( 10^{19} \text{ cm}^{-3} \) and \( \sim 3 \text{ Kev} \). Applying a transverse magnetic field 280 G in the expansion chamber, the radial velocity of the expanded plasma shell is restricted and plasma temperature decreased while its density increased.
b. Second device \((a = 0.5 \text{ cm}, b = 5 \text{ cm}, z = 7 \text{ cm})\).

The most important results obtained are:

- A pulse of energetic electron beam ejected from the pinch region of the focused plasma was detected and estimated to be 0.32 KeV measured by retarding field analyzer.

- Electron temperature of the plasma focus was determined by measuring X-ray intensity to be 2.8 KeV.

Future Experimental Program:

A modified energy source for new design of plasma focus device (inner diameter = 4 cm, outer diameter = 11 cm, its length = 8 cm), bank stored energy up to 40 KJ has been constructed. It is planned to study creation mechanism of the induced axial magnetic field, magnetic field tearing within the plasma sheath as well as its distribution, rotation ... etc. Effect of the applied axial magnetic field along the coaxial electrodes on the plasma sheath dynamics as well as viscosity effect.

Developed diagnostic techniques will be used for measurements processes such as laser and high speed photography.

Recent Published Papers

1. Coaxial electrodes gun characteristics.  
   M.M. Masoud, H.M. Soliman.  

2. Plasma focusing in coaxial gun.  
   Arab J. of Nuclear Science and Applications, Accepted for publication (13/85), (1985).

3. Plasma Rotation in Coaxial Discharge.  
   M.M. Masoud, H.M. Soliman and T.A. El-Khalafawy.  
4. Plasma Sheath and Focus Dynamics.
M.M. Masoud, H.M. Soliman and T.A. El-Khalafawy.

5. 10 Kilo Joule Plasma Focus.

6. Viscosity effect on plasma sheath dynamics in plasma focus.
M.M. Masoud, H.M. Soliman and T.A. El-Khalafawy.

7. Influence of longitudinal magnetic field on current sheath in coaxial discharge.


9. Investigation of energetic electron beam and X-ray generated in a plasma focus.

10. Magnetic Reconnection and Instabilities in Coaxial Discharge.
M.M. Masoud, H.M. Soliman and T.A. El-Khalafawy.

11. Plasma focus matching conditions.

2.2.4 Glow Discharge:

The objective of that experiment is to introduce up to date technology in plasma and laser diagnostics. Glow discharge which is a linear electrode in a vessel of 30 cm length and 10 cm diameter represents the basic experiment for such diagnostics.

Main Problems Studied and Results:

A double electric probes was used to investigate the plasma density and temperature and their radial and axial distribution. The results are in progress and the analysis of the different discharge power parameter will continue till the end of this year. The main interest is the glow discharge fundamental processes. A tunable dye laser is used to confirm the probe results as well as to study the electrodes material effects on the discharge.

Future Plan:

An ion beam injector is designed and is under construction to study beam-plasma interaction as a diagnostic tool.

A data acquisition system has been installed and the measurement will be linked with it, with the proper program. The scientific group are working in the data acquisition system to use it properly as soon as they complete their progress.

3. THEORETICAL RESEARCH:

The theoretical studies in plasma physics are mainly directed during last ten years to study and investigate following topics:

3.1 Plasma Instabilities and Equilibrium:

These studies are of great interest from the confinement point of view, specially in the thermonuclear fusion reactors. In addition, in investigating some of the plasma phenomena as the mechanism of collisionless plasma heating, the nonlinearity and turbulence in plasmas, and MHD generators. The following problems are considered:
3.1.1 Drift Waves and Instabilities in Inhomogeneous Plasma:

The nonlinear dispersion and the kinetic wave equations for drift potential oscillations of weakly inhomogeneous plasma with fixed phases are obtained. The drift kinetic is derived with accuracy to within the terms \( W_{\text{cycl}}^{-2} \) (\( W_{\text{cycl}} \) is the cyclotron frequency of type \( \omega_{\text{cycl}} = e\gamma/2m \)). This equation makes it possible to take into account not only the density and temperature gradients, but also the current velocity inhomogeneity. Coulomb collisions are considered and helped to remove divergences in the matrix elements, describing the nonlinear wave interactions. The derived kinetic wave equation enables to investigate the nonlinear dynamics of drift oscillation saturation, hazardous for plasma confinement, as well as the wide range of homogeneous collisional plasma.

On the basis of weak turbulence theory, the drift instability excited by longitudinal current in isothermal plasma (current-convective instability), and electron-acoustic instability excited in hot ion rotating, are investigated analytically.

For drift instability, the nonlinear Landau damping is the mainly nonlinear mechanism limiting the oscillation amplitude and that the nonlinear instability saturation takes place at high noise level.

The linear stage of the current-convective instability is also investigated for nonisothermal magnetized plasma, where the temperature ratio \( T_e/T_i \) play an essential role, i.e., increasing \( T_i \) over \( T_e \) leads to decreasing the growth rate of the instability in the linear stage.
3.1.2 Kinetic Theory of Buneman's Instability:

The development of Buneman kinetic instability is investigated under different plasma conditions. Expressions for the frequency, growth rate, threshold values, and conditions of excitation of such instability are obtained at current velocity slightly exceeds the instability threshold velocity.

In quasilinear approximation, the major effect was the slowing down of resonance electrons, and connected with it, a reduction of residual electron terms in the dispersion equation for waves with hot ion plasma. This effect leads to a gradual increase of the oscillation growth rate and to the transformation of weak instability - as in the linear stage - into a strong one.

In isothermal collisional plasma, the existence of a critical value of the external applied electric field \( E_{C2} \) is found to divide the quasilinear effect into: amplification of instability at \( E < E_{C2} \) and saturation at \( E > E_{C2} \) with low noise level.

Weak turbulence theory of a homogeneous magnetized plasma with allowance for Coulomb collision is also developed for potential plasma oscillations with random phases. Based on this theory, the nonlinear stage of Buneman's instability excited in hot ion plasma by longitudinal current is investigated. In this case, the nonlinear treatment of the instability is not essential, while the major effect due to quasilinear theory.

In addition, this instability is investigated for hot electron plasma both in linear and quasilinear stages. The linear growth rate in this case found to be much less than for hot ion and isothermal plasmas, and quasilinear effect leads to neglecting the contribution of the electrons in the dispersion equation.
3.1.3 Instabilities and Turbulence in Plasma with Transverse Current:

The effect of plasma ions upon the process of nonlinear scattering of instability excited by transverse current is investigated. In the case of excitation of 3-dimensional wave packets, nonlinear scattering of the waves on ions is small so that the oscillation scattering on plasma electrons play the main role in the stability saturation. The case of 2-dimensional wave packets requires a new approach, and a new model of weak turbulence theory allowing for the broadening of resonant denominators at the expense of the wave growth increments. Therefore, a theory of weak turbulence in a homogeneous collisional plasma without magnetic field and in strong magnetic field is developed.

Based upon the above theory, two types of instabilities are studied:

i. The excitation of oscillations by a cold electron beam in hot free plasma.

ii. The excitation of ion-cyclotron waves by axial current.

The developed theory is especially suitable for analysis of nonlinear saturation of instabilities with a threshold character if plasma parameters correspond to a slight surpassing of instability excitation threshold.

3.1.4 Relaxed States of Toroidal Plasmas:

The problem of calculating the lowest eigen values which connected with the maximum current for the relaxed (force-free) toroidal plasmas "Taylor States" is investigated for axisymmetric case. These eigenvalues (zero-flux and zero-field eigenvalues) have been calculated exactly for toroidal plasmas for both arbitrary aspect ratio and arbitrary cross sections as circle, ellipse, multi-pinch cross section described by a cassini curves, and D-shape of the JET.
For more details concerning plasma instabilities and equilibrium, see references [1-13], (recent publications of the theoretical group).

3.2 Nonlinear Interaction and Wave Generation in Plasmas:

These studies are of prime importance from the practical applications point of view, e.g., in plasma diagnostic technique and in studying the interaction of intensive electromagnetic waves with matter (laser-fusion reaction). Besides, it is of great interest in studying the propagation of electromagnetic waves in ionosphere and using the strong generated waves as a tool for plasma heating. The following main results are obtained:

3.2.1 Isotropic Plasma:

In case of nonlinear interaction of P-polarized incident electromagnetic waves on a semi-bounded isotropic plasma, the tangential electric field components of the waves at combination frequencies are found to be discontinuous at the plasma boundary. This is a new result differs from that of earlier work in which the tangential electric field is assumed to be continuous at the boundary.

The amplitudes and phases of the wave radiated from a transition layer at combination frequencies are found to be depend neither on the width of the transition layer nor on the plasma density distribution through the TL but only on the plasma density in the homogeneous region of the medium. The above work is generalized later for two interacting waves of different polarization (S and P).

In the case the amplitudes of the generated waves with combination frequencies are equally radiated from transition layer into plasma vacuum. Besides,
the amplitudes of S-radiated second harmonic waves into plasma and vacuum are not equal, while amplitudes of P-radiated second harmonic waves are equal.

When one of the interacting waves is a surface wave, the second harmonic is radiated only in the direction of the reflected wave at the basic frequency.

3.2.2 Anisotropic Plasma:

Above studies are considered in case of applied static magnetic field where two plasma geometries are considered:

i. Semi-bounded plasma.

ii. Plasma layer.

The external magnetic field has no effect on the fundamental s-polarized waves only, while it strongly affects the generated waves. The generated amplitudes are found to be sharply increases at frequencies approaches the electron cyclotron frequency. The resonance in the amplitudes of these waves occur for values of the static magnetic field in the neighbourhood of plasma resonance for the waves at the fundamental and combination frequencies.

In case of normal incidence of electromagnetic waves on unmagnetized plasma, waves are not emitted. On the other hand, existence of static magnetic field causes a second harmonic generation for normal incidence.

When the electrons in the plasma layer are relativistic, the amplitudes of the generated waves are found to be sharply increases.

3.2.3 Beam-Plasma Interaction:

The effect of external static magnetic field on the interaction of relativistic beam with
an inhomogeneous bounded cold plasma and plasma heating is investigated in one-dimensional. In this case, more power is absorbed by the plasma, and the relativistic beam, due to the resonant increase of the electric field in the interval where \( W = W' \), acts as a source for feeding the plasma with power and not only for amplification of waves, especially when second harmonic waves are generated.

For more details concerning section 3.2, see references [14-25], (recent publications by the theoretical group).

3.2 Future Plan:

The following programme is supposed for the future plan. It is assumed to continue the theoretical research work of above mentioned topics under the following considerations:

3.2.1 Plasma Instabilities and Equilibrium:

1. To study some of current electrostatic micro-instabilities (Buneman, current-convective, electron-sounds) under the effect of inhomogeneous fields and to find the possibility in this case for instability saturation.

2. To create a complete picture of the plasma-sound instability.

3. To use the derived kinetic wave equations (for magnetized and nonmagnetized plasma) to study and investigate the nonlinear dynamics of current-convective instability in inhomogeneous plasma.

4. To investigate turbulent heating as result of Bunemanl and electron-sound instabilities and the effect of these instabilities on the plasma parameters.

5. To study the case of nonaxisymmetric relaxed force-free toroidal plasma.

6. To study plasma current instability due to two ions streams.
3.2.2 Nonlinear Interaction and Wave Generation in Plasmas:

1. To study the effect of external applied weakly inhomogeneous magnetic field on the wave generation and amplification in plasmas. This consideration is important from the practical standpoint, when the electron displacement from the equilibrium position is considerably less than the characteristic scale of magnetic field inhomogeneity.

2. Relativistic incident radiation on the plasma, which of great interest in connexion with higher energy deposition in various devices for intense electromagnetic radiation generation.

3. The effect of different parameters on the generated waves:
   - Dense or rarefied plasma.
   - Normal or oblique incidence.
   - Plasma shape (more realistic geometry), either flat inhomogeneous plasma layer, or thin inhomogeneous plasma cylinder.
   - Warm plasma.

4. The role of surfaces in the interaction of radiation with plasmas.

3.3 Recent Published Papers:

3.3.1 Plasma Instabilities and Equilibrium:


3. On The Theory of Magneto-Active Plasma Weak Turbulence.

4. Collisionless Quasilinear Current Instability in Field-Free Plasma.

5. Turbulent Ion Heating in Rotating Plasma.

6. Electron-Sound Instability Based on Weak Turbulence Theory.


Accepted for publication at: Arab J. Nuclear Sciences and Applications (1988).
Sh.M. Khalil, Y.A. Sayed, and N.G. Zaki:
Accepted for publication at: Beitrage Aus Der Plasmaphysik (1989).

Sh.M. Khalil, and B.F. Mohamed:

F. Cap, and Sh.M. Khalil:

Sh.M. Khalil, and B.F. Mohamed:

3.3.2 Nonlinear Interaction and Wave Generation in Plasmas:

14. Wave Generation at Combination Frequencies.
A.R. Barakat, V.V. Dolgopolov, and N.M. El-Siragy:
Plasma Physics, 17, 89 (1975).

15. Nonlinear Interaction of Surface Waves with Incident Radiation at A Narrow Inhomogeneous Plasma Layer.
A.M. Hussein:

16. Waves Generation Due to Nonlinear Interaction of S-Surface Waves at The Plasma Boundary.
N.M. El-Siragy, Sh.M. Khalil, W.H. Amein, O.Z. Nagy:
17. Mode-Mode Coupling of S- and P-Polarized Surface Waves at The Plasma Boundary.
N.M. El-Siragy, Sh.M. Khalil, Y.A. Sayed and O.Z. Nagy:

N.M. El-Siragy, Sh.M. Khalil, W.H. Amein, and W.A. El-Feky:

Sh.M. Khalil, N.M. El-Siragy, Y.A. Sayed, and R.N. El-Sherif:

A.M. Hussein:

N.M. El-Siragy, Sh.M. Khalil, Y.A. Sayed, and R.N. El-Sherif:

International J. Theoretical Physics, 24, 1001 (1985).

Sh.M. Khalil:
Sh.M. Khalil, and R.N. El-Sherif.

Sh.M. Khalil, and N.G. Zaki.
The plasma group during 30 years has accomplish 53 M.Sc., 41 Ph.D. and approximately 400 published papers. We usually participate by research papers in most of the International Conferences related to plasma physics and fusion energy, such as Conferences on Phenomena in ionized Gases, European Conference on Controlled Fusion and Plasma Physics, Conference on Plasma Physics, IAEA Conference on Plasma Phys. and Fusion and ICTP Collegue on Plasma Phys. Triesta.

4. Other Plasma Activities in The Egyptian Universities:

4.1 Al-Azhar University, Physics Department, Nasr City, Cairo, Egypt:

Plasma Group
Group Leader
Prof. Dr. A.A. Garamoon
Members
Dr. W. Sharkawy
Dr. A. Nosair
Dr. M.A. Eissa
Dr. A.H. Saudy

Research Student
Mr. A. Seragy
Mr. Gammal
Mr. A. Shahin
The laboratory was established after the return of Dr. A. Garamon from U.K. 1968. The laboratory was formed on two branches of research, Townsend discharge and high temperature plasma. Research was carried mainly on shock wave tube T-type and investigate plasma parameters such as, plasma temperature with and without magnetic field, after glow discharge and second Townsend effect. Later, a UNU ICTP PFF was established in the lab. as well as a Hollow Cathode Experiment and a small Z-Pinch Device.

4.2 Zagazig University, Faculty of Engineering, El-Zagazig, Egypt:

Group Leader Dr. Mohamed El-Shaer.

2 Post Graduate Students (B.Sc.).

The main item in the work performed is the development of small experiments dedicated to research as well as educational purposes. The main experiments performed are glow discharge and microwave discharge. Since 1987 the lab. was prepared with its peripherals of electricity, water, etc. In the end of 1988 the components were installed and we are now in the phase of experiment building and experimental phase will be in the summer 1989.

The physical program is mainly the investigation of the discharge parameter with suitable diagnostics like probes and optical spectroscopy. There are also educational part for postgraduate students in plasma physics. Visiting professor from other institutions are also involved.

The main equipments are provided as gifts from the KFA in Jülich (FRG) and Max Planck Institut für Plasma Physik in Garching (FRG).
4.3 Suez Canal University, Physics Dept., Faculty of Science, Ismailia, Egypt:

Head of the theoretical group is Dr. M.Y. El-Ashry.

The main work is directed to investigate and study theoretically some problems related to parametric instabilities and beam-plasma interaction.

There are some plasma activities in theoretical plasma physics in Tanta University, Alexandria University and Assyout University.
<table>
<thead>
<tr>
<th>Experiment &amp; Authors</th>
<th>Machine Parameters and Dimensions</th>
<th>Diagnostics</th>
<th>Main Study &amp; Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tube radius cm.</td>
<td>tube length cm.</td>
<td>coil length cm.</td>
</tr>
<tr>
<td>1- Fast Thetatron</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.A. El-Khalafawy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.G. El-Hak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.M. Youssef</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.A. Bourham</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.A. Hafiz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1964 - 1968 Quartz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6</td>
<td>50</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2- Hard Core ( \theta )-Pinch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.A. El-Khalafawy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.M. Youssef</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.A. Bourham</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.M. Gabr main</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.G. El-Hak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967 - 1972</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-4</td>
<td>40</td>
<td>16</td>
</tr>
<tr>
<td>Experiment</td>
<td>Machine Parameters and Dimensions</td>
<td>Diagnostics</td>
<td>Main Study &amp; Results</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Tube radius</td>
<td>tube length</td>
<td>coil length</td>
</tr>
<tr>
<td>3 - Helicoidal core 0 - Pinch</td>
<td>Same as previous one</td>
<td>The same as previous one</td>
<td>Field distribution, Formation of zero zone magnetic field to simulate those of the Tokamak acceleration process.</td>
</tr>
<tr>
<td>T.A. El-Khalafawy A.M. Youssef</td>
<td>T.A. El-Khalafawy</td>
<td>4.3</td>
<td>100</td>
</tr>
<tr>
<td>A.N. Gabr M.S. Hanafy H.A. Ahmed 1972 - 1975</td>
<td>T.A. El-Khalafawy</td>
<td>4.3</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>M.A. Bourham 1968 - 1976</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 - Straight Homogeneous 0 - Pinch</td>
<td>4.3</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>T.A. El-Khalafawy M.A. Bourham</td>
<td>M.A. Bourham</td>
<td>4.3</td>
<td>100</td>
</tr>
<tr>
<td>5 - Straight Homogeneous 0-pinch with preionization</td>
<td>---</td>
<td>---</td>
<td>4</td>
</tr>
<tr>
<td>M.A. Bourham M.A. Elissa M.M. Masoud</td>
<td>---</td>
<td>---</td>
<td>4</td>
</tr>
<tr>
<td>1976 - 1985 preionization</td>
<td>1976 - 1985</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiments &amp; Authors</td>
<td>Source Dimensions</td>
<td>Machine Parameters</td>
<td>Diagnostics</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>Electrode dim. mm.</td>
<td>tube dim. mm.</td>
<td>charg. vol. K.V.</td>
</tr>
</tbody>
</table>
| 1- Electroless conic shock tube | 40 | 50 | 40 | 25 | 3.9 | 2.8 | Electric & Magn. probes, X-ray, High speed photography. | - Shock wave interaction with rest gas & walls  
- Shock structure.  
- Collisional processes. |

| 2- Coaxial electrode shock tube. | 34 major | 80 | 40 | 18 | 5 | 10 | 0.6 | Electric & Magn. probes, X-ray, Spectroscopy, diamagnetic loops, High speed photography. | - Shock wave interaction with external magnetic field  
- Energetic particle production. |

| 3- Coaxial shock tube. | 10 minor | 100 | 50 | 3.75 | 6 | 0.1 | Electric & Magn. probes, Diamagnetic loops, high speed photography | - Switch on condition.  
- Collisionless shock structure in magnetic field. |
<table>
<thead>
<tr>
<th>Experimental Apparatus &amp; Authors</th>
<th>Machine Parameters</th>
<th>Diagnostics</th>
<th>Main Studies &amp; Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Coaxial plasma gun with dynamic gas injection</td>
<td>inner elect R(a) cm.</td>
<td>1.6</td>
<td>Diamagnetic loops</td>
</tr>
<tr>
<td>H.M. Saad H.A. Abulnaal</td>
<td>outer elect R(b) cm.</td>
<td>3.2</td>
<td>Electrostatic analyser</td>
</tr>
<tr>
<td>1974 - 1977</td>
<td>length z cm.</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bank energy KJ</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>charge/ disch. Kv K amp.</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>2- Coaxial electrode discharge</td>
<td>inner elect R(a) cm.</td>
<td>1.6</td>
<td>Rogowski coils</td>
</tr>
<tr>
<td>T.A. El-Khalafawy N.M. Masoud N.M. Soliman</td>
<td>outer elect R(b) cm.</td>
<td>3.2</td>
<td>Potential dividers, Double electric probe, magnetic probes</td>
</tr>
<tr>
<td>1977 - 1984</td>
<td>length z cm.</td>
<td>31.5</td>
<td></td>
</tr>
</tbody>
</table>
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 indigenous 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 indigenously 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 \( R = 75 \text{ cm}, \ a = 25 \text{ cm}, \ B_T = 1.5 \text{ T}, \ I_p = 250 \text{ kA}. \) The choice of machine parameters has been guided to a large extent by considerations of simplicity, available technology and allowing maximum flexibility to accommodate 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, $a = 8.4$ 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 spherical 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
solenons, 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.
FUSION RESEARCH IN THE REPUBLIC OF KOREA

C. S. LEE

Nuclear Division, Korea Electric Power Corp., R&D Center
8F Kyobo Bldg., Sunhwa-Dong, Daejeon, Korea

ABSTRACT

This paper reviews the status of fusion research in Korea and works done for the last 10 years. A few experiments are given. The paper also includes a preliminary future program in progress. Necessity of international cooperation is accentuated.

1. INTRODUCTION

Korea, with its dense population and poor resource, has changed itself to an industrialized country from early 1900's. In the process of industrialization, electricity has been one of the most important contributors to the rapid economic growth. During 1961-1987, the installed capacity became multiplied by 52 times and consumption rate per capita expanded itself by 33 times. (1)

In the beginning, electricity generation was mainly shared by hydro and coal fired plants. In 1960's and 1970's KEPCO introduced many oil fired plants. But the oil shock followed by the energy crisis forced Korea to give up the new oil
fired plants and to increase nuclear power plants of which the first unit was built in 1978. Today 8 nuclear plants are supplying more than 50% of demand. (2)

All nuclear power plants in operation and under construction are conventional water reactor plants. For the next century, a combined study in progress is seeking the most viable path to energy security. (3) Two new concepts, the liquid metal fast breeder reactors and fusions, are briefly stated in the study. So far the fusion is not treated as a real reactor to be introduced, rather it is considered as a way of possible alternative energy source.

2. FUSION RESEARCH ACTIVITIES IN KOREA

There are several organizations involved in fusion research. Two institutes, Seoul National University (SNU) with its medium scale experimental Tokamak SMT-79 and Korea Advanced Energy Research Institute (KAERI) with its small scale Tokamak KAERIT, have steered most of the experimental activities. Other institutes are involved in theoretical study for educational purposes. Table I is a list of the important works done in SNU and KAERI since 1979. (3)

Table I. List of Important Works During 1979 - 1989.

- Design of Tokamaks
- Plasma Focus Experiments
- Fabrication of Plasma Chamber
- Magnetic Field Control Test for Plasma Confinement
- Fabrication of Toroidal Magnets
• High Voltage Switching System Test
• Completion of Tokamak Main Bodies
• Establishment of High Vacuum
• Development of Large Current Crowbar Switch for Magnetic Field Coil Power Supply
• Establishment of Preionization and Toroidal Plasma Production Technology
• Development of Discharge Cleaning
• Set up of Basic Diagnostic System

It is worth while to note that all of the software work and much of the hardware work were done by the young researchers. Main bodies of the two devices were completed in 1984. Though they still need to be equipped with higher power supply and more accurate detectors in order to operate at full power, researchers accumulated quite a bit of experiences in plasma generation and concentration. The current topic is to maintain a uniform plasma column as long as possible.

Among the various experiments, the following three tests from SMIT-79 may give some idea to see the status of fusion technology in Korea.

2.1 Toroidal Field Measurement

16 D-Shape toroidal coils which can generate the magnetic field of 3T in the center of plasma were designed as in figure 1. Design was done by use of computer code DSHAPE and prediction of experiment results were done by TFIELD code. Both computer codes were developed by the researchers.

The measured parameters were toroidal field, field ripple, electromagnetic forces, coil current, ohmic loss, time-space dependence of temperature, etc.
The results verified simplicity and good approximation of DSHAPE and TFIELD codes.

2.2 Plasma Control and Diagnostics

In 1984, SNUT-79 system became ready for operation and diagnostic instruments were provided to make a basic system as shown in figure 2.

The following data came out from the operation experience.

- The ultimate pressure of the torus after 24 hour glow discharge cleaning with 6 - 7 amp in hydrogen atmosphere of $10^{-2}$ torr resulted in $1.4 \times 10^{-6}$ torr.
Through a low current test, the toroidal magnetic field per coil current along main radius was measured to be 0.95 KG/KA which was very near to the design value 0.98 KG/KA.

During operation, toroidal magnetic field reached maximum of 2.4 KG, total magnetic flux variation to plasma loop was 0.17 V-sec, initial plasma loop voltage was 47V. But the instantaneous peak plasma discharge current was only 6 KA at 0.8 KG of toroidal field and 35V of loop voltage, because at the time of experiment the time delay operation of magnetic field was in poor condition and equalizing magnet system was not equipped.
From the operation data, the following factors were calculated.

- Safety Factor $q \sim 2.3$
- Plasma Temperature $T_e \sim 7$ eV
- Plasma density $n \sim 2 \times 10^{13}/\text{cm}^3$
- Plasma $\beta \sim 8.7~%$

2.3 Breakdown Test

These experiments executed in 1988 aimed to find several characteristics related to breakdown phenomena during initial start up of ohmic heating system.

The preionization which is essential to overcome the problems due to the limit of power transfer and stray magnetic field was cleared by use of $\nabla \times B$ drift preionizer illustrated in figure 3.

The experiment allowed to reduce plasma loop voltage as low as 24 V. A computer program describing the spatial distribution of seed electrons of preionizer was also developed.

![Diagram](image)  
**Fig 3.** $\nabla \times B$ Drift Preionizer
Meanwhile, using double probe system researchers measured time-space dependent plasma distribution to investigate plasma characteristics at breakdown phase.

The results showed that at the breakdown phase, electron temperature reduces exponentially along the chamber wall but the spatial plasma density depends on that of initial seed electrons. Computer program proved to be well consistent with measurement.

3. FUSION PROGRAM

As a matter of priority, fusion has always remained in one of future options rather than an objective of real project. Last year, the situation changed a little. KEPCO established a mid-term research program with assistance of various other organizations. This program declares KEPCO’s intention to invest in fusion research as a way to evaluate the so-called new concept reactors. It means that attentions are paid by government, utility and industries. This 12 year program consists of 3 phases as follow.

Phase I starts this year and lasts 3 years. KEPCO-SNU-KAERI will collaborate for the project. The project aims primarily to add experimental data and put the existing Tokamaks in design capacity. The numeric goals of the parameters are:

- Power Supply by Motor Generator Set to Toroidal Field Coil ≥ 30MW
- Max Plasma Heating : 400 - 600 eV
- Plasma Density : $10^{13}$/cm$^3$
- Ultimate Pressure : $1 \times 10^{-9}$ mbar
- Sustain Time : 5 msec
At the termination of this phase, the control of plasma in those two Tokamak will be possible, as hoped.

Phase II will be dedicated to the design of large scale Tokamak. The specification will depend on the results of phase I, international cooperation and technical level of advanced large Tokamaks. Some people think in mind that the scale would be similar to PLT (Princeton Large Tokamak). Related institutes will be integrated to the design project and a part of components fabrication will be attempted. During this period, cooperation with other countries will be available and much of the work will be done on international basis. This phase will cover the years 1993-1996.

Phase III doesn’t give a clear vision but is regarded as a period of large Tokamak construction. Newly developed technologies will be applied, and development of super conducting coil will have a high priority. The phase will probably start around 1997.

![Mid Term Fusion Program](image)
CONCLUSION

The research people in Korea want to raise their level of technology by the end of this century to that of advanced countries in late 1970's. It's not an easy task and present situation is not so promising. But most of all they have confidence in the will of development and econo-technical potentiality.

A good international cooperation is one of the vital requisites. Korea strongly believes that a fair cooperation will be beneficial to all participants and that every country can contribute to a degree in order to bring earlier use of fusion energy, and the international agency is expected to expand its role for that purpose.

REFERENCES

Fusion Programmes in Malaysia
S. Lee
Physics Department, University of Malaya
59100 Kuala Lumpur, Malaysia.

Abstract:
Fusion Programmes in Malaysia are briefly reviewed with some attention to historical perspective and to the academic continuity from undergraduate through to doctoral programmes. The research in the areas of glow-discharge, small tokamak, pinch, current-stepped pinch, vacuum spark pinch and the plasma focus is then reviewed. The central research theme threading all this research is identified as a study of the limits and enhancement of compressions. Our work shows that in general density compressions are limited and independent of the absolute magnitude of the compressive force. Enhancement of compression may be achieved through time variation of the force field, e.g. specifically using a force-stepping technique, through a reduction in specific heat ratio and in the case of the pinch through an elongation of pinch length during the compression. These ideas are applicable to magnetic field compressions as well as to radiation-driven compressions and should prove useful to aid in understanding e.g. the plasma focus scaling laws.

This review also reports the experience of the research group in its attempt to share fusion related technology on a South-South basis by the development of specific training packages. One such package the UNU/ICTP Plasma Fusion Facility has already been developed and 8 sets have been sent back to the home institutes of the UNU/ICTP Fellow trainees. A compact torus FRC based on the Rotamak concept is also being developed.

Paper prepared for the Symposium on Third World Fusion Programmes and South-North Collaboration, 8-9th June 1989 Trieste, Italy.
Introduction

Fusion Research in Malaysia is centered in the Plasma Research Laboratory, University of Malaya. This laboratory was started in the early 1960's by S.P. Thong who at that time was associated in glow discharge work in collaboration with K.G. Emeleus of Queens University, Belfast. Aware of the work already on-going at that time in Britain on controlled fusion research Thong had the foresight to acquire from the British Government through the Colombo Plan 100 pieces of 40kV 0.6 μF fast discharge capacitors. Preliminary work with these and other capacitors resulted in the first Physic's M.Sc thesis in Malaysia being produced on the topic of electric and electromagnetic shock waves under the supervision of H.H. Teh in 1966.

In 1970 the technical problems of installing these capacitors were solved with a design dividing the 100 capacitors into 4 modules each switched by 2 ignitrons with the help of a voltage division technique proposed earlier by C.P. Lim. In 1972 1.9MA was measured in a full test. This capacitor bank is still operational and will soon be converted to be switched by parallel plate swinging-cascade spark gaps. A plasma focus was designed and in October 1973 D-D nuclear fusion neutrons were measured from the focus by time-of-flight method giving an energy of 2.2 ± 0.1 MeV in a 'backward' direction.

During this period of development and since then we have planned our research mainly on academic basis resulting in the production of 5 Ph.D and 15 M.Sc theses in plasma and fusion physics. Continuity between undergraduate and postgraduate work is maintained by undergraduate courses in plasma and fusion physics augmented by undergraduate experiments in glow discharge, electromagnetic shock tube and pulse electronics experiments.
Experimental plasma research in Malaysia is currently carried out on the following devices: glow discharge, small tokamak, current-stepped Z pinch, vacuum spark x-ray source and the plasma focus. Various lasers are being developed for diagnostic work. A transistorised Rotamak which is a compact torus FRC with current drive is being developed at our associated Pulse Technology Laboratory and an elongating Z-pinch is being designed at the Technology University.

Programme areas

Over the years the research has developed a pattern propelled primarily by the academic needs and perceptions of individuals within a framework of limited infrastructure and financing typical of the university environment of a developing country. Yet a pattern has loosely developed and three broad areas may be identified:

I. Long-lived plasmas, production and diagnostic techniques.
II. Pulsed plasmas, production and properties and techniques for compression enhancement.
III. Development of fusion-related technology for research initiation in developing countries.

I. Long-Lived Plasmas

Work on these plasmas include the Glow Discharge, a Small Tokamak and recently we have started constructing a transistorised compact torus FRC device with current-drive from either a rotating magnetic field or from a transverse oscillating magnetic field. This device called the Rotamak was first developed at Flinders University of South Australia and was transistorised as a specific project to bring the technology of a compact torus FRC within the reach of a developing country.
and the USSR) should be supplemented by a bi- or tri-annual worldwide conference on fusion-reactor technology and if not the increasing efforts in this field warrant the creation of a journal for fusion technology aiming at a market position comparable to that of Nuclear Fusion.

i) The Agency's staff, in preparing their annual list of meetings, should consult with prominent workers in the field. As far as large-tokamak research and generic subjects are concerned, reference can be made to the ITER-team (Sec. III). For areas other than the large tokamaks, the Agency staff should, perhaps in consultation with the IFRC, establish a list of correspondents who are competent to inform them about the needs of workers in fields like stellarators, mirrors, RFP's, high density plasmas, a-neutronic fusion, muon catalysis, laser- and beam-driven inertial-confinement fusion, and the like. The IFRC may be relied upon to see to it that these correspondents' advice will not detract unduly from main-line activities.

j) The fellowship programme of the IAEA has not, so far, been used extensively for training fusion scientists and engineers.

k) It is probably no exaggeration to say that INTOR, which has been extremely important in drawing fusion physics and technology closer together in one mission-oriented effort, and in confronting the four major programmes with each other, could not have originated and have been so successful if the IAEA had not previously earned confidence, both of the governments involved and of the R and D community, of its competence in the field.

ITER builds on the success of INTOR and is benefitting from IAEA support in many ways.
III. Contacts with ITER

The tokamak is now the most advanced confinement system, and the only one for which construction of a test reactor is being considered for the near future. Hence, fusion reactor technology studies, inasmuch as they are not of a generic nature, relevant to any reactor concept, are mostly tokamak-oriented. In physics, there is also a strong concentration of activities on the problems of reactor-like tokamak plasmas, but in addition there are important programmes related to other confinement systems. Leaving these alternative systems aside for the moment, one may say that asking oneself to what extent the IAEA activities on generic fusion problems as well as on large-tokamak physics and technology do serve urgent needs of the fusion community, is almost tantamount to asking how well they serve tokamak reactor studies, of which ITER is now the prime example. Although the transient nature of the ITER organization might create future problems if the Agency were to rely too strongly on formal arrangements about consultations with ITER, nothing should be left undone to strengthen the ties between the Agency staff and the R and D community through semi-official consultations with ITER. For as long as it will exist, the ITER team provides the best source of information one can think of on generic, as well as tokamak-related reactor problems. Moreover, by taking the specific needs of ITER into account, the Agency can only enhance the usefulness of its work.

IV. Developing Countries

It appears that interest in fusion research - which has traditionally been an area reserved mainly for highly industrialized nations - is gradually receiving more attention throughout the world, both in energy-oriented government-sponsored research establishments and in universities. As a consequence, the Agency increasingly receives calls for assistance, both from governments and from individual scientists. On different occasions, notably in a special meeting in the margin of the 1988 Nice Conference, exchanges between the Agency and representatives from long-standing, as well as from recently started fusion research centres have taken place which, however, have not yet crystallized into broad action programmes.
The issue of selecting approaches that will work is a difficult one. With regard to training programmes priority should be given to those scientists who have a viable home programme to which the trainee would return. If this condition is fulfilled, then almost automatically the scene is set for fruitful bilateral collaboration between institutes. In the European programme, excellent results have been obtained with the Mobility Fund, which supports costs above the normal salary (which continues to be borne by the employee's homebase) resulting from a stay in another associated laboratory than one's own. This scheme, supplemented by assistance in moving equipment, has promoted many exchanges, among which full-scale expeditions of teams with major equipment to other laboratories. Clearly, this suggestion is most relevant to those cases where a home-base already exists. The problem how to establish one in the first place requires different forms of assistance, such as a trainee and fellowship programme. The Agency cannot at this time find its analogue of the Mobility Fund. Other sources of revenue might be found.

In this connection the possibilities offered by International Centre for Theoretical Physics and the Third World Academy of Sciences, could be worth exploring. These institutes do support fusion activities beneficial to developing countries. Increased collaboration between the Agency and these institutes could enhance these programmes with provision of additional resources.

V. Newsletter

As an additional service to organizations and individuals who have to find their way in the fusion landscape, consideration might be given to establish a bi- or tri-monthly Fusion Newsletter. This could include:

- the fusion calendar as regularly published in Nuclear Fusion, and other sources;
- current contents of Nuclear Fusion and of the most prominent other journals in the field, in the form of copies of their indexes;
- news from ITER;
- brief reports about other Agency activities in fusion;
- information on activities from all countries with fusion programmes.
VI. The IFRC

From its inception in 1971, the IFRC has played a dual role in the international fusion scene. On the one hand, it has given advice to the Director General and his staff on fusion-related IAEA activities while, on the other hand, it has promoted understanding and exchange of information among research leaders in the various countries represented in the Council. As the scene changes, one should, from time to time, reconsider the usefulness of the IFRC in either of its dual capacities.

It goes without saying that the numerous and sometimes penetrating impacts which the Agency has on the conduct of worldwide fusion research require that authoritative advice be given to the DG on these matters. It is hardly conceivable that the Agency could maintain its prominence in this field without such advice. The question may be asked, however, if the IFRC should change in composition or in its ways of operating, to accommodate to changing circumstances. Let us touch some of the points that could be raised in this connection.

The first of these is, whether the IFRC can properly represent the interests of fusion technology. The fact that in major countries this subject is well coordinated with fusion physics tends to give a positive reply to this question.

Second, there is the problem of the representation of Inertial Confinement Fusion (ICF) in the IFRC. There are many open meetings on ICF that are attended by scientists from all countries active in the field; nevertheless strong voices are raised against IAEA involvement. It may be difficult to accept the rationale of these objections, but it must be accepted that the Agency cannot act against the expressed wishes of governments of major countries. Therefore, there is no way at the present time, to alleviate the understandable frustrations of inertial-fusion scientists in civilian programmes, other than tactfully promoting purely-scientific exchanges in non-controversial sectors of inertial confinement research. The Agency should not however miss the opportunity when closer collaboration on this subject appears to become possible. The IFRC should therefore make a conscious effort, as in the 1987 meeting, to hear, discuss, and respond to regular presentations on the subject and should see to it that it deems appropriate receives coverage in the journal, as well as in conferences and meetings.
A third question is, whether newcomers in the field can find their interests properly considered in the Council. The recent joining of China and India have already broadened the IFRC's outlook. Consideration should be given to whether the addition of one or two members from developing Member States would not be of additional benefit.
Sponsors: Third World Plasma Research Network, ICTP, TWAS
Venue: ICTP, Trieste, Italy
Duration: one month
Tentative dates: September or October, 1990
Organizing Committee: A. Sen, P.H. Sakanaka & S.M. Mahajan

PURPOSE

To provide intensive training and development skills in large scale computational projects relevant to magnetically confined plasmas. The working groups will also aim to accomplish some research results during the workshop.

WORKING STRATEGY

* The choice of project topics will be based on existing and planned research programmes of third world countries.
* Experienced researchers from established computational groups with new ideas and active interest in developmental work will be selected to lead the working groups.
* Participants will be required to possess basic computing abilities and will be selected on the basis of their research interests and their probable usefulness to computational programmes in their home institutes.
* The workshop will use the computing facilities at ICTP: Convex 210, micro-VAX, Sun workstations and PCATS.
- 2 days on introduction to computing facilities at ICT and instructions regarding their use (editors, operating systems, graphics etc.)

- 2 days on project definition and discussion and formation of appropriate working groups. Some comprehensive lecture on existing codes and associated physics will be given by the project leaders.

- 3 weeks project work by working groups.

- 2 days presentation of results, discussions and summary session.

NUMBER OF PARTICIPANTS & PROJECT LEADERS

- 5 Project leaders (from developed or third world countries)
- 20 participants from developing countries.

TOPICS

Some possible topics for selection of research projects are given below:

- Equilibrium, Stability and Transport studies for small to medium sized tokamak experiments.

- Radiofrequency heating and current drive

- Particle simulation studies on basic phenomena

- Simulation of Plasma Focus experiments.

- Equilibrium, Stability and Transport studies for field reversed configurations.

- High density Z pinches.
The AAAPT was formed at an Inaugural meeting in Kuala Lumpur on 7th June 1988 by sixteen institutions from 12 countries (list given in Appendix). Prof. Abdus Salam is the Patron of the Association.

Objectives and Method

1. To promote the initiation/strengthening of plasma research, especially experimental research, in developing countries in Asia and Africa.

2. To promote cooperation and technology sharing among plasma physicists in the developing countries in the region.

The method for carrying out the above objectives is by:

1. Holding a series of coordinated training programmes and colleges specially designed for effective training geared towards prevailing local conditions, on various aspects of plasma physics (experimental, technology and theoretical).

2. Publishing a newsletter about AAAPT activities, institutions and members.

3. Further developing relationship among member institutions and associate member institutions.

4. Developing a coordinated scientist/fellow exchange scheme with the aim of technology sharing and acquisition.

5. Developing relationships with agencies, such as UNESCO, ICTP, TWAS, IAEA, IUPAP, COSTED, UNDP, World Laboratory and AVH Foundation in order to obtain financial and fellowship support.
Membership

Membership is open to all research institution in developing countries in Asia and Africa having an interest in the acquisition or sharing of plasma technology, particularly on an experimental basis.

Associate Membership is open to all other institutions having an interest to assist or participate in the objectives of the AAAPT.

The inaugural meeting decided on the formation of the Executive Council as follows:

President : Prof. S. Lee (Malaysia)
Vice President : Prof. T. A. El Khalafawy (Egypt)
Prof. G. Murtaza (Pakistan)
Prof. M. P. Srivastava (India)
Prof. Tsai Shih Tung (China)
Assoc. Prof. S. P. Moo (Malaysia)
Hon Secretary : Assoc. Prof. C. S. Wong (Malaysia)
Hon Treasurer : Assoc. Prof. A. C. Chew (Malaysia)

with the first secretariat based at the Physics Department, University Of Malaya.
Activities

(a) Administrative

The first Council Meeting was held in Kuala Lumpur on 7th June 1988 and appointed the following Coordinators:

(I) Newsletter : Assoc. Prof. S.P. Moo

(II) Development for training:
   (a) Plasma Applications : Assoc. Prof. C. Silawatshananai (Thailand)
   (b) Plasma Diagnostics : Assoc. Prof. Li. Yin An (China)
   (c) Plasma Devices : Assoc. Prof. Y.H. Chen (Malaysia)

(III) Development for Theoretical Training:

   Prof. M.P. Srivastava (Convenor) (India)
   Prof. Tsai Shih Tung (China)
   Prof. G. Murtaza (Pakistan)

The Second Council Meeting was held at the ICTP, Trieste on 6th June 1989.

(b) Newsletter

Two issues of the AAAPT Newsletter have been circulated.

(c) Membership

The current membership list is included in the Appendix A.
(d) **Training Programme**

A series of coordinated training programmes and colleges has been planned in association with the AAPT as follows.

1. **June 20th 1988 - October 5th 1988**
   Second (UNU) ICTP Training Programme on Plasma and Laser Technology, Kuala Lumpur, Malaysia. This has been successfully completed and resulted in 3 sets of the UNU/ICTP PFF (Plasma fusion facility) 5 sets of nitrogen laser and parts for laser shadowgraphy and glow discharge transferred to participants and their institutions in Thailand, India, Nigeria and Egypt. From reports received most of these equipment are now operational.

2. **October 29th - November 9th 1989**
   Beijing College on Plasma Diagnostics, Beijing, China. This college will be geared towards hands-on experimental work on selected plasma diagnostics that may be implemented in the smaller plasma research institutions in the Third World.

3. **December 1988 - April 1990**
   Third ICTP-UM Training Programme on Plasma and Pulse Technology.
   This will continue the proven series of specialised 4 - 6 months training programmes aimed at the transfer of an integrated research facility.

4. **January 7th - 14th 1990**
   Regional College on Plasma Applications.
   The aim of this college is to provide training to participants in the region interested in the applications of plasma physics to industry. Topics include plasma spraying, plasma deposition, plasma radiation sources and plasma extractive metallurgy. There will be laboratory demonstrations on some of these topics.
The major objective of the AAAPT is to promote and strengthen experimental plasma research in developing countries. One proven method is the development of integrated research facilities and the running of training and exchange programmes to have these facilities transferred to institutions desirous of starting experimental plasma research. The UNU/ICTP-PFF is a proven package with a successful programme which has transferred 9 fusion machines and associated research programmes to 7 countries, initiating experimental plasma research to the level of M.Sc and Ph.D. Others packages being developed include a linear theta pinch, a double plasma device with surface magnetic confinement a multi-plasma device that may be used to produce low density glow plasmas to high density pinch plasmas and a Rotamak. Various diagnostics and pulse laser packages are also being developed. The AAAPT is recently associated with an initiative by the ICTP office of External Activities to form a Plasma Technology Resource Network to extend the concept of the development and exchange of equipment packages and technology.
# Appendix A: Membership of AAAPT (as of June 1989)

<table>
<thead>
<tr>
<th>Member Institution</th>
<th>Designated Delegate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Institute Of Nuclear Science &amp; Technology,</td>
<td>Dr. U.A. Mofiz</td>
</tr>
<tr>
<td>Atomic Energy Research Establishment,</td>
<td></td>
</tr>
<tr>
<td>G.P.O.Box 3787 Dakar,</td>
<td></td>
</tr>
<tr>
<td>Bangladesh.</td>
<td></td>
</tr>
<tr>
<td>2. Association for Plasma Studies,</td>
<td>Prof. Tsai Shih Tung</td>
</tr>
<tr>
<td>c/o Plasma Physics Division,</td>
<td></td>
</tr>
<tr>
<td>Institute Of Physics,</td>
<td></td>
</tr>
<tr>
<td>Chinese Academy Of Sciences,</td>
<td></td>
</tr>
<tr>
<td>Beijing, P.R.China.</td>
<td></td>
</tr>
<tr>
<td>3. Plasma Physics Division,</td>
<td>Assoc. Prof. Li Yin An</td>
</tr>
<tr>
<td>Institute Of Physics,</td>
<td></td>
</tr>
<tr>
<td>Chinese Academy Sciences,</td>
<td></td>
</tr>
<tr>
<td>Beijing, P.R.China.</td>
<td></td>
</tr>
<tr>
<td>Atomic Energy Authority,</td>
<td></td>
</tr>
<tr>
<td>13759 Cairo, Egypt.</td>
<td></td>
</tr>
<tr>
<td>5. Plasma Research Group,</td>
<td>Prof. A.A. Garamoon</td>
</tr>
<tr>
<td>Department Of Physics, Faculty Of Science,</td>
<td></td>
</tr>
<tr>
<td>Al-Azhar University,</td>
<td></td>
</tr>
<tr>
<td>Nasr City, Cairo, Egypt.</td>
<td></td>
</tr>
<tr>
<td>6. University Science Instrumentation Centre,</td>
<td>Prof. Y.S. Shishodia</td>
</tr>
<tr>
<td>University Of Rajasthan,</td>
<td></td>
</tr>
<tr>
<td>Jaipur 302 004, India.</td>
<td></td>
</tr>
<tr>
<td>7. Department Of Physics &amp; Astrophysics,</td>
<td>Prof. M.P. Srivastava</td>
</tr>
<tr>
<td>University Of Delhi,</td>
<td></td>
</tr>
<tr>
<td>Delhi 110 007, India.</td>
<td></td>
</tr>
<tr>
<td>8. Plasma Physics Section,</td>
<td>Prof. S.K. Majumdar</td>
</tr>
<tr>
<td>Saha Institute Of Nuclear Physics,</td>
<td></td>
</tr>
<tr>
<td>Calcutta 700 064, India.</td>
<td></td>
</tr>
<tr>
<td>9. Plasma Group,</td>
<td>Drs. Suryadi</td>
</tr>
<tr>
<td>Nuclear Research Centre,</td>
<td></td>
</tr>
<tr>
<td>PPNY, Yogyakarta, Indonesia.</td>
<td></td>
</tr>
</tbody>
</table>
10. National Institute for Aeronautics and Space, Lapan, Jalan Pemuda Persil No 1, Jakarta 13220, Indonesia. Prof. Wiranto Arismunandar

11. Physics Department, University Of Nairobi, P.O.Box 30197, Nairobi, Kenya. Prof. J.O.Malo

12. Plasma and Pulse Technology Research Groups, Department Of Physics, University Of Malaya, 59100 Kuala Lumpur, Malaysia. Prof. Lee Sing

13. Physics Department, Universiti Teknologi Malaysia, Jalan Gurney, Kuala Lumpur, Malaysia. Dr. Md. Yusuf Abu Bakar.

14. Plasma Research Group, Physics Department, River State University of Science & Technology, Port Harcourt, Nigeria. Prof. A.R.Bestman

15. Department Of Physics, Quaid-i-Azam University, Islamabad, Pakistan. Prof. G.Murtaza

16. Physics Department, Njala University College, PMB Freetown, Sierra Leone. Dr. A.J.Smith

17. Ngee Ann Polytechnic, Mathematics and Science Centre, P.O.Box 4052, Singapore 9158 Mr. Yong Yeow Chin

18. Plasma Research Laboratory, Physics Department, Prince Of Songkla University, Hatyai, Songkla, Thailand. Dr. Chaivitya Silawatshanana

19. Laser Fusion Programme, Laser Division, Bhabha Atomic Research Centre, Bombay 400085, India. Dr. H.C.Pant
20. Dokuz Eylul University, 
Plasma Laboratory, 
Faculty Of Engineering, 
Boronya, Izmir, 
Turkey. Dr. Ahmet Oztarhan

21. Plasma Physics Department*, 
Tajoura Nuclear Research Centre, 
P.O.Box 30878, Tajoura, 
TRIPOLI, 
LIBYA Arab Jamahiriya. Dr. Alebyad Al-Hashmi 
Mohamed.

*to be ratified by Council.
FUSION RESEARCH IN 'SMALL' COUNTRIES

Ieuan R. Jones
School of Physical Sciences
The Flinders University of South Australia
Bedford Park, S.A. 5042

ABSTRACT

The adjective 'small' is applied in the present context to countries which have very limited financial resources or to countries which, for one reason or another, have opted out of a national fusion research programme. Reasons are advanced why such countries should pursue fusion research and the case-histories of two projects undertaken in 'small' countries are presented to illustrate them.

1. INTRODUCTION

I shall start this paper by explaining what I mean by the word 'small' in the present context. Here 'small' is applied to countries which have very limited financial resources or to countries which, for one reason or another, have opted out of a national fusion research programme. In Australia, for example, our main governmental nuclear research centre, the Australian Nuclear Science and Technology Organisation, has recently decided that its fusion programme will be terminated. Fusion research in Australia will revert to its pre-1983 status of being undertaken by small groups of researchers at 3 or 4 (out of a total of 20) universities. Australia thus qualifies as a 'small' country in the present context. I suspect that most countries in the Asia-Pacific region fall into this category.

There are two very strong reasons why 'small' countries should pursue fusion research. In the first instance, fusion research provides an ideal vehicle by which to train applied physicists. The
inter-disciplinary nature of plasma physics (an amalgam of the theories of electromagnetism, statistical mechanics, fluid dynamics and atomic physics with the experimental aspects of vacuum systems, high currents and voltages, diagnostic techniques and data acquisition and analysis) provides a sound grounding for the physics graduate, even though he/she may not continue in the field. Plasma physics is also one of the more vital branches of physics; its relevance to the energy problem motivates students. As a gauge, we note that the Plasma Physics Division is one of the largest divisions within the American Physical Society.

A second reason why 'small' countries should undertake fusion research is that such an activity will inevitably unearth a number of very talented young physicists who, subsequent to their initial training, can contribute to the world-wide effort aimed at harnessing fusion power. The ultimate pay-off from fusion research is so immense that one needs as much brainpower as possible concentrating on the problems; and the U.S., Western Europe, U.S.S.R. and Japan do not have a monopoly on that commodity.

It is preferable that fusion research be engaged in as a group activity, even though the team may consist of only 3-4 physicists. One needs the possibility of discussing ideas and results at the local level. Suppose that such a team in a 'small' country decides to take up the challenge of fusion research, what kind of problems should it tackle? In my view, the answer is clear. I agree with an old friend of mine who once told me that you only obtain real satisfaction from fusion research if you are involved either with the 'biggest' or the 'first'. By definition, a 'small' country cannot contemplate building, for example, the 'biggest' tokamak or stellarator. It could, in principle, involve its physicists in large experiments in overseas laboratories but that approach would defeat the more desirable objective of having an indigenous group training home-grown researchers.

The only real possibility for a 'small' country research group is, therefore, being the 'first', the first, for example, with a new diagnostic technique or a new confinement concept. It needs to be emphasized that this constraint need not be an onerous one. On the
contrary, a small fusion research team, by not being constrained by the demands of a rigid, large scale research programme, is at liberty to conceive of entirely new approaches to fundamental problems and, more importantly, put them to the test in modestly funded experiments.

The identification of a suitable project is probably the most difficult task the research team will face. The original idea may come from an individual member of the team; may arise, serendipitously, from a chance remark of an experienced physicist or advisor; may be the result of a careful reading of the vast literature which has been assembled over the past three decades or may originate from a combination of the above, and other, sources. Whatever the source of the idea, it will have to be examined very carefully. One could indeed mount an argument that small fusion research groups have made a disproportionately large contribution to fusion research because of the very fact that they have had to think carefully before assigning their scarce resources. The bandwagon is not available to the groups I have in mind. Once a suitable project has been identified, it should be pursued diligently and with, above all else, a large measure of enthusiasm.

There will be two possible outcomes to the research work. It is often the case that, for a variety of reasons, a project simply does not work or, more usually, just peters out in an inconclusive manner. This possibility should be recognized from the outset and, equally, it should be recognized that no project will ever be a complete and utter failure. The chances are high that, during the course of their work, the group will discover and develop new scientific techniques (both theoretical and experimental), all of which, to some degree, can be of future use. At the very least, students will have been trained who are well-versed in the techniques of applied physics.

The second outcome is that the project flourishes and that future directions unfold naturally as the work progresses. This circumstance can also occur!

In order to illustrate the points I have just made, I propose to present in the rest of this paper the case-histories of two projects which were undertaken by small teams of researchers separated by both
4. geography and time. The common thread is that I was involved in both of them.

2. ROTATING FIELD PINCH AT THE CENTRE DE RECHERCHES EN PHYSIQUE DES PLASMAS, LAUSANNE, SWITZERLAND, 1961-1970

In 1961, Erich Weibel and Robert Keller were invited by the Fonds National Suisse de la Recherche Scientifique to start a plasma physics research group in Lausanne, Switzerland. At that time, the group was not attached to an university and was located in office space above a ladies' hairdressing salon near the station in Lausanne. It was truly a small group operating, at that time, in a 'small' country as I have defined it.

Weibel had returned to his native Switzerland from California with the firm intention of investigating a novel approach to plasma confinement which he had conceived during his latter years in the U.S.\(^1\)-\(^3\). His idea was to confine a high-\(\beta\) cylindrical plasma column by means of a magnetic field having an axial (\(B_z\)) and an azimuthal (\(B_\phi\)) component of identical amplitudes. Both components would be made to oscillate at the same fixed frequency but dephased by 90°. The magnetic field lines on the plasma surface would thus change their directions continuously (Fig. 1(a)). At any given point on the plasma surface, the magnetic field vector would rotate in a tangent plane with its tip moving along a circle (Fig. 1(b)). The name 'rotating magnetic field pinch' was given to this proposed configuration.

Weibel perceived a number of distinct advantages to his scheme. The plasma would be magnetic field free except for a thin boundary layer which would be periodically reconstituted by the rotating field. No diffusion of plasma through this time-independent magnetic boundary would take place. Furthermore, no cyclotron radiation would be emitted from the bulk of the plasma which is an important consideration in view of the influence this loss mechanism has on the overall energy balance of a fusion reactor. Probably the most important reason for studying this interesting configuration was the theoretical prediction that, given a certain minimum frequency of rotation, the plasma column could be made positively stable against all macroscopic surface...
Fig. 1. (a) The rotating magnetic field pinch configuration.
(b) The magnetic vector at any point on the surface rotates in a tangent plane.
(c) Practical realization of the rotating magnetic field pinch.
6.

deformations. This stability had its roots in the principles of dynamic stabilization.

The rotating field pinch was to be produced by the superposition of radio-frequency (RF) $\Theta$-pinch and an RF Z-pinch. The RF currents through the structures that produced these two pinches were dephased by 90° (Fig. 1(c)). On re-examining Fig. 1(a), one sees that the configuration switches continuously from being a pure $\Theta$-pinch to a pure Z-pinch. At best, the static $\Theta$-pinch is neutrally stable while the static Z-pinch is definitely unstable. By switching rapidly from one configuration to the other it is possible to achieve 'average stability'. The simplest analogue is the dynamic stabilization of an inverted pendulum. This, and the application of dynamic techniques to unstable plasma equilibria, is discussed in a review paper by Berge\(^4\).

The experimental installation which was constructed at Lausanne\(^5,6\) is shown schematically in Fig. 2. A straight piece of pyrex tube which formed the discharge vessel lay at the heart of the apparatus. It was equipped at each end with a hollow electrode which served to introduce the RF axial (z) current to the discharge region. A single layer solenoid which carried the RF azimuthal (\(\Theta\)) current was wound around the length of the discharge tube. Discharges were made in hydrogen and helium at filling pressures in the range 20-100 mTorr.

In order to generate the rotating field pinch, both the amplitude and phase of the RF $I_z$- and $I_\Theta$- currents had to be carefully adjusted. This process was monitored by measuring the $B_z$- and $B_\Theta$- components of the magnetic field at the inner wall of the discharge tube. Fig. 3(a) and (b) show the time variation of these two components; note the 90° phase difference between them.

The basic parameters of the apparatus were:

- Internal diameter of discharge tube = 4.9 cm
- Distance between z-electrodes = 48.8 cm
- Maximum amplitude of $B_z(B_\Theta)$ field at inner wall of discharge tube = 2.1(2.3) KG
- Frequency of rotation = 3.1 MHz
Resonating capacitors (axial)

Cables from generators

Flexible copper diaphragm

Solenoid

Discharge tube

Resonating capacitors (azimuthal)

R.F. end electrode

Side view

Front view

FIG. 2. Diagram of experimental installation
FIG. 3. (a) $B_z(t)$ at inner wall of the discharge tube 4.25 kG/vertical div; 0.5 μsec/horizontal div.

(b) $B_\theta(t)$ at inner wall of the discharge tube 4.25 kG/vertical div; 0.5 μsec/horizontal div.

(c) $B^2$ output of squaring circuit 3.6(kG)$^2$/vertical div; 0.5 μsec/horizontal div.

(d) Streak photograph of rotating magnetic field pinch. Sweep speed shown below photograph.
Duration of rotating field pulse = 2.3 usec

(7 periods)

An electronic squaring system was constructed which yielded a signal proportional to $B^2(t)$ where:

$$B^2(t) = B_z^2(t) + B_\theta^2(t).$$

In the ideal case where the amplitudes of $B_z$ and $B_\theta$ are equal and the phase difference between them is 90°, then $B^2(t)$ is a smooth continuous signal. In practice, a perfect adjustment of amplitude and phase was hard to achieve and the $B^2$ signal of Fig. 3(c) shows oscillations superimposed upon an underlying steady component of magnetic pressure.

The radial motion of the plasma was observed by means of an image converter camera which could be used either in the streak or framing mode and which was sighted axially along the discharge tube. For the case where the magnetic field at the inner wall of the discharge tube was rotating and the magnetic pressure consequently remained at a non-zero value for a substantial portion of the pulse duration (as in Fig. 3(c)), the corresponding streak picture (Fig. 3(d)) showed that the plasma separated from the discharge tube wall and imploded towards the axis as a well-defined annular sheath. This gross detachment of the plasma from the wall and the subsequent formation of a luminous column constituted the rotating magnetic field pinch. Fig. 4 shows another streak photograph of the rotating field pinch with, below it, a row of framing camera pictures showing that cylindrical symmetry was maintained by the plasma sheath throughout the period of compression.

Superficially, it appeared that a rotating field pinch had been successfully generated. However, measurements showed that the theoretical ideal of a plasma column, well separated from the discharge tube wall and carrying RF currents in a thin layer on its surface had not been achieved; the RF current "hung-up" at the tube wall for the whole of the discharge. The photographs show that towards the end of the implosion stage light again appears close to the tube wall and stays there for the remainder of the discharge. The increase in luminosity was believed to be associated with the production of conducting material at the wall and a subsequent conduction of the RF currents
The time in microseconds from the start of the $I_z$ current is shown under each photograph. The exposure time of each frame is 0.05 microsecond.

FIG. 4. Streak and framing photographs of a rotating magnetic field pinch.
in this material. We note that the path of least inductance for the RF current is indeed along the wall of the discharge tube. It was conjectured that the source of the conducting material was one, or a combination, of the following: plasma which had not been swept up in the implosion process; wall material which had been vapourized by radiation from the central pinched plasma column; gas which had been desorbed from the tube wall. Whatever the cause, the production of a conducting layer at the tube wall unfortunately limited the lifetime of the pinch by screening off the magnetic fields from the central plasma column. In the absence of a confining pressure, the pinched plasma started to expand and its interaction with injected wall material can clearly be seen on the streak photographs.

At this point the project had reached an impasse; Mother Nature would not allow a test to be made of the theoretician's dreams! The project was gradually phased out and other projects (still small at that time) took its place. The research that was done did not receive much attention from the fusion community and it is doubtful whether more than a very small handful of the present practitioners would have heard of the experiment. But it was not a failure! Young plasma physicists were trained. It spawned new plasma diagnostic techniques: a Mach-Zehnder interferometer for measuring electron line densities and a double magnetic probe system. Most importantly, it gave rise to a new technology for the generation of high power RF pulses.

The main problem in producing the rotating field pinch was technological; large magnetic fields (in the kG-range) at radio-frequencies (1-5 MHz) had to be produced. At Lausanne the problem was resolved by the development of high power pulse generators based on transmission lines of the lumped and continuous varieties. As will become clear, this development had a vital impact on the project which is the subject of our second case-history.

In the 1970's, the Centre de Recherches en Physique des Plasmas, Lausanne became a major component of a Swiss Fusion Research Programme and entered into an association with Euratom. From its humble beginnings in Avenue Ruchonnet, it has developed into a major laboratory which has made notable contributions to both the theory of tokamak
equilibrium and stability and the area of Alfvén wave heating in tokamak plasmas.

3. ROTATING MAGNETIC FIELD CURRENT DRIVE AND ROTAMAK RESEARCH AT FLINDERS UNIVERSITY 1979-1988

The main contender in the search for a controlled nuclear fusion reactor is the tokamak. The tokamak vessel is toroidal (i.e. doughnut-like) in shape and it is a requirement that a current be made to flow in the closed plasma ring contained within it. In the standard tokamak this ring current is induced by transformer action and this means that the tokamak reactor, as presently envisaged, cannot operate in a steady state manner. The plasma ring is created and destroyed in each pulse of the current transformer. A number of serious engineering difficulties, related to mechanical and thermal stressing, arise from this limitation. An important branch of contemporary fusion physics research is, therefore, concerned with a study of the various possible methods which are available to drive continuous plasma currents in toroidal systems. These methods mainly involve the use of RF techniques.

A second major problem with the standard tokamak is that it is particularly wasteful in its use of magnetic energy. It has been recognized that the situation can be improved if the aspect ratio of the plasma ring is decreased, that is, if the 'hole in the centre of the doughnut' is shrunk. Taken to its limit, this procedure results in a device which, superficially, appears more spherical than toroidal but in which a plasma ring of D-shaped cross-section tightly encircles the central axis. Experimental investigations of such configurations have started in a number of laboratories, defining a new avenue of fusion research known as 'compact torus research'. In addition to a more efficient use of magnetic energy, the advantages of the compact torus configuration include compactness, engineering simplicity and the presence of a natural magnetic divertor.

Plasma physics research started at Flinders University as a small group activity (3-4 physicists plus students) in the late 1960's. For the first ten years of its existence, experimental and theoretical
research was conducted in the areas of plasma wave propagation and pinch physics. Amongst the staff was Professor Harry Blevin who, while working at the U.K.A.E.A. Culham Laboratory in the early 1960's, had collaborated with another Australian, Dr. Peter Thonemann, to investigate a new technique of driving plasma current based on the use of a rotating magnetic field.$^{12}$ On his return to Australia, Blevin attempted to continue the work but, because of inadequate funding, was forced to abandon the project.

During the period 1974-1976, Paul Weber, a research student, and I were involved in pinch physics and, following discussions with Harry Blevin, we attempted, with little success, to generate and maintain a reversed field pinch configuration using the rotating field technique which had, by then, lain dormant for a number of years.$^{13,14}$ This was again an example of a project which, while still being a 'first', achieved only limited success. Nevertheless, a student was trained; new high-power circuitry was developed.$^{15}$ and, most importantly, we were exposed to the rotating field current drive technique for the first time.

At the Seventh IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research which was held in Innsbruck in 1978, Dr. Harold Furth$^{16}$ drew attention to the reactor advantages of compact plasma/field configurations. I attended that conference and immediately realized that the rotating field current drive technique could be used in a straightforward manner to generate and maintain a steady-state compact torus configuration in an apparatus which has come to be known as the Rotamak.$^{17}$ In brief, it looked as if we could 'kill two birds with one stone'!

Since early 1979, an extensive analytical, computational, experimental and technological research programme has been pursued at Flinders University which has, as its goal, a thorough understanding of the rotating magnetic field current drive scheme and its application in the rotamak. Our work is thus of significance to two disparate groups within the international fusion research community: those studying RF current drive techniques and those studying compact torus configurations. It is this work which constitutes our second
3.1 Rotating Magnetic Field (RMF) Current Drive

Let us consider the generation of a continuous azimuthal (θ-direction) electron current by the application of a transverse rotating magnetic field to a plasma cylinder (Fig. 5). The principles underlying this current drive technique are best understood if we allow the plasma to be described by a simple MHD model in which the ions are assumed to form an uniformly distributed, immobile background of positive charge and the electron gas is treated as an inertialess, pressureless, negatively charged fluid. For this model, the equation of motion of the electron gas and the generalized Ohm's law are identical and reads:

\[ \mathbf{E} = \eta \mathbf{j} + \frac{1}{ne} (\mathbf{j} \times \mathbf{B}) \]

where \( n \) and \( \eta \) are the (uniform) number density of the electrons and the (uniform) resistivity, respectively. The first term on the right-hand side of the above equation is the resistive term; the second is the Hall term.

FIG. 5. Distribution of \( \mathbf{j}_z \) screening current arising from the application of a transverse rotating magnetic field to a plasma column.
The applied rotating magnetic field induces an \( \hat{E}_z \) field (where \( \sim \) denotes an oscillatory quantity) in the plasma cylinder. If we first consider the situation in which the influence of the resistive term in the above equation dominates that of the Hall term, this \( \hat{E}_z \) field drives an oscillating axial screening current, \( \hat{j}_z \), in the plasma which acts to prevent the penetration of the applied rotating field into the plasma; this is the normal classical skin effect for RF fields. The precise distribution of \( \hat{j}_z \) in the \( \theta \)-direction depends on the values of \( n \) and \( v_{ei} \) (the electron-ion momentum transfer collision frequency) and on the degree to which the resistive term dominates the Hall term.

That part of the Hall term which is due to the crossing of oscillatory quantities, \( \hat{j} \times \hat{B} \), has two components: \( \hat{j}_z \hat{B}_r \) acting in the \( \theta \)-direction and \( \hat{j}_z \hat{B}_\theta \) acting in the \( r \)-direction. Here, \( \hat{B}_r \) and \( \hat{B}_\theta \) are the \( r \)- and \( \theta \)-components of the applied rotating field which, in the absence of the plasma, have the form:

\[
\hat{B}_r = B_\omega \cos (\omega t - \theta) \\
\hat{B}_\theta = B_\omega \sin (\omega t - \theta)
\]

where \( B_\omega \) is the amplitude of the rotating field.

Since \( \hat{j}_z \) and \( \hat{B}_r \) are quantities which vary in time with a frequency \( \omega \), the \( \theta \)-component, \( \hat{j}_z \hat{B}_r \), has a steady part, \( \langle \hat{j}_z \hat{B}_r \rangle \), and a part which varies at \( 2\omega \). The electron fluid will attain that steady value of azimuthal velocity, \( \nu_{e\theta} \), which corresponds to the balancing of the steady accelerating torque (due to \( \langle \hat{j}_z \hat{B}_r \rangle \)) by the retarding torque (due to the collision of the electrons with the ions). In this way, a small, steady, conventional azimuthal current of density

\[ j_\theta(r) = -n e \nu_{e\theta}(r) \]

is produced. For the situation presently under discussion (resistive term dominant), the electrons do not rotate synchronously with the rotating field. Note that azimuthal symmetry precludes the generation of an electrostatic \( \hat{E}_\theta \)-field which could prevent the flow of the Hall current.

Analysis \(^{18,19}\) shows that by increasing the value of the non-dimensional quantity, \( (eB_\omega)/(m_e \nu_{ei}) \), the influence of the Hall term
relative to that of the resistive term is increased. Such a procedure is accompanied by
- a decrease in the amplitude of the screening current, \( j_z \);
- an enhanced penetration of the rotating field into the plasma cylinder;
- an increase in the value of \( v_{e\theta} \) and, hence, in the amount of driven current.

The maximum value of \( v_{e\theta} \),

\[
v_{e\theta}^{\text{max}} = r\omega,\]

is obtained when the electron fluid rotates in perfect synchronism with the applied rotating field. The corresponding value of the driven current density is:

\[
j_{e\theta}^{\text{max}}(r) = -ne\omega.\]

There is an intimate connection between the generation of azimuthal electron velocity by the Hall term and the enhancement in the rotating field penetration. As viewed from a local frame of reference rotating with the electron fluid, the observed rotating field frequency \( \omega^* \), is Doppler shifted downwards from its rest frame value. Since the skin depth is inversely proportional to the square root of the frequency, it is appealing to connect the enhanced field penetration with the larger effective skin depth which is associated with the lower frequency, \( \omega^* \). One can proceed further with this physical interpretation (correctly, as it turns out) and anticipate the result that if the electron fluid rotates synchronously with the rotating magnetic field, then the apparent frequency of the rotating field is zero, the effective skin depth is infinite, and one has complete penetration of the applied rotating magnetic field.

A powerful analogy exists between the rotating field current drive scheme and the workings of the well-known induction motor\(^{20}\). Fig. 6 shows the bare essentials of such a motor. A rotating magnetic field of magnitude \( B_\omega \) and angular frequency \( \omega \) is generated by means of a polyphase stator winding (not shown in the diagram). The rotor consists of a long single-turn coil which is coupled to a mechanical load.
In the general case where a mechanical loading exists, the rotor does not rotate synchronously with the applied rotating field \((\omega_m < \omega)\). Accordingly, the magnetic flux linking the rotor oscillates in time and an e.m.f. is induced which drives a circulating current, \(\tilde{i}\), in the rotor. Since both \(\tilde{i}\) and \(B_\omega\) are time-varying quantities, a magnetic torque acts on the rotor which has both a second harmonic component and the desired steady component which maintains the rotation of the load.

For the special case where the mechanical loading is zero, the rotor rotates synchronously with the rotating field, no e.m.f. is induced and no rotor current will flow. Consequently, the torque exerted on the load is zero.

One is now in a position to appreciate that the operation of the rotating magnetic field scheme for driving plasma current is closely related to that of the induction motor. The rotating electron fluid is analogous to the rotor (in the sense that it carries the \(j_z\) current) while the electron-ion collisions provide a retarding torque analogous to the mechanical loading. The steady spinning of the "electron fluid rotor" constitutes the desired driven azimuthal electron current.

In summary, provided the amplitude and frequency of an externally applied rotating field are suitably chosen, the field will penetrate a plasma column to an extent greater than that predicted by the usual
classical skin effect, the degree of penetration depending on the amplitude of the rotating field. This enhanced penetration is accompanied by the generation of an azimuthal electron current. The amount of generated current is a strongly nonlinear function of the amplitude of the rotating field; it saturates at a value corresponding to complete penetration of the field and perfect synchronous rotation of the electron fluid.

3.2 The Rotamak

The Rotamak is a compact torus device in which a rotating magnetic field (rotating in planes normal to the z-axis; see Fig. 7) is used to

![Rotamak Diagram](image-url)
generate and maintain the toroidal plasma current. Equilibrium requires the presence of an additional, externally generated, poloidal field (the so-called 'vertical field' in tokamak research) which couples with the toroidal plasma current to produce an inward force. The steady component of the poloidal magnetic field consists of the combination of closed and open field lines shown in Fig. 7.

The components of a typical rotamak device are shown in Fig. 8. A spherical pyrex discharge vessel is equipped on the outside with a pair of orthogonally oriented Helmholtz coils. RF currents of the same frequency and amplitude, but dephased by 90°, are passed through these coils to produce a magnetic field which rotates about the z-axis. The vertical field needed for equilibrium is produced by passing a steady current through a pair of coils located at the z-axis as shown in Fig. 8. Coils wrapped around the tube leading to the vacuum system...
are used to preionize the filling gas by either RF or θ-pinch discharges.

Typically, the quantities measured in a rotamak experiment are some, or all, of the following:
- the total toroidal plasma current, \( I_0 \);
- The \( r \)- and \( z \)-components, \( B_r(r,z) \) and \( B_z(r,z) \), of the total poloidal magnetic field. This data can be used to construct contour plots of the poloidal flux function, \( \Psi \), and the toroidal current density, \( j_0 \);
- the penetration of the rotating field into the rotamak plasma;
- the power transferred from the RF generators to the load;
- the line-averaged electron density across a plasma chord in the equatorial plane;
- Langmuir probe measurement of local values of electron temperatures and densities;
- the integrated \( H_\alpha \) emission which can be interpreted in such a manner as to yield the particle confinement time, \( \tau_p \).

At the very beginning of rotamak research (~1979) it was decided that, in the absence of any guidance as to an appropriate amplitude for the applied rotating field, as large a value as practical would be used. This decision, coupled with the fact that I had worked at the Lausanne laboratory, led, quite naturally, to an embracing of the relatively inexpensive RF line generator technology. The use of these RF line generators proved to be crucial since the immediate observation of apparently stable compact torus configurations in these first experiments motivated us to significantly extend the duration of the rotamak discharges and, thereby, moved us into the field of conventional vacuum tube technology. Financial pressures constrained us to work with very low power RF sources (~6 kW) in the first instance; we have, by now, progressed to medium (on the fusion research scale) RF power levels (~70 kW).

The following is a partial summary of the experimental results obtained, to date, in the Rotamak research programme:

(a) The application of the rotating field both creates the target plasma and drives appreciable plasma current.
(b) Compact torus configurations (like that shown in Fig. 7) can be generated in a straightforward manner in a simple apparatus.
(c) The rotamak discharges are highly reproducible. Some experiments have involved the generation of many thousand identical discharges.
(d) Long duration rotamak discharges have been generated (up to 40 msec).
(e) The shape of the separatrix can easily be controlled (from slightly oblate to highly prolate).
(f) The rotamak discharge is observed to be macroscopically stable. Preliminary calculations suggest that the rotating magnetic field, in addition to driving the desired current, plays a stabilizing role.
(g) Even though the instantaneous field lines are open, experiments indicate that any magnetic confinement of the plasma is due to the time-averaged fields and that the rotating field does not have any major deleterious effect on this confinement.

We close this section of the paper by outlining our future plans in rotamak research.

The plasma parameters achieved to date in rotamak discharges can at best be described as modest. In hydrogen rotamak discharges one obtains, typically, \( n_e \approx 5 \times 10^{18} \text{ m}^{-3} \) and \( T_e \approx 10 - 15 \text{ eV} \). Even so, measurements show that the \( j \times B \) forces which are present can only confine about 50% of the peak plasma pressure in the present generation of rotamak devices; the rest of the plasma pressure is taken up by the vessel wall. This circumstance can be understood as follows.

When a rotamak discharge is initiated by the application of an RF rotating magnetic field, two things occur
- a plasma is formed which exerts a certain pressure on its surroundings
- a plasma current is driven and the \( j \times B \) forces associated with it assist in maintaining the pressure gradient of the plasma.

There is no a priori reason to expect that the radial \( j \times B \) force will completely confine the plasma pressure which is generated by the application of the RF fields. What is observed in present-day rotamak experiments is that the plasma pressure is at least double that which can
be held by the magnetic forces acting alone. Improved magnetic confinement and, hence, improved plasma parameters, will only come about if we can increase the value of the driven current. In present experiments, the filling gas is not fully ionized and any attempt to increase the driven current by increasing the input power only results, in the first instance, in an increased percentage ionization, the electron temperature being clamped at a nearly constant, low value (as in a change of phase). In these circumstances, the value of the electron-ion collision frequency, $\nu_{ei}$ (which is proportional to $n_e/T_e^{3/2}$) is high and the driven current will only increase slowly with increased RF input power.

We can confidently anticipate that if the RF input power is greatly increased, the filling gas will approach full ionization and the electron temperature will significantly increase. The value of $\nu_{ei}$ will start to decrease at this stage (since $n_e$ is constant and $T_e$ is increasing) and the current drive mechanism will become much more efficient (recall that the amount of driven current is a strongly non-linear function of $1/\nu_{ei}$).

What value of RF input power will give full ionization in present-day rotamak experiments with hydrogen? A zero-dimensional, time-dependent model has been used to evaluate the level of RF power which is required to significantly improve the low ionization levels and electron temperatures which characterize our present experiments. On the basis of these calculations, two new RF output stages, each capable of delivering 400 kW in a 40 msec pulse (RF frequency: 0.5 to 1.0 MHz) are being constructed at Flinders University. These stages should be ready for use by the end of 1988 and a new series of rotamak experiments will be carried out in a 60 cm (diameter) x 80 cm (length) glass cylinder in early 1989.

The Rotamak project has been a successful one, right from the very beginning. The next step to be taken in the programme has always been self-evident; it is the gathering of the necessary resources which has provided us with the most headaches! So far, 7 students have received higher degrees and there are 3 more presently in the pipeline. At the latest count, 49 papers have appeared, or are about to appear, in
An interesting development in the rotamak project, which should be of interest to this Conference, occurred in 1987. In response to Professor Sing Lee's (University of Malaya, Kuala Lumpur) suggestion that his Third World plasma physics programme needed a long duration plasma source in which magnetic confinement could be demonstrated, an inexpensive (< A$5000) rotamak apparatus was designed and constructed at Flinders University. The RF power supplies are based on the use of MOSFETS and each of two channels is capable of providing 2 kW. The frequency can easily be varied between 0.1 - 2.00 MHz. Compact torus configurations can be generated by using either both RF channels (rotating field) or just one channel (transverse oscillating field). The plasma parameters obtained in this device are only modest: \( n_e \sim 1 \times 10^{18} \text{ m}^{-3}, T_e \sim 7 \text{ eV} \) in hydrogen discharges. Nevertheless, partial magnetic confinement of the plasma can be demonstrated and new investigations in rotamak physics can be undertaken with the apparatus.

4. FINAL COMMENTS

I have presented the case-histories of two projects which, at their time, were 'firsts' and I have described how the ideas for the projects arose in the first instance. In one case it was the sole idea of the leader of the group while, in the second, the proximity of two congenial colleagues, together with attendance at an overseas conference, conspired to yield a successful recipe.

On the surface, the first project was a 'failure'. But I hope that I have successfully conveyed the impression that the second, 'successful', project would not have advanced at all without the use of the RF line generator technology developed at Lausanne. Both projects were successful in the sense that students were trained and new experimental and theoretical techniques were developed.

The lesson to be learnt is that if a group of physicists in a 'small' country is intent on contributing to the world-wide effort aimed at harnessing fusion power, they should choose their project carefully and then pursue it with vigour and enthusiasm. No one can predict the eventual outcome of the work but the group should be confident
that its efforts will bear some fruit. It is to be hoped that, in
turn, the funding agencies in the 'small' countries will recognize
both the intrinsic merit of the work and the benefits which will
accrue from the group's activities.

I end by wondering how far rotamak research would have progressed
had it been decided, in the late 1960's at Lausanne, to turn the plane
of rotation of the rotating field through 90°!

1. Weibel, E.S., Proceedings of the Second International Conference
   United Nations.
2. Weibel, E.S., Space Technology Laboratories, Los Angeles, Report
   (1968).
   13, 611 (1971).
   113 (1969).
    (1962).
    Proceedings Australian-U.S. Seminar on Energy Storage, Compression
16. Bussac, M.N., Furth, H.P., Okabayashi, M., Rosenbluth, M.N. and
    Todd, A.M.M., Proceedings of the Seventh International Conference

JOINT WORK RESUMED IN GARCHING

Another extended session of joint work at Garching began on June 1. Scientists and engineers from Europe, Japan, the USSR and the USA are now vigorously working side by side in the second phase of the ITER Conceptual Design Activities. The first phase, Concept Definition, in 1988 produced agreement on principal features and dimensions of the tokamak machine that would be the heart of ITER (see Table 1). Since then assigned "homework" - specific tasks carried out in the laboratories of the four Parties - produced further basis for proceeding jointly with the second phase of the Activities. This Design Phase will include the current session and two more sessions at Garching in 1990, with homework in the intervening periods. The Conceptual Design Report is scheduled for completion by the end of 1990.

TABLE 1. ITER OPERATING PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Physics Phase</th>
<th>Technology Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inductive</td>
<td>Inductive</td>
</tr>
<tr>
<td></td>
<td>Operation</td>
<td>Steady-state</td>
</tr>
<tr>
<td>Major radius, R (m)</td>
<td>5.8</td>
<td>5.5</td>
</tr>
<tr>
<td>Minor radius, a (m)</td>
<td>2.10</td>
<td>2.0</td>
</tr>
<tr>
<td>Elongation, 95% flux surface</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>Toroidal field on axis, B(T)</td>
<td>5.0</td>
<td>5.3</td>
</tr>
<tr>
<td>Current, I_p (MA)</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Ion temperature, T_i (keV)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Confinement time, T_e (s)</td>
<td>3.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Fusion power, P_f (MW)</td>
<td>1000</td>
<td>880</td>
</tr>
<tr>
<td>Neutron wall load (MW/m^2)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

* Initial configuration, without tritium-breeding blanket

* Modified configuration, with tritium-breeding blanket

The current session of joint work will last almost 5 months, ending on October 20. The major objective is to prepare an ad interim conceptual design report addressing major issues such as detailed review of parameters and performance, integration and design analysis of critical components; in addition the status of R&D and preliminary cost estimate of the machine construction will be included.

This year, a total of about sixty scientists and engineers from the four ITER Parties will be engaged in the ITER work at Garching for the entire time. The full-time workers will be joined by experts in six critical areas of design to work with the resident staff for up to two months. Other specialists will participate in more than...
ten workshops. The organization that proved so effective in the Definition Phase has been retained. That is a matrix organization, with a leading expert heading each of eight areas of design and four other experienced technical managers playing major roles in design integration as leaders of Project Units. Each group includes members from all four ITER Parties. Overall management responsibility rests with the ITER Management Committee, each of whose members is the Managing Director of the work carried out separately by one of the Parties.

At the end of June the ITER Scientific and Technical Advisory Committee (ISTAC) will meet in Garching to examine the evolution of the design and progress in the continuing, ITER-co-ordinated research and development by each Party. This process will ensure that the broad thinking and the latest results of development work in all the world’s fusion programmes will be properly incorporated in the ITER design.

An overall review of progress and plans will be made by the ITER Council (IC) at a meeting in Vienna in July. The IMC and the ISTAC will make presentations and the IC will consider issues and provide guidance.

International ITER Team, Garching, 5 June 1989

EDITOR’S NOTE:

A basic fact about magnetically confined fusion is that a plasma must be heated to temperatures in the range of 100 million degrees Celsius to achieve the desired thermonuclear reactions. In tokamaks, confinement relies partly upon the magnetic field caused by the current flowing in the plasma. In ITER, as in other tokamaks, electrical induction can produce a plasma current, which in turn raises the temperature by ohmic heating in the plasma. However, to reach ignition temperature and to keep the current going as long as desired in ITER, induction alone is inadequate. Other systems for heating the plasma and sustaining the current are absolutely essential for ITER success.

The following article, by the Leader of the Heating and Current Drive Design Unit, describes the approaches being followed in the ITER conceptual design.

HEATING AND CURRENT DRIVE IN ITER
by V.V. Parail, Leader, ITER Heating and Current Drive Design Unit

A requirement of the Terms of Reference is that “the ITER shall demonstrate controlled ignition and extended burn of deuterium-tritium plasmas, with steady state as an ultimate objective.” The Definition Phase of the Conceptual Design
Four heating and current drive systems are being studied. Activities set more specific criteria for the 'extended burn' operation. The target for the energy gain factor (Q) is \( \geq 5 \). The burn duration must noticeably exceed the time of ohmic current redistribution in the plasma and also suffice for transient-free nuclear testing in the technology phase of the ITER operation programme; this requires a burn time, \( T_b > 10^3 \text{s} \). Steady-state current drive represents a more demanding requirement than heating to ignition, and it is this requirement that determines the choice of current drive and heating (CD/H) systems.

Tokamak experiments have shown that either electromagnetic waves or neutral atom beams can drive such a current. At present, four systems are being studied for ITER. They are: neutral injection (NI), electron cyclotron (EC) waves, lower hybrid (LH) waves, and ion cyclotron (IC) waves. Six functions must be provided for ITER which are described below and are illustrated in Fig. 1.

![Fig. 1. Evolution of Plasma Parameters](image)

**Fig. 1. Evolution of Plasma Parameters**

Functions of heating and current drive systems in ITER

First, the system should provide a breakdown and plasma preionization at the initial stage of a discharge, when there is no longitudinal current providing the plasma confinement. The characteristic time of this process, \( T_1 \), is of the order of some seconds and the plasma parameters can be much lower than at burn stage. At this time, it appears that EC-waves would be a good choice to provide this function.

The next typical phase of a discharge is the current ramp-up up to the rated value, \( I_p = 18 \text{ MA} \). This process develops much slower than the first one; characteristic time of non-inductive current ramp-up, \( T_2 \), is estimated as ten minutes. All of the systems under study theoretically can provide this function and, at this time, LH appears to be the best candidate.

To heat the plasma up to ignition is the next task. This function, as well as the two previously mentioned functions, will be performed by the CD/H-system during both physics and technology phases of the ITER operation. The analysis carried out shows that the considered techniques, except probably LH-waves, can efficiently heat the plasma up to ignition. The characteristic time of plasma heating, \( T_3 \), is of the order of ten seconds, and the necessary power is \( \leq 50 \text{ MW} \).

The fourth task, which requires the highest power, is to provide steady current drive under conditions of fusion burn with Q = 5. All four systems theoretically can contribute to providing current drive with NB and LH best supported by experimental data. Though LH efficiently drives current in the moderate size tokamaks, it appears in ITER that the waves will not penetrate to the center of the
Combination of systems will be used

Operability under reactor conditions needs further study

So, the best solution which provides all the functions may be a combination of the systems under study. In the Definition Phase, three possible combinations (scenarios) were chosen for ITER. According to scenario 1, neutral injection should be used for the plasma heating and current drive in the central part of the plasma column, while LH-waves will be used for the current drive in the external half of the plasma column and for the current ramp-up. Plasma breakdown and preionization, as well as the current profile and burn control, would be provided by EC-waves. Comparing to scenario 1, in scenario 2, the function of Ni is performed, partly or completely, by EC-waves, and in scenario 3, IC-waves are used instead of Ni.

Above, the various heating and current drive systems and scenarios were considered. Taking into account that the CD/H system should work under reactor conditions, i.e. in the presence of high-power neutron flux, γ -radiation and heat flux from the plasma, creates additional complicated and challenging problems. For example, operability of the system components under conditions with plasma disruptions, when a rapid change in the plasma current results in the emergence of considerable electrodynamic forces affecting the elements of the radio-frequency power launchers is probably the most critical issue for the LH and IC techniques. All these problems need further detailed analysis, and the Heating and Current Drive Design Unit of the ITER team will be engaged in their solutions during the 1989 summer session of joint work in Garching.

FENDL - REFERENCE NUCLEAR DATA LIBRARY FOR USE IN NATIONAL AND INTERNATIONAL FUSION REACTOR PROJECTS

by E.T. Cheng, General Atomics, San Diego, California, USA
V.G. Goulo, D. Muir, J.J. Schmidt, Nuclear Data Section, IAEA

The programme of activities of the IAEA Nuclear Data Section related to fusion reactor research has the objective of creating nuclear and atomic data bases for D-T fusion reactors in support of the design and test studies of national and international fusion reactor projects such as the International Experimental Thermonuclear Reactor (ITER), the Fusion Engineering Reactor (FER, Japan), the Next European Torus (NET) and other existing or planned projects. The ITER Newsletter has already briefly mentioned the potential IAEA support to the ITER-project in November 1988 and present note has the objective to show the significant progress in this field made by the IAEA Nuclear Data Section since then in co-operation with national nuclear data centres and that the files and libraries mentioned below are available for the ITER team upon request.

Nuclear data requirements for fusion reactor studies were formulated at the 1986 IAEA Advisory Group Meeting on Nuclear Data for Fusion Reactor Technology in Gaussig, German Democratic Republic, in December 1986. The nuclear data required for neutronics and safety calculations for D-T fusion reactors are summarized as follows: (1) neutron flux determination: total cross sections, neutron emission spectra, neutron multiplication cross sections, and dosimetry cross sections; (2) fuel production: mainly Li-6(n,α)T and Li-7(n,2n,α)T cross sections and competing reactions; (3) radiation hazard: activation cross sections and decay data; (4) transmutation: cross sections for the production of hydrogen
and helium, and stable isotopes of other elements; (5) power generation: gamma-ray production cross sections and neutron and gamma-ray KERMA factors; (6) radiation damage: DPA production cross sections; (7) fusion-reaction cross sections for the D-D and D-T reactions and (8) covariance data for uncertainty analysis.

The IAEA Nuclear Data Section is now creating a nuclear data library which eventually will include all the required information mentioned above. It is called Fusion Evaluated Nuclear Data Library (FENDL) and is intended to serve as a reference fusion nuclear data library for use in national and international fusion reactor projects and activities.

FENDL-1, the first version of the library is planned to be finished by the end of 1990. It will consist of nuclear data files, selected from five national evaluated nuclear data libraries that already exist or currently are under development:

- the ENDF/B-VI USA library maintained by the National Nuclear Data Center at the Brookhaven National Laboratory;
- the BROND library maintained by the USSR Nuclear Data Center at the Physics and Energetics Institute in Obninsk;
- the JENDL-2 and 3 Japanese nuclear data libraries maintained by the JAERI Nuclear Data Center;
- the EFF-1 European Fusion File maintained by ECN Petten, Netherlands.
- the ENDL-84 library maintained by the Livermore National Laboratory in the USA.

At present, FENDL-1 includes evaluated nuclear data for the main elements and isotopes of the following fuel, blanket, structural and shielding materials:


Most of them were recently received by the IAEA from national nuclear data centres. Several more materials will be added as further needs are identified.

In addition, FENDL will contain the following special purpose libraries:

- the International Reactor Dosimetry File for use in neutron dosimetry maintained by the Nuclear Data Section with the support of the Institute fuer Radiumforschung und Kernphysik, Vienna, Austria;
- the Charged Particle Data Library DATLIB maintained by the Technical University in Graz, Austria;
- large comprehensive activation data library covering several thousand activation reactions selected and compiled from various national files; and
- library of gamma-ray interaction data.

The selection of nuclear data for the FENDL-library was organized using expertise of specialists from national nuclear data centres and laboratories. At the first IAEA Specialists' Meeting on FENDL (November 1987, Vienna) a preliminary choice of elements and isotopes was performed, and a programme of benchmark calculations for nuclear data testing was begun starting with the lead sphere measurements of the University Dresden, German Democratic Republic.

The second IAEA Specialists' Meeting on FENDL and Benchmark Calculations (May 1988, Vienna) analyzed the differences between the various evaluated nuclear data files available for each of the main fusion reactor materials and, in addition, compared these evaluations with experimental data from the international EXFOR-library.
The first stage of intercomparison included only neutron reaction cross sections. The next intercomparison exercise will be devoted to angular and energy neutron emission spectra, gamma production data, charged particle neutron production data and activation cross sections. As part of the long-term plan of the FENDL project, the results of these intercomparison exercises will be used to improve and supplement the data contained in the FENDL-1 library and a second improved version of the library, FENDL-2, be developed by 1992.

The processing of microscopic data files into forms usable in neutronic and safety calculations will be conducted by the Nuclear Data Section of the IAEA in collaboration with laboratories that contribute to the FENDL project. In particular, FENDL will be converted into a fine-mesh point data library and from this a multigroup data library for use in discrete ordinate codes and a library for use in continuous-energy Monte-Carlo calculations will be prepared.

Priorities in integral testing of data

The integral testing of the data files is an important process to examine the quality of the FENDL-1 files. It will identify the deficiencies of FENDL-1 and suggest actions for improvement for the development of FENDL-2. The integral data testing has been started with the lead benchmark problem and will be continued to include the beryllium benchmark in 1989 due to the importance of the neutron multiplication reactions needed for the design of the near term experimental reactors. Beginning in 1990, high priority structural, blanket and shield materials such as Fe, Cr, Ni, B, and C, will be considered in the international benchmark comparison activities. In addition to the benchmark data testing, the programme discussed at the second IAEA Specialists' Meeting on FENDL also includes calculational benchmarks for the verification of neutron transport codes.

The development of the FENDL library is an approved programme of the IAEA and is supported by several IAEA Co-ordinated Research Programmes involving the cooperation of a number of national nuclear data centres and research laboratories. In addition, it is expected that both the data processing and data testing efforts described above will benefit significantly from informal contributions from the participating data centres and research laboratories.
In support of the ITER team design work, several specialists' meetings will be held in Garching during the summer session of joint work on the following topics:

- **Current Drive/Heating Modelling**: 12 - 16 June
- **Electromagnetics**: 20 - 22 June
- **Basic Device Engineering Requirements/Siting**: 10 - 12 July
- **Diagnostics**: 10 - 14 July
- **Power/Particle Control (Model Validation)**: 17 - 21 July
- **Safety**: 31 July - 4 Aug
- **Tritium Fuel Cycle**: 1 - 8 Aug
SPRING COLLEGE ON PLASMA PHYSICS

15 May - 9 June 1989

Symposium on Third World Fusion Programmes and South-North Collaboration

FUSION PROGRAMMES IN MALAYSIA

S. Lee
Department of Physics
University of Malaya
59100 Kuala Lumpur
Malaysia
Fusion Programmes in Malaysia

S. Lee
Physics Department, University of Malaya
59100 Kuala Lumpur, Malaysia.

Abstract:

Fusion Programmes in Malaysia are briefly reviewed with some attention to historical perspective and to the academic continuity from undergraduate through to doctoral programmes. The research in the areas of glow-discharge, small tokamak, pinch, current-stepped pinch, vacuum spark pinch and the plasma focus is then reviewed. The central research theme threading all this research is identified as a study of the limits and enhancement of compressions. Our work shows that in general density compressions are limited and independent of the absolute magnitude of the compressive force. Enhancement of compression may be achieved through time variation of the force field, e.g. specifically using a force-stepping technique, through a reduction in specific heat ratio and in the case of the pinch through an elongation of pinch length during the compression. These ideas are applicable to magnetic field compressions as well as to radiation-driven compressions and should prove useful to aid in understanding e.g. the plasma focus scaling laws.

This review also reports the experience of the research group in its attempt to share fusion related technology on a South-South basis by the development of specific training packages. One such package the UNU/ICTP Plasma Fusion Facility has already been developed and 8 sets have been sent back to the home institutes of the UNU/ICTP Fellow trainees. A compact torus FRC based on the Rotamak concept is also being developed.

Paper prepared for the Symposium on Third World Fusion Programmes and South-North Collaboration, 8-9th June 1989 Trieste, Italy.
Introduction

Fusion Research in Malaysia is centered in the Plasma Research Laboratory, University of Malaya. This laboratory was started in the early 1960's by S.P. Thong who at that time was associated in glow discharge work in collaboration with K.G. Emelius of Queens University, Belfast. Aware of the work already on-going at that time in Britain on controlled fusion research Thong had the foresight to acquire from the British Government through the Colombo Plan 100 pieces of 40kV 0.6 µF fast discharge capacitors. Preliminary work with these and other capacitors resulted in the first Physics M.Sc thesis in Malaysia being produced on the topic of electric and electromagnetic shock waves under the supervision of H.H. Teh in 1966.

In 1970 the technical problems of installing these capacitors were solved with a design dividing the 100 capacitors into 4 modules each switched by 2 ignitrons with the help of a voltage division technique proposed earlier by C.P. Lim. In 1972 1.9MA was measured in a full test. This capacitor bank is still operational and will soon be converted to be switched by parallel plate swinging-cascade spark gaps. A plasma focus was designed and in October 1973 D-D nuclear fusion neutrons were measured from the focus by time-of-flight method giving an energy of 2.2 ± 0.1 MeV in a 'backward' direction.

Experimental plasma research in Malaysia is currently carried out on the following devices: glow discharge, small tokamak, current-stepped Z pinch, vacuum spark x-ray source and the plasma focus. Various lasers are being developed for diagnostic work. A transistorised Rotamak which is a compact torus FRC with current drive is being developed at our associated Pulse Technology Laboratory and an elongating Z-pinch is being designed at the Technology University.

Programme areas

Over the years the research has developed a pattern propelled primarily by the academic needs and perceptions of individuals within a framework of limited infrastructure and financing typical of the university environment of a developing country. Yet a pattern has loosely developed and three broad areas may be identified:

I. Long-lived plasmas, production and diagnostic techniques.
II. Pulsed plasmas, production and properties and techniques for compression enhancement.
III. Development of fusion-related technology for research initiation in developing countries.

I. Long-Lived Plasmas

Work on these plasmas include the Glow Discharge, a Small Tokamak and recently we have started constructing a transistorised compact torus FRC device with current-drive from either a rotating magnetic field or from a transverse oscillating magnetic field. This device called the Rotamak was first developed at Flinders University of South Australia and was transistorised as a specific project to bring the technology of a compact torus FRC within the reach of a developing country.
Glow Discharge

Measurements on glow discharge have been continued. Recent developments include pulsed Langmuir double probe studies in various gases and a computer based data acquisition system.

Small Tokamak

A small Tokamak was planned and plasma obtained in June 1983 with the following parameters:

- Major radius $R = 0.25m$
- Major radius $a = 0.05m$
- $R/a = 5$
- Toroidal field $B = 0.5T$
- Plasma current $I_p = 10 kA$
- Safety factor $q = 2.5$
- Lifetime (optically observed) $200 \mu s$
- Operational pressure $10^{-3}$ torr
- $T_e = 10$ eV

<table>
<thead>
<tr>
<th>Stabilization Bank</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance</td>
<td>60 $\mu F$</td>
</tr>
<tr>
<td>Charging voltage</td>
<td>26 kV</td>
</tr>
<tr>
<td>Coil inductance</td>
<td>63 $\mu F$</td>
</tr>
<tr>
<td>No. of turns</td>
<td>100</td>
</tr>
<tr>
<td>Coil current</td>
<td>25 kA</td>
</tr>
<tr>
<td>Riset time</td>
<td>100 $\mu s$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Heating Bank</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance</td>
<td>100 $\mu F$</td>
</tr>
<tr>
<td>Charging voltage</td>
<td>4 kV</td>
</tr>
<tr>
<td>Coil inductance</td>
<td>360 $\mu H$</td>
</tr>
<tr>
<td>No. of turns</td>
<td>20</td>
</tr>
<tr>
<td>Coil current</td>
<td>2 kA</td>
</tr>
<tr>
<td>Riset time</td>
<td>300 $\mu s$</td>
</tr>
</tbody>
</table>

The toroidal stabilization field, planned at 2T is severely reduced by induced current effects in the stainless steel wall of the plasma chamber.

Rotamak

In the Rotamak a plasma current is driven around an axial bias field in such a direction that the axial field of the plasma current opposes the axial bias field. When the driven plasma current becomes large enough it reverses the original axial field in the central region. These reversed field lines in the central region join up with the field lines having the original direction in the outer regions to form a compact-torus field-reversed configuration with closed field lines. The Rotamak traditionally uses a magnetic field, rotating at a frequency between $\omega_e$ (plasma electron frequency) and $\omega_i$ (plasma ion frequency), to pull along the electrons, thus producing the current drive in the plasma.

In conventional Rotamak devices the RF generators for the rotating magnetic field require expensive triode valves. In a specific attempt to develop low-cost Rotamak technology suitable for the Third World transistorised RF generators using MOSFETs were developed at Flinders University. Moreover during that exercise it was found that an oscillating magnetic field transverse to the axial bias field was sufficient to produce the Rotamak configuration. This provided a further simplification.
The Rotamak we are building uses a glow-discharge for preionisation and a MOSFET RF generator of 2 kW to power the oscillating transverse magnetic field at 500 kHz. We expect to drive a plasma current of 200 A in a chamber of diameter 25 cm holding an FRC plasma at a temperature of 7eV and an electron density of $10^{12}$/c.c with a lifetime of several 10's of ms.

II. Pulsed Plasmas - Studies of Compression Limits and Enhancement

Much of our plasma and fusion-related programmes deal with pulsed plasmas and may be connected by the research theme of compression limits and compression enhancement. From energy and pressure consideration applied to fast compressions it may be shown that generally for a spherical compression driven by piston-like force field with force $F$, the final compressed radius $r_m$ is related to the initial radius $r_0$ by the compression limit expression:

$$r_m = f(y) \frac{f_{rs}}{f_{rs}} \int_{r_m}^{r_0} \frac{f_{ds}}{F} \, dr$$

where $f(y)$ is a function of the specific heat ratio $\gamma$ and $f_{rs}$ is related to the reflected shock over-pressure as the reflected shock hits the incoming piston force field.

This simple relationship has the following important features, determining compression limits and indicating methods of enhancement. These features are:

1. It determines the radius ratio $r_m/r_0$ and shows that the radius ratio is determined by energy and pressure considerations.

2. The radius ratio (hence density compression) is independent of the absolute peak magnitude of the force $F$.

3. The density compression depends on the space - or time - variation of the force field.

4. It depends on the specific heat ratio.

5. It depends on the reflected shock over-pressure factor $f_{rs}$.

For a radiation-driven compression in a spherical geometry, the corresponding energy balance equation is:

$$R = \frac{3}{2} (\gamma - 1) \int_{r_m}^{r_0} \frac{r_0}{r_{rs}} \, dr$$

where $R$ is the radiation power.

This expression may be used to show that a square power pulse radiation piston will produce a density compression of only 27 for $\gamma = 5/3$ fully ionised plasma whereas a sequenced double pulse each with linearly rising power may increase the compression limit to 1750 greatly increasing the fusion energy gain factor for a given absorbed energy in a spherical D - T target.

For a pinch the compression limit expression takes the form:

$$r_m = 2(\gamma - 1) \int_{r_m}^{r_0} \frac{dx}{x_{rs}}$$
where $i, r$, and $l$ are the normalised current, radius and length respectively and $m$ indicates the quantity at time of maximum compression. From this expression several methods of compression enhancement are proposed:

1. Pinch elongation, as in the elongating pinch or plasma focus.\(^{34}\)
2. Reduction\(^{35}\) of $\gamma$, e.g. $\gamma + 1 \frac{r_m}{r_o} = 0$.

This applies particularly to high-Z plasmas which remains freely ionizing even at high temperatures e.g. argon or xenon in pinches, hollow pinches or plasma focus or high-Z plasmas in vacuum-spark pinches.\(^{36, 37}\)

3. Current-stepped compression.\(^{38}\)

Effects of radiation cooling\(^{20}\) have also been considered.

**Vacuum Spark Pinch**

In this experiment a cloud of high-Z material is injected into a vacuum gap by irradiating a pointed stainless-steel cathode with a 60MW ruby laser pulse. This high Z-material is then compressed using the current from a fast 22μF capacitor charged to 20kV. From x-ray emission experiments hot spots, possibly radiation collapsed, with electron temperatures up to 10 keV have been measured.\(^{37}\)

Recently a miniature vacuum spark device using nF capacitors is being developed as an x-ray source.

**Current-Stepped Pinch**

In preliminary work a low performance linear Z-pinch with $\alpha = 15$, where $\alpha$ = electrical characteristic time/pinch characteristic time, has been built for laser scattering diagnostics in a joint project with the Laser Group.\(^8\) This pinch produces a plasma with $T_e = 30,000$ K estimated from observed converging shock waves.

Modelling of pinch has been carried out using circuit-coupled snow-plow model with energy balance limit\(^ {39-40}\). A generalised slug model was also developed for general pinch computation including radiation cooling effects\(^ {20, 41}\).

Another pinch with $\alpha = 0.8$, $\beta = 0.9$ has been designed to give a hotter plasma with the aim of connecting to two sequenced capacitor banks for testing the current-stepped pinch compression enhancement effect.\(^ {42}\)

In preliminary work the design was constrained by existing conventional capacitor banks. It was decided to operate the 15cm diameter pinch at average collapse speed of 2.5 cm/μs increasing to 6cm/μs before the current step. However no increase in compression was observed since at this speed range the expected increase in compression may be cancelled by an increase in $\gamma$ at 6cm/μs and beyond.

To remove this $\gamma$ -compensation effect the current-stepped pinch needs to be run at a higher speed so that the $\gamma$ remains at constant high value and does not change substantially during the current-step. The design considerations require a 150kV 0.6μF Marx generator to
provide a 70kA pulse to be current-stepped by means of a 150kV water-line pulsed-charged by a 0.1\mu F, 150kV Marx. These are at present being constructed.

**Plasma Focus**

A Mather's type plasma focus, the UMDPF1\textsuperscript{43}, has been operated in the laboratory for a number of years. The following are the typical operating conditions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner electrode radius</td>
<td>1.3 cm (hollow copper tube)</td>
</tr>
<tr>
<td>Outer electrode radius</td>
<td>4.3 cm (six copper rods)</td>
</tr>
<tr>
<td>Length</td>
<td>16 cm</td>
</tr>
<tr>
<td>Capacitance</td>
<td>60\mu F (ignitron switched)</td>
</tr>
<tr>
<td>Current</td>
<td>550kA at 20 kV</td>
</tr>
<tr>
<td>Current risetime</td>
<td>3\mu s</td>
</tr>
<tr>
<td>Pressure ($D_0$)</td>
<td>8 torr</td>
</tr>
<tr>
<td>Neutron yield</td>
<td>$10^9$ per discharge</td>
</tr>
</tbody>
</table>

The device has also been operated in argon.

Measurements made on this device include device characterisation\textsuperscript{43-45} soft X-ray pinhole photography and temperature measurement\textsuperscript{46}, shadowgraphy\textsuperscript{47,48}, holographic interferometry\textsuperscript{49}, neutron time of flight\textsuperscript{50}, neutron counting\textsuperscript{51}, neutron half-life measurements\textsuperscript{51,52}, and dynamic modelling\textsuperscript{53}. We have also started work on charged particle measurements using emulsions and mass spectrometers.

The objectives of the plasma focus research are shifting more and more to the following:

- Development of diagnostics\textsuperscript{53} and modelling of dynamics\textsuperscript{54}
- Development of applications e.g. as neutron\textsuperscript{55} or soft X-ray sources
- Development of fusion neutron scaling laws
- Development as a cost-effective training package for international cooperation\textsuperscript{56,57}

The latest development include a target technique\textsuperscript{23} for determination of fusion neutron source structure in the plasma focus and more efficient nitrogen lasers\textsuperscript{54,55} for focus diagnostics with shadowgraphy, Schlieren system and H-Z interferometry\textsuperscript{56}.

On the question of neutron scaling the plasma focus seems to be unduly restricted to a fusion neutron yield - (current)\textsuperscript{4} law due to an observed restriction of axial speed to 10 cm per microsecond. We are studying the possibility of increasing this speed. Preliminary studies\textsuperscript{58} seem to indicate that increasing the axial speed leads to a decoupling of the magnetic piston and shock front during the end of the axial phase - a natural consequence of the rise of $\gamma$ towards 5/3. If this problem can be solved, by geometry, by seeding with small amounts of high-Z material, by gas puffing or current-stepping; this might lead to a yield - (current)\textsuperscript{7} scaling with great consequence to the plasma focus as a fusion device.

**Elongating Pinch**

An elongating pinch\textsuperscript{59} is being designed at the Plasma Research Laboratory of the University of Technology. This is a linear Z-pinch with a hole (radius - 0.5r_o) in the centre of each of the cathode and anode. To each hole is attached a straight side arm. When the plasma column pinches to the size of the hole any further
Compression by the pinch current causes the plasma pinch to elongate into the side arms. This elongation will enhance compression and stability.

III. Development of Fusion-related Technology for research initiation in Developing Countries

In view of our relatively extensive experience in experimental plasma physics the Plasma research group has pioneered the concept of sharing of fusion-related technology in developing countries. We have developed the concept of packaging cost-effectively an integrated facility consisting of well-defined sub-systems which together make up a complete facility for research and training.

For example we have identified that the following sub-systems are necessary to start experimental research in a developing country on the plasma focus:

- Simple vacuum system
- Focus electrode system with vacuum feed-through and proper insulation
- Small capacitor bank (3kJ) and high current switch
- Control and triggering electronics
- Power supplies
- Simple diagnostics for current, voltage, magnetic field, x-ray, neutron and laser shadowgraphy
- Plasma dynamic model with structure and chemistry suitable for use on a microcomputer.

These ideas expounded at the ICTP in Trieste have been further developed with the help of the First, Second and Third Tropical Colleges and has received full tests in the 6-months UNU Training Programme in Plasma and Laser Technology (1985/86) and a subsequent UNU ICTP Training Programme (1992). For these Training Programmes twelve UNU/ICTP Fellows (from Indonesia, India, Pakistan, Egypt, Nigeria, Sierra Leone and Thailand) have worked together with us to develop research packages for the plasma focus, glow discharge and nitrogen laser. The work has produced a number of research reports and papers.

During this Training Programme was developed a complete Fusion Facility now designated as the UNU/ICTP PFF (Plasma Fusion Facility).

In the First Training Programme five complete sets of the device were tested over a period of two months, and each was found to work reliably producing well-defined dynamics and reproducible fusion neutron bursts. On 20th January 1986 ICTP Director Professor Abdus Salam honoured with a visit to the training programme when he witnessed a fusion discharge.

As a result of the training programmes plasma focus fusion facilities are in various stages of development in Pakistan, Nigeria, Indonesia, Thailand, India, Sierra Leone and Al Azhar University of Cairo. The first experimental plasma physics Ph.D has been produced in Pakistan and several M.Sc's in Nigeria.
The momentum generated by these results has led to the formation of the Asian African Association for Plasma Training (AAAPT) with the aim of extending the concept of effective hands-on training at progressively higher levels by making available resources in plasma physics of countries like China, Egypt and India. It is felt that our training resources in experimental plasma/fusion physics will become more comprehensive when we have developed a simple cost-effective package in a Tokamak-type plasma or a compact torus FRC plasma.

Conclusion

It may be seen that after some 28 years of plasma/fusion research in Malaysia our programmes are still physics-based aimed primarily at academic production and the development of practical methods for the sharing of plasma/fusion technology among the smaller Third World Countries. We feel that the time is not ripe for us in Malaysia to have a large programme, or a programme involving a 'large' or 'national-sized' machine. We see ourselves playing a useful role in fusion-related technology in the community of smaller Third World Countries. We hope to continue fulfilling this useful role, with the help of ICTP and TWAS, using small but high quality machines in the area of long-lived and pulsed plasmas.

Acknowledgement

The fusion research programmes in Malaysia are sponsored mainly by the Ministry of Science, Technology and the Environment under the Intensification of Research Priority Areas (IRPA) mechanisms through grants number 04-07-04-40, 02-07-04-33 and by the University of Malaya. The South-South fusion technology transfer programme is sponsored by the ICTP in Trieste, Italy under its OEA and ICAC programmes. We also acknowledge the help of the Third World Academy of Science, the United Nations University, the Alexander von Humboldt Foundation and the British Government Colombo Plan.
Reference

1. S. Lee, Some shock wave phenomena in a ring-electrode system, (M.Sc. Thesis UM 1966)
5. S. Lee and Y.H. Chen, Malaysian J. of Science 3(8), 159 (1975)
13. S.P. Chow, Current sheath studies in a coaxial plasma focus gun, (M.Sc Thesis UM 1972)
15. A.C. Chew, Plasma focus in an axial magnetic field, (M.Sc Thesis UM 1974)
17. Y.C. Yong, Multiple ionization in an argon plasma focus, (M.Sc Thesis UM 1978)
25. Laser and Plasma Technology Ed. S. Lee et al. (World Scientific Co. 1985)
31. S. Lee, S. Xu, I.R. Jones, to be published
33. S.Lee, Laser and Particle Beams 6, 597 (1988)
34. S.Lee, J. Appl. Phys. 54, 3603 (1983)
44. S.P. Chow, S. Lee and B.C. Tan, J. of Plasma Physics 8, 21 (1972)
52. S.Lee, Regional Centres for research transfer within South-east Asia Countries - Invited paper presented at the International Conf.on Physics & Development 1984, ICTP, Trieste, Italy.
64. Laser and Plasma Technology Ed. S. Lee et al (World Scientific Co. 1988)
1. AAAPT INAUGURAL MEETING

The AAAPT was formed at an Inaugural Meeting on 7th June 1988 in Kuala Lumpur. It was convened by Prof. S. Lee and Prof. M.P. Srivastava was voted as the Pro tem Chairman.

a) Objectives and Method

The objectives of the AAAPT are:

1. To promote the initiation/strengthening of plasma research, especially experimental research, in developing countries in Asia and Africa.

2. To promote cooperation and technology sharing among plasma physicists in the developing countries in the region.

The method for carrying out the above objectives is by:

1. holding a series of coordinated training programmes and colleges specially designed for effective training geared towards prevailing local conditions, on various aspects of plasma physics (experimental, technology and theoretical).

2. publishing a newsletter about AAAPT activities, institutions and members.

3. further developing relationship among member institutions and associate member institutions.

4. developing a coordinated scientist/fellow exchange scheme with the aim of technology sharing and acquisition.

5. developing relationships with agencies, such as UNESCO, ICTP, TWAS, IAEA, ICSU, ZUPAP, COSTED, UNDP, World Laboratory and AVH Foundation in order to obtain financial and fellowship support.

b) Membership

Membership is open to all research institutions in developing countries in Asia and Africa having an interest in the acquisition or sharing of plasma technology, particularly on an experimental basis.
Associate Membership is open to all other institutions having an interest to assist or participate in the objectives of the AAAPT.

c) The following list of Member Institutes has been compiled and accepted. It is expected that the list will grow in the near future.

<table>
<thead>
<tr>
<th>Member Institution</th>
<th>Designated Delegate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Institute of Nuclear Science &amp; Technology, Atomic Energy Research Establishment, G.P.O. Box 3787 Dakar, Bangladesh</td>
<td>Dr. U.A. Mofiz*</td>
</tr>
<tr>
<td>2. Association for Plasma Studies, c/o Plasma Physics Division, Institute of Physics, Chinese Academy of Sciences, Beijing, P.R. China</td>
<td>Prof. Tsai Shih Tung*</td>
</tr>
<tr>
<td>3. Plasma Physics Division, Institute of Physics, Chinese Academy of Sciences, Beijing, P.R. China</td>
<td>Assoc. Prof. Li Yin-An*</td>
</tr>
<tr>
<td>5. Plasma Research Group, Dept. of Physics, Faculty of Science, Al-Azhar University, Nasr City, Cairo, Egypt.</td>
<td>Prof. A.A. Garamoon (Dr. M.A.A. Eissa*)</td>
</tr>
<tr>
<td>6. University Science Instrumentation Centre, University of Rajasthan, Jaipur 302 004, India.</td>
<td>Prof. Y.S. Shishodia*</td>
</tr>
<tr>
<td>7. Department of Physics &amp; Astrophysics, University of Delhi, Delhi 110 007, India.</td>
<td>Prof. M.P. Srivastava*</td>
</tr>
<tr>
<td>8. Plasma Physics Section, Saha Institute of Nuclear Physics, Calcutta 700 064, India.</td>
<td>Prof. S.K. Majumdar</td>
</tr>
</tbody>
</table>
9. Plasma Group,
   Nuclear Research Centre,
   PPNY, Yogyakarta,
   Indonesia.
   Drs. Suryadi
   (Mr. Agus Purwadi*)

10. National Institute for Aeronautics and Space,
    Jakarta,
    Indonesia.
    Prof. Wiranto Arismunandar*

11. Physics Department,
    University of Nairobi,
    P.O. Box 30197,
    Nairobi,
    Kenya.
    Prof. J.O. Malo

12. Plasma and Pulse Technology Research Groups,
    Department of Physics,
    University of Malaya,
    59100 Kuala Lumpur,
    Malaysia.
    Prof. Lee Sing*

13. Physics Department,
    Universiti Teknologi Malaysia,
    Jalan Gurney,
    Kuala Lumpur,
    Malaysia.
    Dr. Md. Yusuf Abu Bakar*

14. Plasma Research Group,
    Physics Department,
    Rivers State University
    of Science & Technology,
    Port Harcourt,
    Nigeria.
    Dr. A.V. Gholap
    (Mr. A.G. Warmate*)

15. Department of Physics/Electronics,
    Quaid-I-Azam University,
    Islamabad,
    Pakistan.
    Prof. G. Murtaze
    (Prof. S. Beg*)

16. Physics Department,
    Njala University College,
    Sierra Leone.
    Dr. A.J. Smith
    (Prof. S. Lee*)

17. Ngee Ann Polytechnic,
    Mathematics and Science Centre,
    P.O. Box 4052,
    Singapore 9158.
    Mr. Yong Yeow Chin

18. Plasma Research Laboratory,
    Physics Department,
    Prince of Songkla University,
    Hatyai, Songkla,
    Thailand.
    Dr. Chaivitya Silawatshananai*
Sixteen institutions from 12 countries were represented at the Inaugural Meeting.

The ICTP Office of External Activities gave a special grant for the travel of Prof. T. El Khalafawy, Prof. M.P. Srivastava and Prof. G. Murtaza (represented by Prof. S. Beg).

d) **Executive Council**

The following were elected into the Executive Council:

- President: Prof. S. Lee
- Vice Presidents: Prof. T.A. El Khalafawy, Prof. G. Murtaza, Prof. M.P. Srivastava, Prof. Tsai Shih Tung

The following were appointed to the Executive Council by the President:

- Vice President: Assoc. Prof. S.P. Moo
- Hon. Secretary: Assoc. Prof. C.S. Wong
- Hon. Treasurer: Assoc. Prof. A.C. Chew

The first secretariat of the AAAPT consisting of the President, Vice President, the Hon. Secretary and the Hon. Treasurer will be based at

Physics Department,
University of Malaya,
59100 Kuala Lumpur,
Malaysia.
2. COUNCIL MEETING

The first Council Meeting was held immediately following the Inaugural Meeting. The following were appointed Coordinators for specific functions.

I. Newsletter: Assoc. Prof. S.P. Moo

II. Development for Training
   a) Plasma applications: Assoc. Prof. C. Silawatshananal
   b) Plasma diagnostics: Assoc. Prof. Li Yin-An
   c) Plasma devices: Assoc. Prof. Y.H. Chen

III. Development for Theoretical Training
    Prof. M.P. Srivastava (Convenor)
    Prof. Tsai Shih Tung
    Prof. G. Murtaza

3. ACTIVITIES

The following activities are planned for the period June 1988 to 1990.

a) June 20th 1988 - October 15th 1988:
   (UNU) ICTP Training Programme
   in Plasma and Laser Technology, Kuala Lumpur.

   This programme funded by ICTP will be attended by 5 Fellows from Nigeria, India and Thailand. The Programme includes follow-up equipment, constructed during the Programme by the Fellows, and a 1-year University of Malaya - Prince of Songkla University Plasma Technology Exchange Scheme. The Programme aims to transfer the technology of the training package designated as the UNU/ICTP PFF.

   Director: Prof. S. Lee

b) Spring (April 15th-28th) 1989:
   The First Spring College on Plasma Physics - Diagnostics
   Beijing, P.R. China

   This College will be geared towards hands-on experimental work on selected plasma diagnostics that may be implemented in even the smaller plasma research institutions in the Third World. Funding is being sought from UNESCO, ICTP and NSFC.

   Director: Prof. Tsai Shih Tung
c) December 1989 (7 days):
Regional College on Plasma Applications

This is an initiative made on behalf of the AAAPT by the Prince of Songkla University Plasma Group to focus efforts in the region on applications of plasma technology. Together with review and research papers the College will prepare special detailed demonstrations on devices for plasma applications including the plasma torch, plasma deposition and spraying devices and a plasma radiation source. Funding is being sought from UNESCO, ICTP and COSTED.

Director: Assoc. Prof. Chaivitya Silawatshanamai

d) December 1989 - April 1990:
(UNU) ICTP - UM Training Programme on Plasma and Pulse Technology.

This will continue the proven series of specialised 4-6 months training programmes aimed at the transfer of an integrated research facility. Funding is being sought from UNESCO and ICTP.

Director: Prof. S. Lee

These 4 activities are firmly planned. Other possible activities on a coordinated basis are being discussed.

4. TRAINING DEVICES/TECHNIQUES

It is felt that one of the most effective method of the AAAPT is to use the concept of specially developed comprehensive training packages in a training programme. Each package is designed for the transfer of the integrated technology of a specially selected device. The programme, of duration 3-6 months, consists of lectures and experiments, design, construction, testing, research, planning and computation all geared towards one device. The transfer of technology includes basic components, parts and equipment, preferably constructed by the Fellow himself/herself during the course.

The first package, already proven successful in implementation at Quaid-I-Azam University, Yogyakarta Nuclear Research Centre, Al-Azhar University, Rivers State University of Science and Technology and Njala University College, has been designated the UNU/ICTP Plasma Fusion Facility.

An attempt is being made in Kuala Lumpur to develop a transistorized Rotamak (a long-lived plasma PRC with current-drive based on a device at Flinder University of South Australia) as a training package.
5. HIGHLIGHT ON MEMBERSHIP

Plasma Physics Division
Institute of Physics
Chinese Academy of Sciences
Beijing, P.R. China

The Plasma Physics Division of the Institute of Physics under the Chinese Academy of Sciences, Beijing, China, is one of the first Chinese Institutions engaged in plasma research. It began as early as 1958 and in the years that followed, a first Chinese plasma focus with high neutron yield, a 100 KJ linear theta pinch, which is the first Chinese pinch experiment, where neutrons from fusion reaction were observed, a Nd-glass laser-produced plasma experiment, and a first Chinese tokamak were built.

At present, this division has about 50 physicists and engineers. They are divided into 5 research groups working in the following fields:

I. Tokamak CT-6B

This device is featured by a major radius 45 cm, a minor radius of Plasma 10 cm, toroidal field 13 KG, electron temperature 200 eV, electron density \((1-4) \times 10^{13}\) cm\(^{-3}\) and energy confinement time 1-2 ms.

Available diagnostics on the tokamak include basic electric and magnetic measurements, space-resolved soft and hard X-ray measurements, microwave interferometry, HCN far infrared laser interferometry, far infrared laser scattering, laser fluorescence spectroscopy, visible and ultra-violet spectroscopy, vacuum ultra-violet spectroscopy and ECRH which has achieved a significant progress very recently with output power 200 kW of gyrotron at 34.34 GHz and pulse duration 10 ms, which is the highest level achieved on Chinese tokamaks.

II. Field-Reversed Pinch

The field-reversed pinch, FRP-1 was put into operation in 1984, and is now being modified into FRP-1B with a coil radius of 6.5 cm, a coil length of 60 cm, an energy storage of 140 kJ, main field 1.6T with rise time 3 \(\mu\)s. Diagnostics include magnetic probes, diamagnetic loops, visible and ultra-violet spectroscopy, framing photography and Mach-Zehnder interferometry.
III. Mirror

A hot electron ring simple mirror is under construction with the following main parameters: field at mirror center 4-4.5 KG, mirror ratio 2-2.4, length between mirrors 38 cm, microwave input power 8 kW at 20.4 GHz, and diameter of vacuum vessel 25 cm.

IV. Basic Plasma Experiments

1) Steady-state Plasma Device (SPD) was put into operation in 1987. It is characterised by diameter 0.8 m, length 1.6 m, electron density $10^8 - 10^9$ cm$^{-3}$, and electron temperature 3 eV with the interest in solitons of acoustic wave or electrostatic wave, and density fluctuation.

2) Nonneutral plasma experiment is under construction and featured by diameter 8 cm, length 100 cm and magnetic field 200 G with the interest in particle transport and waves in a pure electron plasma.

3) Whistler experiment and ion-acoustic wave experiment.

V) Plasma Theory

Recent subjects are as follows:

1) Instabilities and transport of inhomogeneous and high $\beta$ plasma, which include: generalised gyro-kinetic equations, general dispersion relation, drift dispersion function, drift waves and $\varphi T_i$, DCLC, LHD, whistler and other instabilities;

2) Properties of instability of plasma with particles of energetic component, such as: a) stability effects on the ballooning $m=1$ internal kink, interchange and Alfven modes, b) suggesting a possible direct access to the second stable region in tokamak and stellarator, c) effect of hot electrons on instability in mirror, d) ICRF, ECRH produced energetic trapped electron component;

3) Maser, which includes electron cyclotron maser, instabilities and radiation power, aurora kirometric radiation;

4) Resistive instabilities, which include non-linear properties of tearing mode, semicollisional resistive ballooning mode and $\eta_-$ effects in MHD resistive mode.
VI. Plasma Applications

The plasma applications include the surface treatment of materials (such as: polyester fibers, polyethylene terephthalate, carbon fibers, rabbit fur) by plasma exposure.

The Plasma Physics Division sponsored jointly with the University of Science and Technology of China (USTC), the Association for Plasma Studies of China (APSC) in 1985. This Association has 11 members (2 institutions and 9 universities). It has conducted two summer schools and one symposium on plasma physics in the past three years, and will hold the second symposium in Shenzhen in November, 1988. In April 1989 it will conduct in Beijing the First Spring College on Plasma Physics - Diagnostics.

(Article contributed by Assoc. Prof. Yin-An Li)

6. A LETTER

A letter to the Editor from Mr. A.G. Warmate, Physics Department, Rivers State University of Science and Technology, Port Harcourt, Nigeria.

The need for South-South Co-operation can hardly be over emphasised in any way. The question of whether technology is transferable has been a matter of much debate. If we concede that it is transferable, then it can only be meaningfully transfered from one people to another people if there is a close relationship between the two peoples - in this case their respective stages of development.

Perhaps the experience of this writer could be used to illustrate this point. The writer had enrolled for a Master of Philosophy programme at the Rivers State University of Science and Technology, Port Harcourt, Nigeria. For his research he was to build a nitrogen laser and use this for some work. His principal supervisor was from the "North". For about a year no meaningful progress was made; most of the works, recommended for reference, used rather sophisticated parts which were not easily available in a moderately equipped laboratory such as ours.

A breakthrough came as a result of a visit to the Department of Physics of the University of Malaya during the Second Tropical College in 1986. The arrangement was made by the then Head of Department of Physics of this writer's University, Dr. A.V. Gholap, and the Head of the Plasma Group of the Physics Department, University of Malaya, Prof. Lee Sing. This writer was allowed free access
to their work - no black boxes. Today the Rivers State University of Science and Technology, Port Harcourt, can boast of its own home built nitrogen laser!

Not only does it have its own nitrogen laser but also has a UNU/ICTP Plasma Focus Facility which is a donation from the UNU/ICTP. This facility was constructed at the University of Malaya during the (UNU/ICTP) Training Programme. This can be said of other countries like Sierra Leone, Egypt, Indonesia and Pakistan which benefitted from such facilities. This writer is reliably informed that the aim of the Training Programme is beginning to pay dividends in the respective countries.

The intention in this writing is not to say that there is no benefit in a North-South Co-operation. Far from it! Indeed the South stands to gain. The problem is that whereas the North is more concerned in developing state-of-the-art machines, the South, generally speaking, should develop its indigenous technology. A North-South Co-operation has a problem of maintenance of the highly sophisticated equipment that may be transferred to the South - a problem of Northern dependence. Again these equipment are usually too costly for a majority of the Southern countries who have debt payment problems.

It is the belief of this writer that a South-South cooperation with a Coordinating body able to organise workshops/seminars at regional and intercontinental levels, where scientific ideas and research findings can be shared has become imperative. The launching of the AAAPT is a bold step in the right direction. We believe that with the drive and steadfastness of the brains behind the idea its objectives will be achieved.

7. STOP PRESS

Prof. Abdus Salam, Director of ICTP, has most graciously agreed to be the PATRON of AAAPT.

Editor

S.P. Mco,
Department of Physics,
University of Malaya,
59100 Kuala Lumpur,
Malaysia.