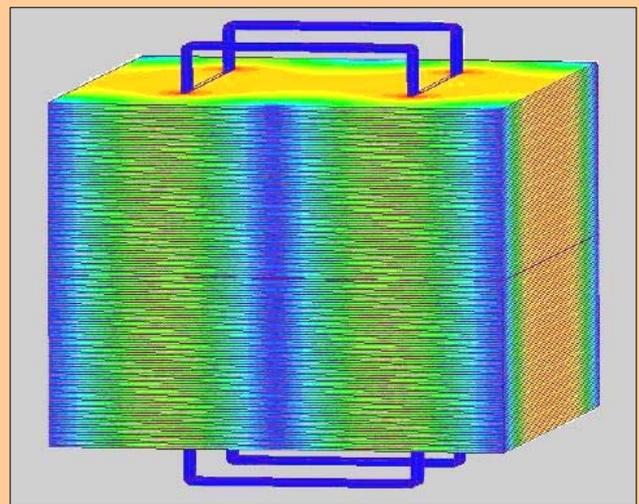
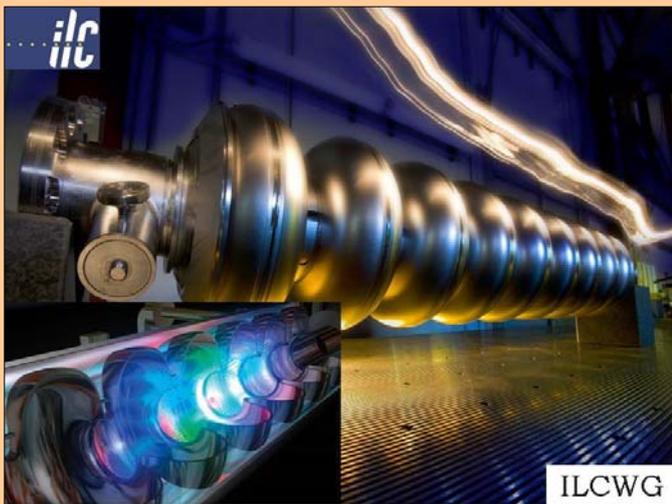


MEGA SCIENCE PROJECTS

Report of the Working Group



*A 9-cell superconducting radiofrequency cavity constructed for TESLA/XFEL
(Inset : Computer animation of the electromagnetic field inside a cavity),
and (Right) Iron CALorimeter (ICAL) Magnet Field*



Government of India
Department of Atomic Energy

MEGA SCIENCE PROJECTS

Report of the Working Group



Government of India
Department of Atomic Energy

September 2006

CONTENTS

		Page Nos.
	Preface	
Chapter 1	Introduction	1
Chapter 2	Summaries of the Projects Discussed	5
Annex 1	Constitution of Working Group	12
Annex 2	The ITER Project	14
Annex 3	The ILC and related Projects	18
<i>Annex 3a</i>	<i>The ILC Project</i>	19
<i>Annex 3b</i>	<i>India-Based Neutrino Observatory (INO)</i>	26
<i>Annex 3c</i>	<i>Advanced Radioactive Ion Beam Facility</i>	33
<i>Annex 3d</i>	<i>International Collaboration on FAIR at GSI, Germany</i>	38
Annex 4	Astronomy based Projects	43
Annex 5	Centre for Semiconductor Heterostructure Research	46
Annex 6	List of Abbreviations	52

Preface

The Working Group on Mega Science Projects, constituted vide Office Memorandum No. Prn.SA/ADV/SC/2006 dated May 8, 2006 (Annex 1), met twice on **July 20, 2006** and **August 8, 2006** at the Anushakti Bhavan, Mumbai.

The following participated in the meetings:

1. Dr. Anil Kakodkar, Chairman AEC Chairman
2. Prof. Shobo Bhattacharya, Director, TIFR, Mumbai
3. Dr. Bikash Sinha, Director VECC & SINP, Kokatta
4. Dr. P.K. Kaw, Director, IPR, Gandhinagar
5. Dr. Y. P. Viyogi, Director, IOP, Bhubaneswar
3. Dr. R. Nityananda, Centre Director, NCRA, Pune
4. Prof. Rohini Godbole, IISc, Bangalore
5. Prof. N.K. Mondal, TIFR, Mumbai
6. Dr. R.K. Bhandari, VECC, Kolkatta
7. Dr. R.B.Grover, Director, SPG, DAE Member-Secretary
8. Shri Arun Srivastava, SPG, DAE
9. Dr. B. Purniah, SPG, DAE

The Working Group had sought inputs from all scientific departments and the various project proposals received were discussed. The recommendations of the Working Group are given in this report.

Chapter - 1

INTRODUCTION

1. Mandate

There was a discussion on the mandate of the Working Group and definition of 'Mega Science Projects' in the light of the discussions held earlier in the meeting of the Steering Committee on Science and Technology on the 19th June 2006 and the following was agreed.

- (a) Mega-Science projects should appeal to **the scientific curiosity of the researchers** in search of answers to some of the important questions facing the world of science, and should be of interest to a large scientific community from various research groups within the country and outside.
- (b) Mega-Science projects would be very large in terms of outlays or the complexity involved. Thus a user group, institution or even individual countries would need to join hands with other similarly interested groups. Implementation of such projects would involve **multi-institutional teams, including possible international collaboration.**

2. Modalities of Implementation and Benefits

There were also discussions regarding the modalities of implementation and the benefits that accrue by taking up and participating in such projects and the following emerged:

- (i) Apart from the scientific facilities, there would be a need to bring together a large group of researchers who come from different institutions situated within the country and from different parts of the globe. This would entail the creation of an appropriate environment and infrastructure at the sites of mega - projects.
- (ii) Even though it is recognized that these projects would be implemented with multi-institutional collaboration and management, it would be appropriate that the funding should be channelised through a mutually agreed host institution.
- (iii) While the actual implementation of these projects would involve multi-institutional involvement, linking the projects to a broader academic framework would help sustain the research activities around these large facilities.

- (iv) These kinds of projects have the advantage that they network a wide range of expertise from a range of different disciplines. This offers a new paradigm for exposing our young researchers to a more holistic training in research involving state-of-the-art techniques.
- (v) One of the major benefits of implementing mega science projects is that it creates an exciting opportunity for our young scientists to participate in cutting edge research and attract them to science by offering meaningful post graduate or doctoral programmes, and at a larger level, it enhances the scientific culture in the country. Specifically, this could include organizing summer/winter schools, summer projects for B.Tech, projects for M.Tech students, and research programmes for students pursuing a Ph. D in science or engineering. Wherever necessary, funding for these activities can be provided by creating appropriate mechanisms under BRNS and DST.
- (vi) Finally, these projects lead to direct technological gains for the country in terms of advanced technologies and equipment building, as well as development of expertise to take on similar projects in future that push the frontiers of technology.

In cases where India's participation in international programmes is being sought, it is desirable that there should be a corresponding pre-existing Indian research or development programme which has considerable overlap and maturity. This will ensure that there is sufficient 'feedback' into our programmes and also enable the possibility of scientists from other countries to participate in such programmes in India, thereby creating greater opportunity for larger number of young Indian scientists to be exposed to their peers. An example would be the Large Hadron Collider (LHC) project at CERN, which has generated considerable interest and excitement and several Indian scientists in a wide range of disciplines, have worked together with scientists from other countries.

Similarly, when a major research facility is being built in India, it should be with some distinctive features with potential to meet the research interests of the larger scientific community, the world over. An example would be the GMRT which today attracts a steady stream of international researchers.

Since the typical project outlays would be very large, leading to higher per-capita expenditure, the decision of the projects should be preferably made by national consensus. An example would be the discussions held by the High Energy Nuclear Physics community. As a matter of fact, a large part of this report is based

on these discussions. Such national level discussion involving scientists belonging to a particular area is crucial before a mega science project is launched.

To facilitate such discussions as well as to facilitate broader national level participation in international mega-science projects, DAE has created frameworks along with DST and through the DAE- UGC Consortium for Scientific Research.

India's participation in ITER has already been approved by the Government. This had been discussed earlier in the DAE Science Research Council. The Institute for Plasma Research (IPR) would be the nodal institution for this project. In addition to projected commitments as part of our participation in the ITER project, a provision is being made to support research across the country in the area of plasma science and fusion technologies. (Details in Annex -2).

There would also be opportunities for Indian scientists to set up their experimental stations around some of the major research facilities abroad. Setting up such experimental stations enables greater access to our researchers and should be promoted wherever such proposals are cost effective.

The Working Group had sought inputs from all scientific departments and the various project proposals received were discussed. The following emerged.

- (i) The inputs included some large projects like the induction of LCA, ALH into the Services, 10 Ton Airship, High speed trains, nano - and micro-technologies, Hydrogen economy etc. It was felt that these large projects are important for the country and should be supported. These should be considered 'mega science' from the national development perspective. These projects should be taken up by the concerned Ministries and Departments.
- (ii) The proposal for a second intense photon source was discussed in detail, and it was felt that the INDUS-2 facility being set up by the Raja Ramanna Centre for Advanced Technology, (RRCAT) would meet most of the requirements. Of the thirty two beam lines which INDUS-2 can support, it would be possible to set apart ten to twelve beam line positions for setting up such dedicated facilities. Interested research groups could be funded by the DST, and RRCAT should provide exclusive space and services for these experiments.
- (iii) The proposal for an X-ray Free Electron Laser (XFEL) is included below in the High Energy and Nuclear Physics proposals.

The remaining projects were discussed and consolidated as follows:

- (A) **High Energy and Nuclear Physics** This includes:
 - (a) **International Linear Collider and related programs**
 - (b) **India based Neutrino Observatory (INO)**
 - (c) **National Radioactive Ion Beam Facility**
 - (d) **Facility for Antiproton and Ion Research (FAIR)**
- (B) **Astronomy based Research**
- (C) **National Hetero-structure Facility**

The details of the above programmes are discussed in the next chapter and annexes.

Chapter - 2

SUMMARIES OF THE PROJECTS DISCUSSED

1. High Energy and Nuclear Physics

(a) International Linear Collider and related programs

Particle physicists the world over have established the physics case for a TeV, Linear electron-positron collider as a machine that would be complementary to the Large Hadron Collider (LHC), and which offers the possibilities of studying directly the 'dark matter' which makes up most of the mass of the universe, as well as answer fundamental questions about the fabric of space-time.

The Indian High Energy Physics Community is interested in the physics studies at this International Linear Collider, (the ILC) which, as said above, is the next frontier of research in the subject. Indeed, the community is in a position to do so meaningfully in view of its important contributions to the subject of collider physics till date.

The HEP community, in its road-map for the next 20-25 years, has identified the ILC and the INO as the two activities which the community is keen on pursuing. The ILC technology has commonality with that of the X-ray Free Electron Laser (XFEL), the High Intensity Proton Accelerator (HIPA) as well as the Facility for Antiproton and Ion Research (FAIR). (See *Annex 3a*) The accelerator Physics Community is keen on participating in the design and construction of the advanced accelerator projects such as the ILC, XFEL, High Intensity Proton Accelerator (HIPA) and FAIR. The Nuclear Physics Community is interested in doing physics with the Radioactive Ion Beam (RIB) and FAIR. It may also be noted that the condensed matter and material science community is keen on participation in the physics studies that are possible with an XFEL. The participation in the design and construction and in the R&D of facilities such as the ILC, XFEL, HIPA and FAIR will enable our accelerator community to take part in highly advanced technologies in the important accelerator field.

All of these programs have a major component of international collaboration and participation in them will allow the Indian scientific community to take its rightful place in the world scene. Even more importantly, participation, as mentioned above will also feed back to the domestic programs in a major way.

While participating in the ILC, the Advanced Accelerator Projects such as XFEL, HIPA and the accelerator aspects of other programs such as the FAIR, one

would like to emulate the highly successful model, of the participation by Indian Scientists in the LHC project which is soon to be commissioned at the European Organization for Nuclear Research (CERN). India's participation in and the 'in kind' contribution to the LHC-machine, generated some funds towards India's further participation in the R&D for the detectors, as well as building them. Our participation in all these has showcased the ability of Indian scientists and the Indian Industry to undertake challenging tasks and deliver on the tight international schedule. It has brought recognition to the country such as the 'Observer status' in the CERN Council. This can only increase, with India's continued contribution in the Physics analysis and studies at the LHC. This has also given Indian Industry the opportunity to meet globally competitive technological demands. Hence it is essential to continue India's participation in these International projects.

An ILC and Advanced Accelerator Technologies Forum, has been initiated to discuss various aspects of participation in the above activities by the Indian scientists, maintaining a synergy with existing and planned programs in related areas in the country. The various activities towards R&D in generic technologies related to the ILC and other high power accelerators: XFEL, High Intensity Proton Accelerator (HIPA) as well as the accelerator component of FAIR are to be taken up in different institutions, (See *Annex 3a* for details.)

The total budget requirements of the above amounts to Rs. 43.5 Crores which have been indicated in the XI Plan proposals of various units as follows:

DAE R&D Sector¹:

- 1. RRCAT: Participation in XFEL and ILC Programmes
(XI Plan 30Cr + XII Plan 10Cr)**
- 2. TIFR: Participation in ILC and Advanced Accelerator R&D (XI Plan 8.5Cr)**

DST ²:

- 1. Development of infrastructure for ILC Programme (XI Plan 5Cr)
To be provided by DST through IUAC.**

¹Confirmed by Member. Secy. XI Plan DAE (R&D) Working. Group.

² Discussed with Director IUAC and also with Dr. Praveer Asthana, DST.

(b) India-based Neutrino Observatory (INO)

An India-based Neutrino Observatory (INO) has been proposed by a large community of scientists from various institutes and universities in India for doing front ranking experiments in the field of neutrino physics. With this objective, a neutrino collaboration group was established in 2002. This collaboration was assigned the task of carrying out the feasibility studies for setting up such a facility for which funds were made available by DAE during the X plan. The INO collaboration has already completed the feasibility study and submitted a detailed report to DAE and other funding agencies. The Collaboration has also identified the Pykara Ultimate Stage Hydro Electric Project (PUSHEP) at Masinagudi in Tamil Nadu state as the preferred site for locating the underground laboratory.

The proposed goal of this project is to:

- Build an underground laboratory and surface lab for doing front ranking experiments in the area of neutrino physics in India.
- Construction of a 50 kton magnetised iron calorimeter to study atmospheric neutrinos which may be augmented to 100 ktons later.
- Creation of an INO centre with all modern facilities like workshop, electronics lab, detector fabrication and testing bay, offices, hostel and guest house.

Apart from being a premier experimental facility in the country, the INO centre is expected to become a nodal centre for initiating collaborations and educational outreach programs with leading HEP and nuclear physics laboratories in the world. An immediate impact of this centre will be in the field of training experimental physicists. In particular the contribution to the culture of doing experiments, small or big, will be enormous. The particle detectors developed by the high energy and nuclear physicists over the years have found wide application in areas such as medical imaging, material science, industrial control and in geological survey. Detector development for such purposes is also expected to be a major part of the over-all activities of this centre. It is therefore going to play a major role in the development of detector technology and in the transfer of this technology to industry for its potential large scale utilisation.

The total cost of the project spread over two Plan periods is Rs. 670 Crores. Of this, Rs. 320 Crores will be needed during the XI plan period and the remaining Rs. 350 Crores during the first two years of the XII plan. Necessary allocations have been included in the XI Plan proposals of the DAE R&D Sector (Unit :SINP). The detailed breakup of cost is given in *Annex 3b*.

In addition, a project of this magnitude will need sufficient trained manpower to construct and run the laboratory and the experiments and to participate in the

development of detectors. It will be necessary to create positions for fifty physicists, thirty five scientific/technical personal and fifteen administrative positions located at the INO Centre. These people will be working full time on the INO project. Further, to involve various institutes and universities in the INO project, it will be necessary to have INO positions in the participating institutes and universities. These physicists should have joint appointments at the INO Centre and at one of the participating institutes

(c) National Radioactive Ion Beam Facility

The nuclear physics community in the country in various universities and research organizations is engaged in carrying out front-line research and has been making internationally reputed contributions. During the deliberations at the recent DAE-DST vision meetings, all the leading nuclear physicists have very strongly and collectively recommended setting up of a world class, National Radioactive Ion Beam (RIB) facility, in the country, for contemporary and front-line nuclear physics experiments. The research areas include the study of explosive stellar events, nucleo-synthesis, structure of exotic nuclei, limits of particle stability, synthesis of super-heavy nuclei etc. Highly advanced materials science experiments will also be carried out with such a facility. A low energy, highly sophisticated RIB facility is under development at VECC, Kolkatta. Several complex technologies relevant to a front-line RIB facility have been developed. It is now proposed to initiate the development and construction of a large and high energy RIB facility in the country, as mentioned above, which will compare with the best in the world in the field of nuclear physics research. The accelerator facility and related experimental facilities will be set up with the participation of several research organizations and universities of the country. International participation in this endeavour is also expected. In fact, VECC has already been collaborating very actively with two leading international laboratories, namely RIKEN at Japan and TRIUMF at Canada, both for accelerator design and development and for the nuclear physics experiments in the field of RIB.

The total budget for the project amounts to Rs. 570 Crores (See Annex 3c). For Phase 1 of this project, production of neutron rich RIB using the electron-LINAC, an amount of Rs. 75 Crores has been included in the XI Plan proposals of the DAE R&D Sector (Unit :VECC).

(d) Facility for Antiproton and Ion Research (FAIR)

This facility will be built around 2011 at GSI, Germany. With this facility, research can be performed in a broad range of areas, namely (a) high-energy nucleus-nucleus collisions to study compressed baryonic matter, (b) nuclear structure and nuclear astrophysics studies utilizing rare isotope beams, (c) plasma

physics utilizing short pulse heavy ion beams, (d) studies in atomic physics and applied research including radiobiology using antiprotons and highly charged heavy ion beams and (e) researches in hadron physics including hypernuclei with antiproton beams. There is enormous interest among Indian researchers to perform experiments at this facility. The areas include nuclear structure physics, high energy heavy ion collisions, plasma physics, radiobiology, medical research etc.

FAIR will have innovations in the field of accelerator science and technology as well. Some of the highlights in the field of accelerator are, (a) fast cycling superconducting magnets, (b) large aperture super-ferric magnets (c) fast stochastic cooling for radioactive ions and antiprotons (d) generation of short (~50ns) and intense (10^{12}) ion pulses with terawatt beam power and (e), operation at very high intensity RIBs.

Some scientific and technological advantages out of participation in FAIR are:

- (i) Opportunity to take part in and contribute to the large variety of highly advanced experimental facilities for nuclear physics and other areas.
- (ii) Working for the development of fast and radiation-hard detectors and electronics which is a unique activity.
- (iii) Experience in parallel beam operation of a large accelerator complex
- (iv) To learn about high intensity target preparation - useful for our ADSS and RIB programs.
- (v) Working in the areas of plasma science and technology complements magnetically confined plasmas and our participation in ITER.
- (vi) FAIR will deal with highly intense beams. Building of any device in this high current environment needs innovative technology. Two areas where we will have direct access and will be useful in our own programs like the ADSS are:
 - Building complex superconducting dipole, quadruple and sextuple magnets from design to installation.
 - Building components for high current proton-LINAC at FAIR.

While the full project details are still being discussed among the various organizations and institutes, VECC has proposed to take up the Development of the High resolution and Superconducting magnet based detectors in the XI Plan proposals of the DAE R&D Sector (Unit :VECC, XI Plan: 35Cr + XII Plan 10Cr).

2. Astronomy based Research

The country at present has several major new telescopes: Currently, the GMRT (Giant Metre-wave Radio Telescope, operated by NCRA-TIFR) represents a major international, competitive, facility for radio astronomy at metre wavelengths, functioning for the last five years. At optical and infrared wavelengths, a very promising beginning has been made by the Indian Institute of Astrophysics (IIA) with its recently commissioned 2m telescope at Hanle in the Himalayas, one of the highest sites worldwide for optical and ground based infrared astronomy. The IUCAA telescope is poised to create and serve a strong university community in astronomy. The ASTROSAT X-ray observatory due for launch in 2008 will give a major boost to X-ray astronomy and related areas in the country. With this background, the astronomy community in the country is considering several new initiatives where the planning and build up will be in the XI Plan and the actual execution is likely towards the end of the XII Plan. These are:

- a) The Square Kilometre Array - an international radio observatory, costing about USD 1 billion, due for construction 2012-2020, NCRA-TIFR is already formally involved in the international discussions and planning.
- b) A 10-m class optical/near-IR telescope in the Himalayas, under serious discussion by IIA, ARIES, IUCAA, TIFR.
- c) New satellites for space astronomy, particularly X-ray and far -infrared work. ISRO is the nodal agency with significant TIFR and RRI involvement.

Further details are given in Annex-4. It is therefore decided that this activity needs to be supported. **While the initial small funding can be met from the existing Plan of TIFR, major funding can be made available in subsequent Plan periods.** Some general observations are:

- i) There is a need for a broad roadmap and consensus in the astronomy community which is best achieved by working papers from individual groups followed by an intensive representative workshop of stakeholders in the various projects
- ii) One strong common thread is user community development, particularly in the universities - clearly IUCAA has a key role here.
- iii) All these areas require very significant technology development. This should utilize the existing agencies as well as engineering institutions plus industry, as appropriate. A consortium approach would give the needed co ordination combined with flexibility.

3. National Hetero-structure Facility

During the last two decades, nitride semiconductors have emerged as strong candidates for high frequency as well as light emission applications. Indeed it is possible to replace household lighting systems with these light emitting diodes (LED) to conserve the power and achieve long life usage. Further, dilute nitrides have emerged from conventional III-V semiconductors such as GaAs or InP by the insertion of nitrogen into the group V sub-lattice, which has profound influence on the electronic properties of these materials and allows a widely extended band structure engineering. This is expected to lead to novel devices, e.g. for optical data transmission, solar cells, biophotonics or gas sensing, some of which are already making their way into the market.

In view of the importance of this area, a proposal to set up a National facility to carry out research in the area of semiconductor heterostructures and related devices and materials was received. The Centre for Semiconductor Heterostructure Research (CSHR) is intended to provide facilities initially for carrying out advanced research which are important for the national energy and security needs.

The above proposal was briefly discussed and it was felt that the project is important. The details of the project were received late (See Annex 5), and detailed discussions could not take place. However, DST has informed that the proposal has been discussed in the DST's Programme Advisory Committee on Condensed Matter Physics and Materials Science. It was further discussed in the Science and Engineering Research Council and also by an Expert Committee constituted by the DST to discuss its XI Plan proposals. **Accordingly, DST has 'flagged' this facility in their documents containing the XI Plan Proposals³.**

³ Personal Communication from Dr. Praveer Asthana, DST

Constitution of Working Group

No. Prn.SA/ADV/SC/2006
Government of India
Office of the Principal Scientific Adviser to the Government of India

311, Vigyan Bhawan Annexe,
Maulana Azad Road,
New Delhi 110011
Dated: 8th May, 2006

OFFICE MEMORANDUM

Subject : Constitution of Working Group under the Steering Committee on Science on Technology for the Formulation of Eleventh Five Year Plan (2007-2012).

Planning Commission has constituted a Steering Committee on Science and Technology for the Formulation of Eleventh Five Year Plan (2007-2012). To assist the Steering Committee and to finalize its recommendations, a Working Group is being constituted on "Mega-Science Projects". The composition and terms of reference of the Working Group would be as follows :

I. Composition

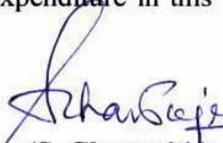
**Sr. Name, Designation and Organization
No.**

- | | |
|---|------------------|
| 1. Dr. Anil Kakodkar, Secretary, DAE, Mumbai | Chairman |
| 2. Secretary, DST, New Delhi | |
| 3. Dr. M.K. Bhan, Secretary, DBT, New Delhi | |
| 4. Dr. P.K. Kaw, Director, Institute of Plasma Research, Gandhinagar | |
| 5. Dr. B.C. Sinha, Director, Saha Institute of Nuclear Physics, Kolkata | |
| 6. Dr. R. Nityanandan, Director, National Centre for Radio Astrophysics, Pune | |
| 7. Prof. Rohini Godbole, IISc, Bangalore | |
| 8. Dr. R.B. Grover, Director, SPG, DAE, Mumbai | Member Secretary |

II. Terms of Reference

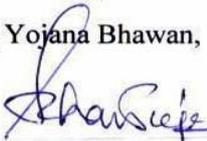
1. To suggest Mega Science & Technology Projects which may be taken up during the next 5 years.
2. To identify the institutions/ research laboratories/ universities and other partners who would be the key stakeholders in these projects.
3. To recommend the infrastructure requirement for these projects.
4. To propose the steps needed for inter-agency collaboration for implementation of these Mega Science projects.

5. To consider any other important and relevant item.
6. To indicate approximate financial outlay for implementation of the recommendations.
7. The Co-Chairmen may co-opt other members, if required.
8. The expenditure on TA/DA in connection with the meetings of the Working Group in respect of the official members will be borne by their respective Ministry/ Department. However, in the case of non-official members, they will be entitled for TA/DA as admissible to Grade-I Officials of the Government of India and the expenditure in this regard would be met by the Planning Commission.
9. The Working Group would submit its report by 15th July, 2006.


(S. Chatterjee)
Adviser

Copy forwarded to:

1. Chairman, all members and Member Secretary of the Working Group.
2. Dr. V.L. Chopra, Member (S&T and Agriculture), Planning Commission, Yojna Bhawan, New Delhi
3. Dr. P.K. Biswas, Advisor (S&T), Planning Commission, Room No. 213, Yojana Bhawan, Sansad Marg, New Delhi


(S. Chatterjee)
Adviser

The ITER Project

ITER, which is Latin for “the way”, is also an acronym for the International Thermonuclear Experimental Reactor. It is a prestigious international project which will nearly complete the scientific and technological investigations required to build a prototype demonstration reactor DEMO, based on the magnetic confinement scheme of controlled thermonuclear fusion. India has recently joined ITER as one of seven full partners, the others being China, European Union, Japan, Korea, Russia and USA. India will contribute equipment worth nearly 500 million US dollars to the experiment and will also participate in its subsequent operation and experiments. The equipment will largely be made by Indian industries in India.

ITER INDIA is a developmental Mega Project, a project of the type where a department undertakes a major R&D effort in a mission mode in an area of national need. ITER INDIA project is connected with the development of nuclear power programs in the country and seamlessly connects to the strategies related to the Third Stage and beyond. These strategies aim at nuclear technologies of importance in the latter half of 21st century and include new technologies like nuclear fusion.

ITER INDIA project, being large in size, is also being used to promote a national program of research and development in fusion energy and plasma physics. Some funds have been earmarked for smaller related R&D programs in Universities, IIT's and other research institutions, which will be simultaneously promoted. This will lead to cross fertilization of ideas by networking of institutions and research programs and will assist in the task of human resource development.

India's energy needs are enormous. With a rapidly growing economy and the rising expectations of its citizens to enjoy a decent standard of living, the energy requirements of India are simply staggering. We have one fifth of the world's population but our per capita electricity consumption is still only a quarter of the world's average, 1/13th of that of Western Europe and 1/30th of that of the United States. Today we are consuming about 130 GW of power, 95% of which comes from thermal or hydro sources. This number is likely to go up to a 1000 GW by the middle of this century. If this power continues to be produced by the mix we have today, the consequences for our environment are ominous. Therefore, we have to change the

energy mix and go to a more aggressive pursuit of nuclear energy and renewable sources. We have an ambitious, indigenous nuclear energy programme within the country. Right now about 3% of our electricity generation is based on nuclear power. This power generation is based on reactors using the pressurized heavy water concept, a technology has been mastered. We are now in the process of building the first 500 MW prototype fast breeder reactor, at Kalpakkam, Tamil Nadu. This is a follow up on the successful experiments with the 40 MW Fast Breeder Test Reactor. We would like to bring the share of nuclear power to about 10 per cent by the year 2020. Nuclear fusion is viewed as an advanced successor technology to nuclear fission, and is likely to play a commercially important role sometime in the second half of this century.

Nuclear fusion is the process which has kept the stars burning brilliantly for billions of years. On the earth its devastating power has been seen through the hydrogen bombs. The most convenient fusion reaction is that of heavy isotopes of hydrogen, which are either readily available or may be readily bred from available material in earth's crust and the oceans :



For the past fifty years or more, controlled thermonuclear fusion experiments have been investigating on how to confine a low density fusion grade plasma of deuterium and tritium at temperatures approaching hundred million degrees by magnetic fields, so that slow and controlled release of fusion energy may become possible. This search has led to a successful magnetic bottle concept, viz. the tokamak concept, in which the magnetic confinement geometry is produced by a combination of fields produced by external coils and fields produced by plasma currents. The plasma is heated by the plasma currents and by injection of radio frequency waves and energetic neutral particle beams into the plasma. Once the fusion reaction is ignited, the fusion plasma can be kept hot by the stopping of energetic helium nuclei in the plasma. The electrically neutral neutrons carry their energy out of the plasma where it is collected in a blanket, used to generate steam and utilized for electricity generation by the use of standard steam turbine cycles. Large experiments with millions of amperes of plasma current and tens of Megawatts of injected power (like JET in Europe and JT-60U in Japan) have produced fusion reactor grade plasmas with breakeven conditions. Empirical scaling laws have been

established which indicate that an experiment of the size of ITER will produce an energy amplification by a factor of 10 and will thus be able to generate about 500 MWatts of fusion power. This is why it is important to do an experiment of the size of ITER before designs for prototype commercial fusion reactors can be finalized.

India has had a fusion research programme of its own since the early eighties. Two tokamaks have been indigenously built at the Institute for Plasma Research (IPR) near Ahmedabad and a small tokamak has been imported from Toshiba, Japan at the Saha Institute for Nuclear Physics, Kolkata (SINP). The SINP tokamak has been used for an intense study of low q tokamak discharges. ADITYA, the first indigenously built Indian tokamak, has been extensively used for the study of plasma turbulence in the edge and scrape-off layer regions. This novel work led to the discovery of intermittency in tokamak turbulence, which is related to the presence of coherent structures in the turbulence and leads to burst transport effects. The second IPR tokamak, SST1, is a steady state superconducting tokamak and is currently undergoing commissioning tests. It will have Megawatts of ion cyclotron and neutral beam based auxiliary heating. These two tokamaks and associated auxiliary equipment have been built by Indian industries with designs and integration responsibilities taken up by IPR. Many sophisticated diagnostic tools have also been developed at IPR and SINP.

India's contributions to ITER are largely based on the indigenous experience and the expertise available in Indian industry. India will be fabricating the 28 m dia, 26 m tall SS cryostat , which forms the outer vacuum envelope for ITER. It will also take up the design and fabrication of eight 2.5 Mwatt ion cyclotron heating sources, complete with power systems and controls. It will also take up the fabrication of a diagnostic neutral beam system which will give crucial information about the physics of burning plasmas in ITER. India will also be responsible for a number of other diagnostic subsystems. Finally, India will contribute to cryo-distribution and water cooling subsystems. All this equipment will have to be built with ITER quality standards and in a time frame (approximately ten years) as determined by the International Team at the host site in Cadarache , France. This is the challenge.

The opportunity that participation in ITER offers us is also enormous. This is the first time we will be full partners in a prestigious international experiment. We will have to come to international standards of quality, safety, time schedule

maintenance etc immediately. Our scientists and engineers will get direct hands on experience in design, fabrication and operation etc of the latest fusion technologies. We will get access to a number of fusion technologies on the scale relevant to fusion reactors for the first time. If we backup the ITER INDIA effort with an aggressive well focused national programme, it will allow us to leapfrog by at least a couple of decades.

The ILC and related Projects

The Indian High Energy Physics Community is interested in the physics studies at the International Linear Collider, (the ILC) which is the next frontier of research in the subject. The community is in a position to do so meaningfully in view of its important contributions to the subject of collider physics till date. The HEP community, in its road-map for the next 20-25 years, has identified the ILC and the INO as the two activities which the community is keen on pursuing. The ILC technology has commonality with that of the X-ray Free Electron Laser (XFEL), the High Intensity Proton Accelerator (HIPA) as well as the Facility for Antiproton and Ion Research (FAIR). The accelerator Physics Community is keen on participating in the design and construction of the advanced accelerator projects such as the ILC, XFEL, High Intensity Proton Accelerator (HIPA) and FAIR. The Nuclear Physics Community is interested in doing physics with the Radioactive Ion Beam (RIB) and FAIR. It may also be noted that the condensed matter and material science community is keen on participation in the physics studies that are possible with an XFEL. The participation in the design and construction and in the R&D of facilities such as the ILC, XFEL, HIPA and FAIR will enable our accelerator community to take part in highly advanced technologies in the important accelerator field.

All of these programs have a major component of international collaboration and participation in them will allow the Indian scientific community to take its rightful place in the world scene. Even more importantly, participation, as mentioned above will also feed back to the domestic programs in a major way. The annexes below (3a, 3b, 3c and 3d) give the details of the different projects, their current status, funding breakup and work methodology.

The ILC Project

A meeting was held on 11.07.06 in the Tata Institute of Fundamental Research (Mumbai) to exchange ideas regarding the Indian involvement in Advanced Accelerator Projects and the ILC, as well as the formation of an ILC and Advanced Accelerator Technologies Forum. The group examined various aspects of participation in these by Indian scientists, maintaining a synergy with existing and planned programs in related areas in the country:

- 1) The R&D of the design and construction of the International Linear Collider, the ILC and the advanced accelerators, in particular the High Intensity Proton Accelerator, the XFEL and the accelerator elements of the FAIR and the RIB program
- 2) The Linear Collider World Wide Study Group for the Physics and Detector studies

The following scientists were invited by the convener of the meeting, Rohini Godbole (IISc): R.K. Bhandari (VECC), Sunanda Banerjee (TIFR), Atul Gurtu (TIFR), S.Kailas (BARC), R.G. Pillay (TIFR), D.D. Sarma (IISc/IACS), Amit Roy (IUAC), M.B. Kurup (TIFR), V.C. Sahni (RRCAT), S. Krishnagopal(RRCAT)

The Physics case for participation in these activities

The committee went over the executive summary of the Roadmap for High Energy and Nuclear Physics, which had been prepared after holding a joint DAE-DST meeting of the high energy and nuclear physicists and has been submitted to both the Secretary DAE and the Secretary DST. It was clear from the document that the High Energy Physics Community in India as well as the Accelerator Physicists are very keen on getting involved in the extremely challenging and the interesting project of the International Linear Collider. Particle physicists the world over have established the physics case for a TeV range, Linear, $e^+ e^-$ collider as a machine that would be required complementary to the LHC; to study the properties of the Higgs boson with great precision which would help answer the basic questions of the fabric of space-time, and to offer possibilities of studying 'directly', the 'dark matter' which, as established by astrophysicists, makes up most of the mass of the Universe. The committee on Elementary Particle Physics in the 21st Century of the National Academy of Sciences, for example, has identified in its roadmap for the next 25 years, the International Linear Collider as the program to prepare for, in the coming decades. Same is true of Japan too. The need for global coordination for the

International Linear Collider is also mentioned in the European Strategy for Particle Physics released last week by the CERN Council. The HEP community in India, both the theorists and experimentalists, who have been successfully involved in theoretical investigations of 'Physics beyond the Standard Model' and its experimental probes, at the LHC respectively, are also unanimous about the need of India's participation in the program if and when it should be realized. Further, the accelerator physics community in India is also excited about participating in such an exercise, particularly in view of its successful participation in the LHC machine programs. The accelerator physics and technology needed to build the ILC are going to be at the cutting edge. The participation in the design and construction of the machine will enable our accelerator community to take part in highly advanced technologies in the all important accelerator field. Interestingly, the program and the technologies involved are not of interest only to the high energy physicists and the builders of the high energy machines but also to the high power accelerator physicists. There are common technology elements to the ILC program, the XFEL program, the HIPA and the accelerator elements of the Facility for Antiproton and Ion Research (FAIR) and Radioactive Ion beam (RIB) programs which are of direct interest to the country.

The Superconducting Radio Frequency (SRF) cavity technology has been adopted as the technology for the International Linear Collider for accelerating electrons and positrons. In fact, all new accelerators for electrons, ion and protons, e.g., XFEL, High intensity proton drivers for spallation neutrons or neutrinos, incorporate SRF cavities. This technology is the key technology for proton drivers for the Accelerator Driven System program. Thus, participation in the cavity design and its fabrication is an area of prime importance for the accelerator development in the country. Another area is that of RF power generation and control electronics.

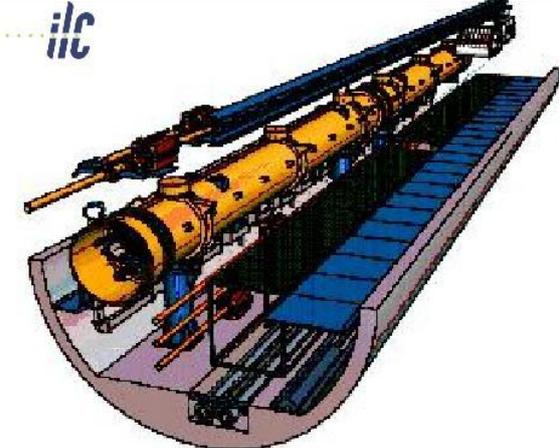
One more area where India can contribute meaningfully is in the design and fabrication of the cryogenics. In all of these technology areas, some expertise has been developed in the country and it would be possible to contribute meaningfully to the world-wide effort on ILC and at the same time train and enthuse young persons in these fields, for the important domestic programmes.

Material Scientists in the country are clearly interested in participating at the Physics studies at the XFEL like the one that is being planned at DESY (Germany), for which some funding has already been sanctioned by the German Government and the European Union. The source brightness available through an XFEL is better by many orders of magnitude than any other known source of X-rays in terms of peak brilliance, ultra-short pulse duration, and transverse coherence. Therefore, it is expected that the use of such a source will open up completely new science in diverse areas of physics and related subjects, such as atomic and molecular

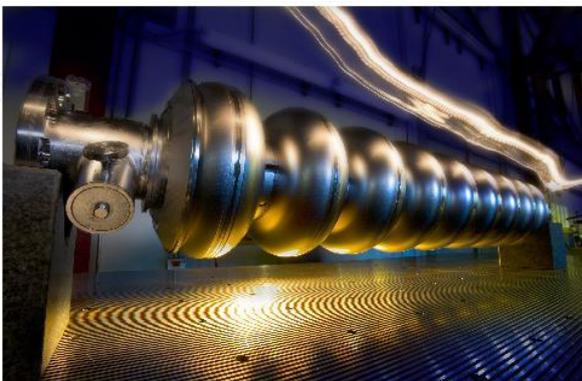
physics, nano-science, plasma physics, condensed-matter physics, materials science, chemical physics, and non-linear optics. In particular, its unique properties will allow us to probe time and space domains that are way beyond the present day limits, for example allowing us to probe sub-femto-second time-resolved processes. The extreme brilliance will allow us to probe non-linear phenomena that are altogether inaccessible today. This approach is believed to pave way for the determination of the crystal structure of even a single macro-molecule. There is also great need to work on new materials for such cutting-edge technologies, for example for accelerating cavities. This provides a great challenge as well as excitement to the material scientists. This is another area where the material scientists in India could effectively contribute to the global effort.

Indian expertise and relevance for the domestic programs

In summary, the High Energy Physics community is interested in and in a position to participate in the physics studies at the ILC and the condensed matter community in studies at the XFEL. In addition participation in either the building and construction or R&D of these facilities will also feed back to the domestic programs. Areas of collaboration on the XFEL, which would benefit the domestic activity in this area and prepare the ground for a future XFEL in India, are: high-brightness electron sources; insertion devices; accelerator theory and design; study of nonlinear beam

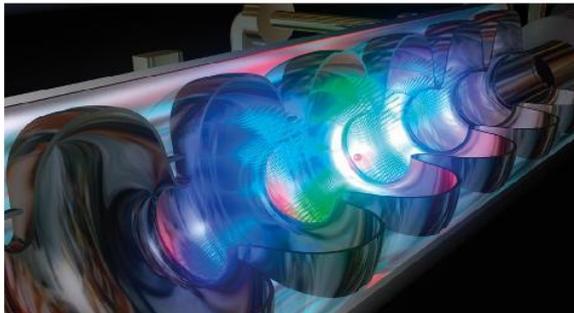


A linear collider tunnel
The yellow tubes conceal the supercooled, superconducting cavities which are also used in XFEL.



A 9-cell superconducting radiofrequency cavity constructed for TESLA/XFEL

ILCWG
Indian Linear Collider Working Group
The Indian collaboration for studying the physics potential of a linear collider



Computer animation of the electromagnetic field inside a cavity

dynamics and beam halos and material science studies. Areas of collaboration on the ILC that would tie in with present and future accelerator activities in the country are: superconducting RF technology high-brightness electron sources; accelerator theory and design; damping ring: new material development suitable for RF cavities, etc. (See Figure above for details of ongoing collaboration); Fermilab has already proposed collaboration with IUAC on cavity development and RRCAT has a collaboration with CERN on LINAC and RF development. RRCAT has already been approached by DESY for participation in the XFEL program, by collaborating in the testing and commissioning of modulators and related systems and the manufacturing, commissioning etc. of RF-components, particularly as an 'in kind' contribution following the CERN-INDIA model used for the LHC. The high energy physicists have been part of the worldwide study of the physics potential of the Linear Colliders and an Indian Linear Collider Working Group had been functioning under a DST project for the past few years. The TIFR DHEP group has projected R&D activity related to the ILC detectors in their XI Plan projections.



Magnet Assembly Supplied by
RRCAT to the LHC

There are groups, for example at the Vishva-bharati University and Delhi University who would also be interested in participating in these activities. In short, a very strong case can be made for Indian participation in three projects which can be seen spanning the ILC and related studies:

- 1) R&D towards generic technologies related to the ILC and other high power accelerators: XFEL, High Intensity Proton Accelerator (HIPA) in addition to setting up infrastructure at IUAC. One would need an outlay of **Rs. 35 crores** over a period of **five years** towards this.
- 2) Participation in R&D towards detectors and experiments at the ILC would require **Rs. 1.5 crores** over the same period
- 3) Participation of Physicists in physics studies towards the ILC would require an outlay of **Rs. 2 crores** over the same period.

ILC and Advanced Accelerator Technologies-India Forum:

In view of the technology commonality in all these programs and the same needs in terms of the links to the domestic programs as well as the aspect of development of human resources needed to participate in the programs along with the aspect of the International involvement, the committee felt that it would be desirable to form an ILC and Advanced Accelerator Technologies-India Forum which can facilitate effective participation of the community in these areas. Such a forum also seems to us a natural activity which would fall in the areas which could be considered under the DAE-DST MOU. The committee also discussed possible financial outlay of such a Forum and the *modus operandi*.

The required financial outlay per year will be

- A) "Common Fund" expenditure related to the overall GDE (Global Design Effort) for the ILC, which is discussed and agreed upon by representatives of various "interested" Funding agencies, FALC (Funding Agencies for Large Collider). The Indian Funding Agencies (DAE and the DST) have been contacted for the Indian contribution towards the effort. Under FALC, there is a designated "Resource Group" (RG) which examines the funding requirements and reports to FALC. Currently the total common expenditure expected is around US\$ 400,000 per annum. This is to be shared equally between the three regions, America, Europe, and Asia. Within Asia the present proposal is that Japan should cover half the cost and three countries, China, India, and Korea, cover the remaining half. Thus the Indian contribution would come to around US\$ 23,000 or around Rs 12 lakhs/year.

- B) In the ILC context, the High Energy Physicists and Accelerator Physicists need to attend meetings which are held regularly the year around. Annually it is foreseen
 - 1) Participation in FALC meetings twice a year of two representatives,
 - 2) Three persons in GDE meetings again twice an year,
 - 3) An Indian contingent of ten, in the yearly held International Linear Collider Workshop held by the WWS and GDE (which in 2006 was held in Bangalore India),
 - 4) A group of 10 persons to participate in the meetings of the ACFA workshops on Linear Collider Physics and the GDE,
 - 5) Eight to ten persons to participate in the various related conferences such as XFEL, SC cavity technology, High Intensity Proton Driver etc.

In all, it is foreseen the participation by about 120 people over a period of three years, in a phased manner with 30,40 and 50 in the first, second and the third years respectively.

In addition to this, participation in the international program of R&D would mean visits to the Accelerator laboratories such in the USA (like SLAC, Fermilab), KEK (Japan) and DESY (Europe) by about 12 persons, four persons per lab per year. We expect the local expenses for these visits to be covered by the local sources at the laboratory or by other means. Most importantly this means networking among the Indian community at the Indian end, holding domestic meetings and collaborative visits as well as the outreach.

The total estimated expense per year (on the average) for the point B above is

- 1) about 12 lakhs for visits,
- 2) 60 lakhs for attending the different meetings related to the activity, and
- 3) 20 lakhs for the domestic program.

When added to the 12 lakhs for the FALC (under A) we estimate about **1 Crore per year** for the running of the ILC and Advanced Accelerator Technologies Forum.

Thus the overall outlay is **Rs. 43.5 crores**, which has been indicated in the XI Plan proposals of TIFR, RRCAT and IUAC as already stated. In all these cases one hopes to be able to follow the CERN-INDIA LHC model

Modality of the forum's operation:

The forum is envisaged as a pan institute, pan DAE/DST entity. One suggestion would be to organise on the lines of the CERN-India program where there are bodies such as India-CMS, India-Alice etc. There can be a core group. Some of the suggested members of this core group are:

- 1) Director, TIFR or Nominee
- 2) Director, RRCAT or Nominee
- 3) Director IUAC or Nominee
- 4) Director VECC or Nominee
- 5) Rohini M. Godbole (Representative of Theoretical Particle Physics Community)

- 6) D.D. Sarma, (Representative of the community interested in Physics studies using the XFEL as well as studies of other material properties relevant for the Accelerator program.)

One DAE Institute such as TIFR and another non-DAE Institute like the IISc, may be the joint hub of the core group for purposes of funding. The committee would appreciate advice from the secretaries DAE/DST on the composition and size of this core group. The core group should of course co-opt more members as may be needed. This core group will work towards

- 1) Facilitation of the participation of the scientists and engineers in the activity
- 2) Human resource development in the areas of accelerator physics, engineering, high energy, nuclear and condensed matter physics.
- 3) Outreach to the scientific community which resides outside these specialized institutes and have not been traditionally been involved in these activities but possess the requisite expertise and research interest. Here we have in mind plans of reaching out to IISc, IIT, and Engineering Colleges.

India-Based Neutrino Observatory (INO)

Introduction

Very important developments have occurred recently in neutrino physics and neutrino astronomy. Data from several neutrino detectors around the world, in particular, that from the Super-Kamiokande (Super-K) and KamLAND detectors in Japan, and the Sudbury Neutrino Observatory (SNO) in Canada have shown that neutrinos have mass and 'oscillate'.

The existence of non-zero neutrino masses has profound implications on fields as varied as nuclear physics, geophysics, astrophysics and cosmology apart from being of fundamental interest to particle physics. The discovery of neutrino mass and oscillation is but a first step and there are several questions to be resolved, which may require several experiments spanning many decades.

Indian scientists were pioneers in neutrino experiments. In fact neutrinos produced by cosmic ray interactions in the Earth's atmosphere were first detected in the deep mines of the Kolar Gold Fields (KGF) in India in 1965.

It is now planned to revive underground neutrino experiments in India. The possibility of a new neutrino observatory located in India was discussed in the meeting of the Neutrino physics and Cosmology working group during the Workshop on High Energy Physics Phenomenology (WHEPP-6) held at Chennai in January 2000. Further discussions took place in August 2000 during a meeting on Neutrino Physics at the Saha Institute of Nuclear Physics, Kolkatta. The Neutrino 2001 meeting was held in the Institute of Mathematical Sciences, Chennai during February 2001 with the explicit objective of bringing the country's experimentalists and theorists in this field together. The INO collaboration was formed during this meeting. The first formal meeting of the collaboration was held in the Tata Institute of Fundamental Research, Mumbai, during September 6 and 7th, 2001 at which various subgroups were formed for studying the detector options and electronics, physics goals and simulations, and site survey. In 2002, a document was presented to the Department of Atomic Energy (DAE), Government of India, which laid out the goal of establishing an India-based Neutrino Observatory outlining the physics goals, possible choices for the detector and their physics reach. As a result of the support received from various research institutes, universities, the scientific community and the Department of Atomic Energy, a Neutrino Collaboration Group (NCG) was established to study the possibility of building an India-based Neutrino Observatory (INO). The group was assigned the task of doing the feasibility studies for which

funds were made available by the DAE. A memorandum of understanding (MoU), was signed by the participating institutes on August 30th 2002 to enable a smooth functioning of the NCG during the feasibility period.

Major facilities to be created

The following major facilities need to be created for the INO project.

- Building an underground laboratory, and surface facilities, for doing front ranking experiments in the area of neutrino physics in India.
- Construction of a 50 kton magnetised iron calorimeter to detect atmospheric neutrinos which may be augmented to 100 ktons later.
- Creation of an INO Centre with all modern facilities like workshop, electronics lab, detector fabrication and testing bay, offices for scientific as well as administrative personnel, hostel, guest house and residential houses. Apart from the INO detector R& D and fabrication, this will act as a nucleus for detector development in India. Mysore may be a possible location for the INO Centre because of its proximity to the INO underground site.
- A detector development centre to be used for detector R & D and to transfer the technology to industry whenever possible.

INO Physics Goals

Considering various physics possibilities and keeping in mind the past experience at KGF, it was decided, after a prolonged discussion, to start with a modern magnetized Iron CALorimeter (ICAL) detector with Resistive Plate Chambers (RPCs) as the active detector elements.(See Fig 1 below) The detector will be housed in an underground laboratory at a suitable place. There is world-wide interest in this type of a detector and a quick implementation of such a project can achieve many physics goals such as:

- Unambiguous and more precise determination of oscillation parameters using atmospheric neutrinos.
- Study of matter effects, through electric charge identification, that may lead to the determination of the unknown sign of one of the mass differences which is of fundamental importance since it fixes the ordering of the neutrino mass levels.
- Study of charge-conjugation and parity (CP) violation, in the leptonic sector as well as possible charge-conjugation, parity, time-reversal (CPT) violation studies.

- Study of Kolar events, possible identification of very-high energy neutrinos and multi-muon events.

Although INO will start its activity with atmospheric neutrinos, it is envisaged that it will ultimately have other neutrino experiments as well under its umbrella. Several possibilities are open for future directions:

- High-precision determination of the oscillation parameters when ICAL is used in the future as a far-end detector for a long base-line neutrino oscillation experiment.
- Neutrino-less double beta decay, to determine whether neutrinos are Dirac or Majorana particles,
- Solar, supernova and geo-neutrino studies.
- Tomography of the Earth using natural and laboratory neutrino sources.

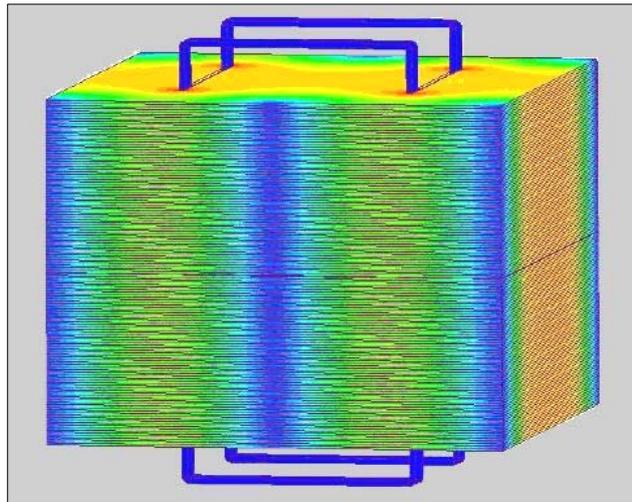


Fig.1 : Resistive Plate Chambers (RPC) Detectors and Iron CALorimeter (ICAL) Magnet Field

Other objectives of INO

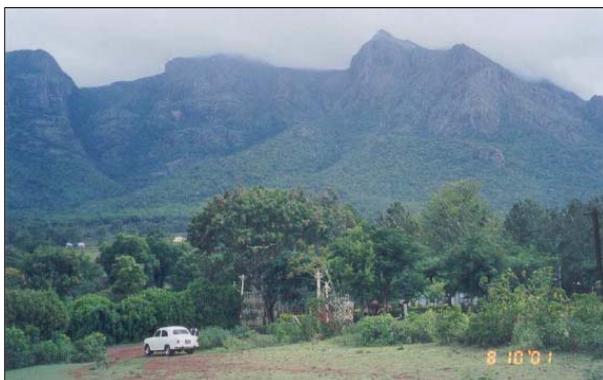
One of the main aims of INO is to setup the underground laboratory and the ICAL detector in a time-bound manner. To achieve this, it is necessary to setup an INO Centre in a city close to the underground laboratory. It is hoped that the INO centre will eventually play the role of a national high energy physics centre in India,

similar to the HEP Centre in China, KEK in Japan and CERN in Europe. Apart from being a premier experimental facility in the country, the laboratory will also become a nodal centre for initiating collaborations and educational outreach programmes with the leading HEP and nuclear physics laboratories in the world. An immediate impact of such a centre will be in the field of physics education, in particular, and science education in general. The contribution to the culture of doing experiments, small or big, will be enormous. The training and educational programmes directed at the students, technicians and educators will, in the long term, have a positive influence on the educational scene as it has, elsewhere in the world.

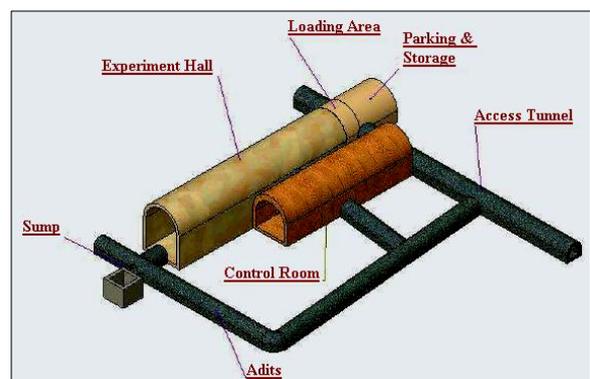
The particle detectors developed by high energy and nuclear physicists over the years have found wide application in areas such as medical imaging, materials science, industrial control and in geological survey. The primary motivation of the India-based Neutrino Observatory is to build and operate an underground laboratory and to set up experiments in the field of neutrino physics. Detector development is, however, expected to be a major part of the over-all activities of this centre. It can therefore play a major role in the development of detector technology and in the transfer of this technology to industry for its potential large scale utilization in other areas, especially in the area of medical imaging.

Location of INO Lab

Two possible locations for INO were initially identified; PUSHEP in Nilgiris district, Tamil Nadu, and Rammam in Darjeeling district of West Bengal. After going through the merits and demerits of both sites, a site selection committee set up by the INO Collaboration has chosen the Pykara Ultimate Stage Hydro Electric Project (PUSHEP) in the Nilgiris District in Tamilnadu as the preferred site for INO.



Panoramic view of the mountain peak of PUSHEP. The laboratory cavern will be located directly under this peak.



An artist's illustration of the Laboratory Cavern Complex

Cost of the project and yearly outlay during XI plan

The total cost of the project is expected to be **Rs. 670.00 crores**. Of this, Rs. 320 crores will be needed during the XIth plan period and the remaining 350 Crores during the first two years of the XIIth plan. Necessary allocations have been included in the XI Plan proposals of the DAE R&D Sector (Unit :SINP) Depending on the progress, the outlay may be modified to acquire iron required for the second/third module in the XI plan period itself to speed up things.

Yearly outlay of the cost during XI plan

Year	Task	Expenditure (Rs. in crores)
2007 - 2009	Creation of the INO-centre / Surface facilities	10.00
	complete site investigation / Designs	10.00
	Detector R&D : Structure / Magnet / Electronics / RPC / Completed Designs	20.00
	Tunnel and Cavern Excavation	35.00
2009 - 2012	Surface Labs & Facilities / INO centre augmentation	25.00
	Tendering and procuring Iron for Module-I (16 kton)	100.00
	RPC / Electronics / DAQ manufacture	55.00
	Laboratory Outfitting	20.00
2007 - 2012	Project Staff	15.00
	Contingencies including national and international travels etc.	30.00
	Total	320.00

Outlay of funds during first two years of XII Plan

Year	Task	Expenditure (Rs. in crores)
2010 - 2013	Tendering and procurement of Iron for Modules II & III (16 x 2 = 32 kton)	200.00
	Construction of modules	30.00
	Electronics / RPC / DAQ for modules II & III	100.00
	Contingency including national and international travel etc.	20.00
	Total	350.00

Manpower requirements for INO

One of the major goals of the INO project, is to develop trained manpower for carrying out challenging experimental projects in the area of High Energy and Nuclear Physics. The major development work for INO project will take place at the INO Centre to be created. It is expected that over the next five years INO centre will need a total of fifty physicists, thirty five scientific and technical personnel and about fifteen administrative personnel located at the INO Centre. These people will be working full time on the INO project.

In addition, to involve various institutes and universities in the INO project, it will be necessary to have INO positions in the participating institutes and universities. These physicists should have joint appointments at the INO Centre and at one of the participating institutes with his/her duties at both places clearly spelt out. IUAC, Delhi has recently made similar joint appointment at several universities.

Work Methodologies

It will be a national project with participation by a large community of scientists from different institutes and universities. The project may be executed in three phases once the approval is given in principle:

Phase 1 of approximately 12-18 months duration: Site investigation to draw up detailed design reports for tunnel and cavern complex. This could be faster if all the permissions are easily available and work entrusted to reputed engineering groups. During this period, detailed design reports on the detector structure, RPCs, pick-up electrodes, front-end electronics, power supply systems will be ready.

Phase 2 will include tunnel and cavern excavation and related support measures. The estimated time for PUSHEP is 22 months. The basic design of RPC as already available will be frozen by this time. Tenders for the supply of iron, magnet coils, cables, etc., will be issued. The procedure for making detector elements, electronics, gas mixing units will be in place and the production process may begin.

Phase 3 of approximately 12-18 months duration: Laboratory outfitting, transport of detector components and material and assembly begins. The first module will be completed early and data taking will begin. By the end of XIth plan preparation will be made for additional modules.

Current status of INO

The INO group, which has members from sixteen institutions and universities, is now engaged in the following activities.

1. Detector R & D work: The glass RPC detector has been shown to operate with the desired efficiency and the required spatial and time resolution. However, the observed lifespan is smaller than expected and efforts are on to remedy this situation. Larger modules and the related data acquisition systems are being tested. These will be needed for the prototype 1 m^3 calorimeter (12 layers of $1 \text{ m} \times 1 \text{ m}$ plates).
2. Site survey: Two sites have been identified as most suitable after detailed surveys. A site selection committee has gone through the available data on both these sites and recommended that the site situated in Niligiri mountains of South India near PUSHEP as the preferred site for locating INO. Further studies to assess stress conditions for the access tunnel, laboratory cavern design and construction will be initiated soon. (See figures below)
3. Numerical simulations: Simulations for both atmospheric neutrinos and long base line neutrinos are reasonably well understood and under control. The detector simulation, track recognition and event reconstruction programs are getting ready or at testing stage.
4. Documentation: This involves preparing reports on the status of INO.
5. Collaboration Meetings: This includes organising and collaboration meetings of subgroups engaged in the activities listed above. The INO members also meet frequently at all possible venues of conferences in order to review the progress made by individuals and sub-groups. Several members of INO collaboration have already presented INO related work at both national and international meetings.
6. Human Resource Development: Lectures on neutrinos and INO have been given to students in Colleges and Universities to attract them to INO. The first INO training school for about 15 young members of INO was conducted in April-May 2005. The interim report of INO was submitted to DAE, DST and UGC, of the Government of India, at a meeting in Tata Institute of Fundamental Research, on May 1, 2005. A report on INO was presented at a meeting of the Scientific Advisory Committee to the Prime Minister on August 28, 2005 at Indore.

Advanced Radioactive Ion Beam Facility

Motivation

Exciting opportunities for research in nuclear physics, nuclear astrophysics and for understanding of fundamental symmetries in nature will open up with Radioactive Ion Beams (RIB). Using RIB as a tool one can explore hitherto unreachable regions of the nuclear landscape via systematic experimental studies of Exotic Nuclei. This will be possible by exploiting the iso-spin degree of freedom of radioactive beams. We may also expect to discover new phenomena and to develop a better predictability in the theoretical description of the structure and interactions of nuclei. The fact that almost all major accelerator laboratories in the world are constructing RIB facilities points towards the strong scientific motivation in the research and applications with these beams.

Study of explosive stellar events, nucleo-synthesis, structure of exotic nuclei, limits of particle stability, synthesis and study of Super Heavy Elements (SHE), material science with rare isotope beams are few of the research areas that will be investigated.

Guidelines

The configuration and scheme of the facility for producing Radioactive Ion Beams has been suggested based on the following considerations: It should:

- Be a nation-wide collaborative venture
- Not be limited in scope but at the same time be realistic
- Be intellectually rewarding to attract good brains
- Preferably have some unique feature
- Contribute to technological advancement & human resource development

Scheme of the Advanced Radioactive Ion Beam Facility

We propose to produce both neutron-rich (using electron-LINAC) and proton-rich (using proton/alpha particle cyclotron) Radioactive Ion Beams (RIB). Radioactive atoms will be produced in thick target, ionized, mass-separated and then accelerated in linear accelerators up to the energy of about 6 MeV/u. Further acceleration to about 100 MeV/u (e.g. ^{40}Ca ~100 MeV/u*; ^{86}Kr ~70 MeV/u*; ^{150}Nd ~35 MeV/u*), will be done in a separated sector ring cyclotron of K~600, (*approximate values; exact energy would depend on the design details)

Unique features of the Advanced RIB Facility scheme

- Two primary accelerators \Rightarrow low cost option for producing both neutron-rich and proton-rich RIB
- Storage ring for study of charge distribution of n-rich nuclei.
- Acceleration of both stable and radioactive ions to about 100 MeV/u: very short-lived exotic nuclei can be produced using Projectile Fragmentation (PF) reaction and studied after separation in a PF separator
- A combined ISOL & PFS type RIB facility
- Facility gives unique opportunity to produce drip-line nuclei through fragmentation of pure secondary RI Beams of intensity $\sim 10^8$ particles per second

XI plan activity at VECC for Advanced Radioactive Ion Beam Facility

- In phase-1 of the advanced RIB facility project (during 2007 – 2012) it is proposed to produce neutron-rich RIB using electron-LINAC at VECC.
- In the existing facility developed in X Plan, we are already accelerating stable beams to 30 keV/u at the end of RFQ. We will reach 2 MeV/u in the XI Plan period. Acceleration of stable as well as both neutron & proton-rich RIB to energy of 2 MeV/u in this facility will enable a wide range of experiments in Nuclear Astrophysics, Material science and Atomic Physics.
- This, combined with option of acceleration of RIB in the upcoming Super Conducting Cyclotron (SCC) will allow, in about 3 years time, coulomb barrier physics with n-rich RIB.
- The RIB facility up to 2 MeV/u & the electron-LINAC may be shifted to the New Campus at an appropriate time after the building & infrastructure are ready at the new site.

Scientific Opportunities

- Physics can be done at each stage of development in particular, at VEC Salt Lake campus, the XI plan activities include
- Spectroscopy of r-process nuclei & mass measurements in Ion-trap Nucleo-synthesis & Nuclear Structure studies with RIB accelerated in Super Conducting Cyclotron (SCC)
- Material Science, Atomic Physics
- Synthesis & study of Super Heavy Element (SHE)

- Nuclear charge distribution of neutron-rich nuclei
- Precision mass measurements in Storage Rings
- Reaching Drip-lines, study of Halo nuclei, spectroscopy of very short-lived nuclei using projectile fragmentation of stable & radioactive ion beams

Benefits to society

- The country will acquire the capability to design & build a wide variety of state of the art accelerators
- RIB has numerous applications in medicine & biology and will be a major tool for research in these fields RIB will open up enormous opportunity for frontline material science & nano-science research Many technological spin-offs in terms of RF & microwave technology, indigenous construction of high vacuum systems, advanced mechanical engineering system development through virtual reality, etc – just to mention a few, are envisaged

Inter-agency collaboration for project implementation

- Both for construction & utilization of the facility collaboration with International & National Institutes, Universities, IITs etc. is a must
- The design of accelerators for this facility would need knowledge and expertise that is not totally available in the country. So, international collaboration will be necessary. In this context it may be mentioned that VECC has already active collaborations with RIKEN (Japan), GSI (Germany) & TRIUMF (Canada), where very involved RIB facilities are under construction. For experimental facilities the existing collaboration with GANIL (France) needs to be strengthened
- Collaboration with BARC, TIFR, RRCAT, IUAC & SINP, (where high-level of expertise exists for accelerator development, nuclear physics and material science research) should be pursued preferably on a “sharing of responsibility” basis. The community in India should work together to make this facility a truly international one where scientists from different corners of the country & different parts of the world would converge to do experiments

Infrastructure Requirement

- Land : minimum 12 Acres are required to house the facility
- Electrical power : About 8 MW
- Low Conductivity Water: About 10 thousand lit. per. min.

- Building: Detailed plan of the building needs to be made. For the primary accelerators & the ring cyclotron adequate shielding is necessary. In our cost projection we have tentatively kept an amount of Rs. 110 Crore for building & infrastructure. This can at best be considered as a very rough estimate.

Project Implementation Strategy

- Outsourcing will be an important component of the project implementation and daily operation and maintenance of the facility
- Design of advanced systems will be developed by engaging experts (both national and international) as consultants
- Accelerator construction and engineering services development will be done via participation of industries, both public and private sector. VECC has already engaged SAMEER, Mumbai & CMERI, Durgapur for development of RF systems & fabrication of mechanical engineering components respectively for the ongoing RIB project. Both the collaborations have been extremely successful. More such collaborations need to be worked out
- Project design and implementation should be reviewed periodically by an International Committee of Experts

Cost projection for the Advanced RIB Facility

Major activity	Expenditure (Crore)
Acceleration of neutron-rich RIB (e– Linac) and proton-rich RIB (VEC Cyclotron) at VEC Salt Lake campus	140.00
Shifting of facility to new campus & Acceleration of RIP from 2 to 6 MeV/u	60.00
Microtron & Electron Storage Ring (ESR) & Rare Isotope Storage Ring (RIR)	60.00
100 μ A, 30/60 MeV p/ α Cyclotron	45.00
Experimental facilities for nuclear & astrophysics, mat. science	75.00
Building, infrastructure, electrical power	110.00
Ring Cyclotron & PF Separator	80.00
Total (Rs. Crore)	570.00

Of the total project, only the initial part of generating a neutron rich RIB using the electron LINAC at VECC will be taken up in the XI Plan at a cost of Rs.75 Crores. Necessary allocations have been included in the XI Plan proposals of the DAE R&D Sector (Unit :VECC)

The existing capability in the country & scope for collaborative development of the facility is listed below:

- VECC \Rightarrow Production & acceleration of RIB, successful R&D
 \Rightarrow K=130 Cyclotron, SC Cyclotron
- TIFR, BARC, IUAC \Rightarrow SC LINAC technology
- RRCAT \Rightarrow Storage Rings
- VECC, BARC, TIFR, IUAC, SINP, Universities, others
 \Rightarrow Experimental facilities, detector systems, Material Science,
Biological Sciences, Inter-disciplinary research

International Collaboration on FAIR at GSI, Germany

A large high energy accelerator facility is being built at GSI, Darmstadt, Germany. This will be built in a phased manner and will be completed around 2015. Low energy experiments will start around 2011. FAIR is an international accelerator facility of the next generation. This is a unique facility where researches will be performed in several major areas e.g. nuclear physics, high energy physics, plasma physics, atomic physics simultaneously. This facility will be in the centre stage globally for future researches on nuclear, high energy heavy ion and other areas in next decades.

At its heart is a double ring facility with a circumference of 1200 metres. A system of cooler-storage rings for effective beam cooling at high energies and various experimental halls will be connected to the facility. The existing GSI accelerators serve as the injector for the new facility. The double-ring synchrotron will provide ion beams of unprecedented intensities as well as of considerably increased energy. Thereby intense beams of secondary beams - unstable nuclei or antiprotons - can be produced. The system of storage-cooler rings allows the quality of these secondary beams - their energy spread and emittance - to be drastically improved. Moreover, in connection with the double ring synchrotron, an efficient parallel operation of up to four scientific experiments can be realized at a time. The project is based on many technological innovations, the most important ones include: Highest Beam Intensities, Brilliant Beam Quality, High Beam Energies, Highest Beam Power and Parallel Operation

- FAIR will have very high intensity beams with the following specifications.

Primary beams:

$10^{12}/s$ $^{238}\text{U}^{28+}$ 1-2 AGeV

$4 \cdot 10^{13}/s$ Protons 90 GeV

$10^{10}/s$ U 35 AGeV (Ni 45 AGeV)

Secondary beams:

rare isotopes 1-2 AGeV

antiprotons up to 30 GeV

storage and cooler rings:

beams of rare isotopes,

e^- A Collider,

10^{11} stored and cooled antiprotons

(0.8 - 14.5 GeV)

The accelerator facility will be built, based on the latest technology on high intensive heavy ion beams, dynamical vacuum rapidly cycling superconducting magnets and high energy electron cooling

Possible experimental areas:

High-energy nucleus-nucleus collisions: compressed baryonic matter baryonic matter at highest densities (neutron stars), phase transitions and critical endpoint in-medium properties of hadrons

Rare isotope beams; nuclear structure and nuclear astrophysics nuclear structure far off stability and nucleo-synthesis in stars and supernovae

Short-pulse heavy ion beams: plasma physics matter at high pressure, densities, and temperature and fundamentals of nuclear fusion

Atomic physics and applied research on highly charged atoms, low energy antiprotons and radiobiology

Beams of antiprotons: hadron physics, quark-confinement potential, search for gluonic matter and hybrids and hypernuclei

Expected financial involvement in total project and our participation:

Cost of building the facility is about 1 Billion Euro with 25% contribution from International sources. We shall participate in building accelerator and detector components and will take part in experiments in areas of interests.

Previous discussion within Indian research community:

Several meetings have taken place between FAIR members from GSI and Indian nuclear, accelerator and High Energy Physics communities. Several areas have been identified where Indians have expertise and can make good contributions. Another large meeting organized by the DST took place at Mumbai on 7-8th April to discuss future of nuclear physics in India. Participation at FAIR was discussed in detail and was considered to be one of the important avenues for Indian nuclear and high energy physicists. A committee has been setup which is currently working on preparing Conceptual Design Reports (CDR) for different interest areas.

An MoU has been signed between VECC-SINP and FAIR-GSI for participation in building accelerator and detector components and participation in experiments. The details of the projects with Indian Involvement are:

- Development of gas detector for Compressed Baryonic Matter (CBM)
Simulation, design and fabrication of muon detection system at Compressed Baryonic Matter (CBM) experiment at FAIR. This experiment will

investigate the formation of high density nuclear matter likely to be produced at FAIR energy using heavy ion collisions. Studying the matter at high baryon density is important to understand phase-transition from hadronic to QGP phase, location of tri-critical point, understand the environment similar to the core of neutron star. The detector system will consist of up to 16 (sixteen) muon tracking stations placed inside several layers of absorber. The muon stations need to be fast and with high position resolution. A detailed R&D is needed to achieve the design goal. Possible options are GEM and MICROMEGAS based gaseous detector system with high granularity. Advanced electronics (ASIC) systems are to be developed for the data collection from this detector system.

➤ Development of Energy Buncher for FAIR

The objective is to build the end part – the Energy Buncher, of the low energy branch of the FAIR project, which will be dedicated to precision experiments with energy-bunched beams stopped in a gas cell. This branch will be complementary to the ISOL facilities since all elements and short-lived isotopes can be studied. The Energy Buncher, including a high-resolution dispersive magnetic separator stage along with a mono-energetic degrader, comes behind the achromatic pre and main separator of the low-energy branch. The setup will be used to drastically reduce the energy spread and range straggling of the secondary hot fragments separated in the pre and main separator stage. The setup includes a number of superconducting iron dominated (super-ferric) magnets of different types (4 dipoles, 5 quadrupoles and 2 sextupoles), mono-energetic degrader, beam diagnostics, detectors (experimental setup) and the accessories (vacuum system, control system, power supplies etc.).

➤ Design and fabrication of primary beam absorber for exotic nuclei separation:

In a low energy beam line at FAIR, primary beam particles and unwanted secondaries are to be stopped after the production target. The primary beam is high intensity U(238) and stopping of a high intensity beam needs very special design. Preliminary design suggests the use of graded graphite where design criteria are very stringent to avoid possible effects of any transient energy dump. The objective is to design and build this device named as primary beam absorber for exotic nuclei separation.

Participation in nuclear and hadron physics experiments:

It will be an opportunity for Indian nuclear physicists to study in detail nuclear structure and nuclear reaction physics using radioactive heavy ion beam. Suitable experiment(s) where major contributions will be made in terms of detector development and if necessary beam-line development in addition to contribution in data taking and physics studies are being explored. Preliminary discussions have been made with NUSTAR collaboration, (specific experimental groups: R³B, AGATA, RISING, CHARMS, DSPEC) which is a large collaboration of nuclear physicists from all over the world and also in PANDA experimental collaboration for hadron physics studies.

Outcome / Deliverables:

Development of gas detector for CBM:

- (a) Detailed simulated design which will give best Signal/Background ratio. This needs development of tracking and event reconstruction software using detector simulation package.
- (b) Prototype detector modules with two detector technologies (GEM and MICROMEGAS). Initially modules with 30cm x 30cm will be built and then actual size prototype will be developed.
- (c) Front End Electronics (FEE) for prototype system. New R&D needs to be performed to handle high rate.
- (d) Development of radiation-resistant ASIC for handling large data rate and fast data processing.
- (e) 16 muon stations with best available technology, it could be mixture of different technologies. This includes chambers, High Voltage system, Low Voltage systems.
- (f) Gas handling system as this will deal with a large system of gas detectors using different types of gases.
- (g) Front End Electronics: Developed ASIC will be integrated for all muon systems.
- (h) Data Acquisition system: This will be developed along with whole CBM experiment. This involves hardware component for handling trigger and other control signals and corresponding processor software.
- (i) Slow Control system: Development and deployment of controlling HV, LV, Gas parameters, temperature etc via slow control mode. Hardware components involve processors and individual control component. Software involves development of supervisory system, finite state machines.

- (j) Online and Analysis software: This has to be developed using Object Oriented Programming for online monitoring and analysis. Analysis involves track fitting and event reconstruction.

Development of Energy Buncher for FAIR:

The unique characteristic of the setup is its very large acceptance to handle the secondary beam with very large energy spread. Therefore all the superconducting magnets have unusually large aperture and very high field quality. For example dipoles have horizontal and vertical useful aperture of ± 300 mm and ± 100 mm respectively with a field quality of value $\pm 3.0 \times 10^{-4}$. The similar figures for quadrupole are ± 300 mm, ± 200 mm and $\pm 8.0 \times 10^{-4}$. This technology of such a large acceptance beam transport system will certainly be of immense use in the ADSS project where space charge effect of intense beam will require large acceptance magnets. In all future accelerator facilities the superconducting (sc) beam transport elements will replace the normal conducting one to minimize the power consumption. It is worth to mention here that VECC has already the credit of developing the largest SC accelerator magnet in the country. Another important technological challenge in this project is to develop non-interceptive special type of beam diagnostic system for hot fragments, which is also very relevant to intense proton beam in ADSS project.

Institutions in several countries of USA, Europe and Asia are part of the collaboration for this project. Some of these are: the universities of Heidelberg, Frankfurt, Kaiserslautern, Mannheim, Marburg in Germany apart from GSI. The universities of Krakow, Warsaw and Katowice in Poland and the Technical University of Prague. In the Czech republic etc. Apart from these, this project will need the collaboration of several Indian institutes as well. These includes the various DAE institutes like VEC, SINP, IOP, BARC, IUAC, TIFR and various universities and IITs of the country.

Total outlay needed as discussed in DST brainstorming meeting is around **300 crore** over two plan periods (XIth and XIIth). An initial allocation of Rs 45 crores has been made. Necessary allocations have been included in the XI Plan proposals of the DAE R&D Sector (Unit :VECC- XI Plan Rs. 35 Cr. + XII Plan Rs.10Cr)

Astronomy based Projects

Optical Telescope

The optical/near IR community - specifically members of IIA, ARIES, TIFR, IUCAA - have been engaged in discussions on a large telescope in the 8 to 10 metre range, at a Himalayan site. The estimated time for the project is 10 years, and the cost of the order of **600 crores**. Such a telescope would be comparable to the best available elsewhere and could explore the faintest and most distant objects in the optical and near- IR bands. Some members of the Indian community are already users of such telescopes elsewhere, but a national facility would serve and nurture a much larger community, especially if the universities are involved. Current XI plan projects like a 3m optical telescope (ARIES led) and 2m solar telescope (IIA led) could act to build up the core group which can plan and execute a major optical project. IUCAA has a key role since its 2m telescope already has a young core group and is the best platform to build a strong user community in the universities.

The Square Kilometer Array (SKA)

One of the proposals, from the NCRA-TIFR group, is to participate in the Square Kilometre Array, which will play the same role in the future of radio astronomy as the large international accelerators in particle physics. The project requires a scale which no single country can sustain, and should be located at the best site of which there are only a few in the world. The science itself is path-breaking, involving studies of the high red-shift universe, galaxies, pulsars and other objects with unprecedented resolution and sensitivity. SKA will address basic questions relating to cosmology, structure formation, star formation, compact objects like black holes and neutron stars, and magnetic fields. The SKA project has a major low frequency component and the GMRT is currently the best platform for exploring the issues relating to the ionosphere and wide field imaging, and radio frequency interference. This is one of the reasons why many groups from all around the world are not just using the GMRT but developing hardware and software for it in collaboration with NCRA-TIFR. NCRA-TIFR is already a signatory to the SKA MOU, a member of the international steering committee. Indian radio-astronomers have taken part in sub-committees relating to site selection, engineering, and science.

With this background, it is clear that there is a window of opportunity in the XI and XII Plan for India to be a very significant partner in an international mega project - the SKA - in an area where there is already significant achievement and

strength. Participation will imply major growth of the user community and building skills in areas like antennas/electro-magnetics, fast digital hardware, and advanced scientific software. The implied time scale is decadal (construction planned for 2012-2020), and investment if India becomes a full partner approximately 400 crores (estimated as a one-sixteenth share of a billion dollar plus project). It has already been made clear to the international partners that any Indian contribution has to be mainly in the form of contribution to the hardware / software, i.e an 'in-kind' contribution. Proposals for the GMRT upgrade are already part of the NCRA XI plan. However, serious participation by the Indian community in the build up to the SKA during the XI Plan period will need additional funding to the tune of approximately 20 crores. This includes contributions to the increasing international project office activity, interactions with technological partners in India, and prototype/ pilot activities, in antennas and software.

Space based Astronomy

In space based astronomy, ASTROSAT - with hard X-ray, soft X-ray, and UV capabilities - is in an advanced state and opportunities for smaller satellite based astronomy experiments have already been announced by ISRO. Some larger scale project being discussed in detail are a far IR space based observatory, and a 'supermonitor' with very wide X-ray wavelength coverage (originating from TIFR but with a wider base of participants) and an X-ray polarimeter (RRI). Given this wide range of possibilities, ISRO has taken the initiative to set up a centre for space instrumentation. This will enable groups with the science requirements to interact with experts in space technologies at the centre and define projects which are both scientifically fruitful and technically feasible/ optimal. The Chandrayan Mission is of course a space based mega-project but lunar science but is not included since this it now comes under direct in situ exploration rather than astronomy.

While the different parts of the astronomy community are investing time and effort in planning these ventures, there are three points which are critical to their success.

- a) These efforts should not be isolated, but part of a consensus evolved in the community through all groups coming together first with discussion papers and then a workshop, involving the funding agencies, from which a roadmap will emerge for the area on a decadal timescale. This is important because astronomy is already multi-wavelength and will become even more so in the future. While the facilities are distinct, the model should be one of a largely common user community.
- b) These efforts presuppose a wider user community, some of whom will also join in the projects. With a lead time of five years, and a concerted plan, cutting

across wavelengths and institutions, and involving the university community, this seems possible and indeed desirable. While a new monolithic structures are not needed, mechanisms for enhancing and formalising a more co-ordinated functioning of multiple institutions, such as those which have evolved in high energy physics, are highly desirable.

- c) All these projects involve significant technology development, and different models/ mechanisms are possible - working with the science agencies like ISRO and DAE, within the universities / IIT's, and interaction with industry. All these should be vigorously explored, and co-ordinated when there is commonality, as in areas like digital hardware and software. The skills developed in these areas have wider national significance.

Centre for Semiconductor Heterostructure Research

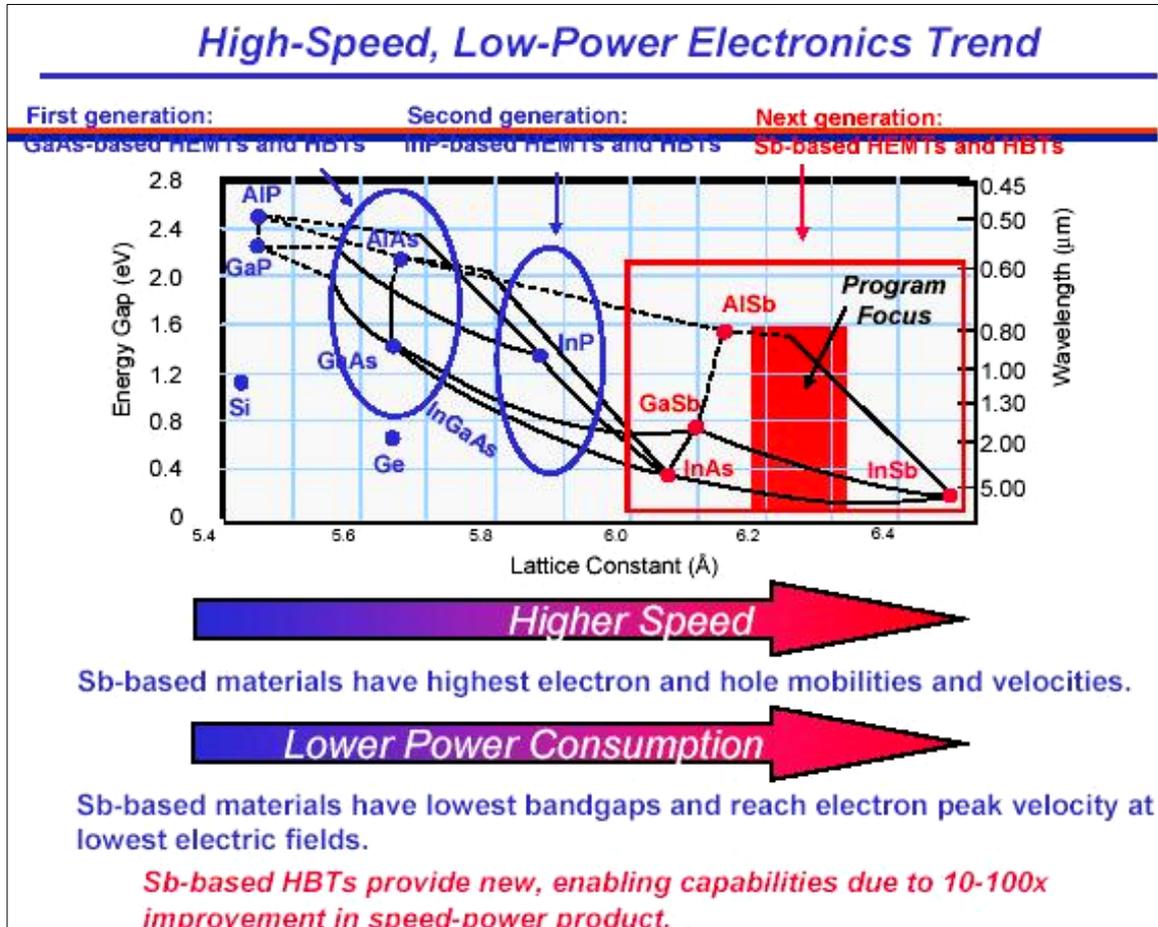
Introduction

The present revolution in communication, computing and entertainment has become possible due to tremendous development of faster and smaller semiconductor devices. The enabling technology has been the material synthesis, fabrication techniques and packaging. Very Large Scale Integrated circuits (VLSI) are the monopoly of Silicon. However, III-V Semiconductors (“III-Vs”) are indispensable for the realization of a wide range of applications. Optical communication systems require lasers as well as detectors based on III-Vs. Likewise, this class of materials is dominant in key high frequency electronics components for wireless communication such as mobile telephone systems as well as control systems used in defence and space. Advanced solar cells for use in space as well as terrestrial applications have been made with this group of materials. Compound semiconductor devices dominate the 10-100 GHz range for high power and high frequency requirements with a variety of structures such as HEMT, PHEMT, and MHEMT. Great diversity in the nature and performance of these devices due to selection of materials, thickness and doping in the stack with band gap engineering providing an additional handle to tailor the material to suit the requirement.

During the last two decades, the nitride semiconductors have emerged strongly for high frequency as well as light emission applications. Indeed it is possible to replace household lighting systems with these light emitting diodes (LED) to conserve the power and achieve long life usage. Further, dilute nitrides have emerged from conventional III-V semiconductors such as GaAs or InP by the insertion of nitrogen into the group V sub-lattice, which has profound influence on the electronic properties of these materials and allows a widely extended band structure engineering. This is expected to lead to novel devices, e.g. for optical data transmission, solar cells, biophotonics or gas sensing, some of which are already making their way into the market. (See following Figure)

Electronics based on the existing semiconductor device technologies of Si and GaAs cannot tolerate greatly elevated temperatures or chemically hostile environments. The wide gap semiconductors SiC and GaN and perhaps sometime in the future diamond with their excellent thermal conductivities, large breakdown fields

and resistance to chemical attacks will be the material of choice for these applications. In the optical device arena ever increasing demand for higher density optical disk storage and full colour display are the drivers for wide band gap emitters.



Potential and existing applications of Gallium Nitride devices.

1. Blue, green and white light and UV emitters for (a) traffic lights, (b) displays, (c) Solid state household lighting.
2. water, food, air sterilization and detection of biological agents.
3. Visible-blind and solar blind photo-detectors
4. High power microwave devices
5. High power microwave switches
6. Wireless communications
7. High temperature electronics
8. Terahertz electronics

Photovoltaic solar cells, which directly convert sunlight into electricity, are made of semiconducting materials. Heterostructure III-V solar cells fabricated on germanium substrates are extensively used by our space organization as they deliver 20% efficiency. More complex multi-junction cells deliver 27% efficiency and special structures have been predicted to deliver 40% efficiency on terrestrial applications. These cells also perform better at elevated temperatures compared to silicon solar cells and hence can be used with concentrators. Thus, photovoltaic application of heterostructures is extremely important for our space as well as terrestrial programmes.

In addition to these proven applications being carried out around the globe with III-V materials, the possibilities of creating low dimensional quantum structures including nano-dots are unending. Due to the lack of necessary sophisticated facilities available in India, we are missing out on all the actions. This proposal is the first step in correcting the situation.

National status

From the above discussion it becomes clear that hetero-structure research holds the key to many areas of applications in future. The national effort in heterostructure research has been pathetically low restricted to only three or four groups. There are only three Molecular Beam epitaxy systems and three MOCVD systems functioning in the whole country. An MMIC fabrication facility has been set up by DRDO at Hyderabad and ISRO is planning to set up a solar cell fabrication facility. On the whole research in semiconducting materials and heterojunctions is minimal and needs a boost particularly in view of its importance in the strategic sectors like space and defence. A very large number of researchers in India do not have access to advanced structures and materials.

Proposal

In view of the importance of this area it is proposed to set up a National facility to carry out research in the area of semiconductor heterostructures and related devices and materials. The Centre for Semiconductor Heterostructure Research (CSHR) will provide facilities initially for carrying out advanced research in the areas mentioned below which are important for the national energy and security needs:

Semiconductor research is capital intensive and requires sustained support both in terms of finances and skilled manpower. CSHR can be based on the model of Nuclear Science Centre, New Delhi where researchers from various universities and institutions in the country are encouraged to actively participate and contribute. The proposed centre will address all aspects from material growth and

characterization to theory of material properties, device modeling and fabrication as well as device characterization in a comprehensive way. This will lead to a knowledge base that can be exploited for use in innovative optoelectronic and electronic devices.

- Establishing critical mass of researchers in disciplines that constitute to the technical work packages
- Integrating of knowledge, equipment, man power and technical resources
- Structuring Indian research activities for enhanced efficiency and more economical use of resources.
- Defining key research challenges and initiating joint research
- Establishing strong links with universities to achieve leadership in the innovative technologies based on heterostructure research.
- Initiate, develop, coordinate and promote activities of spreading of excellence.

Thus the Centre will serve important national needs by developing required technologies as well as generating trained and skilled manpower.

Facilities

Location

The CSHR should be an independent research centre but located close to a premium research institute such as a national research laboratory or an IIT. Since expensive and sophisticated facilities will be housed which will be mostly imported, location should be in a metropolitan city with access to an international airport for ease of operation and maintenance. A committee should be formed to finalize this issue.

Space and Infrastructure

CSHR should have approximately 10 acres of land space for setting up reasonable facilities and future expansion.

The building will have at least 2000 m² of clean rooms. Some of the rooms will have to be class 10 or better. Most of the space will have to be at least class 10000.

HVAC, Utilities like high purity gas, liquid nitrogen, deionized water plant, UPS and DG back up for electricity will be required.

The Centre should have adequate building for staff and also a guest house for the visiting scientists and students.

Manpower

We estimate that the Centre should eventually have approximately 50 full time scientists and 50 technical staff. These can be supported by about 15 administrative staff. There should be provision for considerable number of visiting or temporary scientists. All other services such as security and maintenance should be outsourced to contractors.

Equipments

Initially the CSHR will concentrate on the fields mentioned above. It will require equipment for materials growth, device processing, and characterization at every level.

Materials Growth

Molecular Beam Epitaxy (at least three systems)

GaN

III-As, Sb

Metal Organic Vapor phase deposition (MOCVD) (at least two systems)

GaN

III-As, P

Hydride Vapour Phase Epitaxy (HVPE)

GaN

Liquid Phase Epitaxy

II-VI compounds

Materials Characterisation

High Resolution X - Ray Diffraction(HRHRD)

Photoluminescence

Fourier Transform Infrared spectrometer

Raman spectrometer

Transmission Electron microscope

Secondary Electron Microscope with EDAX, EBIC, Cathodoluminescence
X ray Photo electron spectroscopy
Atomic Force Microscope, Optical Microscope
Low temperature, High Magnetic field transport measurements

Device Processing

Lithography - Optical
Metallization - Thermal, E beam, Sputtering
Dielectric deposition - Plasma Enhanced Chemical Vapour Deposition
Temperature controlled Furnaces for oxide growth, annealing etc
Etching - Wet chemical and Dry etching
Processing - Ashing
Bonding - Die and wire

Device characterization and Process simulation

Electrical - Current Voltage, Capacitance voltage, microwave measurement systems, solar simulator,
Workstations, simulation packages

Funds

It is estimated that Rs.300 crore spread over a period of five years starting year 2008 in the XI plan. This would exclude the land cost.

LIST OF ABBREVIATIONS

ACFA	Asian Committee for Future Accelerators
ADSS	Accelerator Driven Subcritical System
AEC	Atomic Energy Commission
AGATA	Advanced Gamma Tracking Array
ALH	Advanced Light Helicopter
ARIES	Aryabhata Institute of Observational Sciences
ASIC	Application Specific Integrated Circuit
ASTROSAT	India's Multi-Wavelength Astronomy Satellite
BRNS	Board of Research in Nuclear Sciences
CBM	Compressed Baryonic Matter
CERN	European Organisation for Nuclear Research
CHARMS	Collaboration for High Accuracy experiments on nuclear Reaction Mechanisms with magnetic Spectrometers
CMERI	Central Mechanical Engineering Research Institute, Durgapur
CSHR	Centre for Semiconductor Hetero-structure Research
DAE	Department of Atomic Energy
DBT	Department of Biotechnology
DEMO	Demonstration Reactor (Fusion)
DESPEC	DEcay SPECtroscopy experiments (at FAIR)
DESY	German (Deutsches) Electron Synchrotron
DHEP	Department of High Energy Physics
DRDO	Defence Research and Development Organisation
DST	Department of Science and Technology
FAIR	Facility for Antiproton and Ion Research
FALC	Funding Agencies for Large Collider
GDE	Global Design Effort
GEM	Gas Electron Multiplier
GMRT	Giant Metre Wave Radio Telescope
GSI	Society for Research in Heavy Ion Science, Germany
HEMT	High Electron Mobility Transistor
HIPA	High Intensity Proton Accelerator
ICAL	Iron Calorimeter
IIA	Indian Institute of Astrophysicists
IISc	Indian Institute of Science
ILC	International Linear Collider
INO	India-based Neutrino Observatory
IOP	Institute of Physics
IPR	Institute of Plasma Research
ISOL	Isotope Separator On-Line

ISRO	Indian Space Research Organisation
ITER	International Thermonuclear Experimental Reactor
IUAC	Inter-University Accelerator Centre
IUCAA	Inter-University Centre for Astronomy and Astrophysics
KGF	Kolar Gold Fields
LCA	Light Combat Aircraft
LHC	Large Hadron Collider
LINAC	Linear Accelerator
MHEMT	Metamorphic High Electron Mobility Transistor
MICROMEGAS	Micro Mesh Gaseous Detector
MMIC	Microwave Monolithic Integrated Circuits
MOCVD	Metal Organic Chemical Vapour Deposition
NCRA	National Centre for Radio Astronomy
NUSTAR	Nuclear Structure Astrophysics and Reactions
PANDA	anti-Proton ANnihilation at Darmstadt
PHEMT	Pseudomorphic High Electron Mobility Transistor
PFS	Projectile Fragments
PUSHEP	Pykara Ultimate Stage Hydro Electric Project
R ³ B	Reactions with Radioactive Relativistic Beams
RFQ	Radio Frequency Quadruple
RIB	Radioactive Ion Beam
RIKEN	'Rikagaku Kenkyusho' Japanese Organization to Conduct Research in the Physical and Chemical Sciences
RISING	Rare Isotope Structure Investigations with nuclear Gamma rays
RPC	Resistive Plate Chamber
RRCAT	Raja Ramanna Centre for Advanced Technology
RRI	Raman Research Institute
SAMEER	Society for Applied Microwave Electronic Engineering and Research
SCC	Super-Conducting Cyclotron
SINP	Saha Institute of Nuclear Physics
SKA	Square Kilometre Array
SLAC	Stanford Linear Accelerator Centre
SPG	Strategic Planning Group
SRF	Superconducting Radio Frequency
TIFR	Tata Institute of Fundamental Research
TRIUMF	Tri University Meson Facility, Canada
UGC	University Grants Commission
VECC	Variable Energy Cyclotron Centre
WHEPP	Workshop on High Energy Physics Phenomenology
WWS	Worldwide Study of the Physics and Detectors for Future e+e- Linear Colliders
XFEL	X-ray Free Electron Laser