19-4-2012

MEMORANDUM OF UNDERSTANDING

BETWEEN

HOMI BHABHA NATIONAL INSTITUTE

AND

INDIAN INSTITUTE OF SCIENCE, BANGALORE

1. Preamble

The Indian Institute of Science, Bangalore (hereafter referred to as IISc) is a premier institution devoted to the research, teaching and application of science and engineering and is now in the process of setting up a new campus at Chitradurga in North Karnataka. The Homi Bhabha National Institute (hereafter referred to as HBNI) is a newly established institute under the aegis of the Department of Atomic Energy (hereafter referred to as DAE), Government of India, to bring together academic programmes of several institutions of the DAE under a single umbrella. For the purpose of academic programmes, the following units of DAE are the Constituent Institutions (CIs) of HBNI:

1. Bhabha Atomic Research Centre (BARC), Mumbai
2. Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam
3. Raja Ramanna Centre for Advanced Technology (RRCAT), Indore
4. Variable Energy Cyclotron Centre (VECC), Kolkata
5. Saha Institute of Nuclear Physics (SINP), Kolkata
6. Institute of Plasma Research (IPR), Gandhinagar
7. Institute of Physics (IOP), Bhubaneswar
8. Harish Chandra Research Institute (HRI), Allahabad
9. Tata Memorial Centre (TMC), Mumbai
10. Institute of Mathematical Science (IMSc), Chennai

BARC is also setting up a new campus at Chitradurga, near the new campus of IISc.

RECALLING that the BARC Training School started the education programme of its first batch at IISc;

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ALSO RECALLING that several scientists of CIs of HBNI have benefited from the external registration programme of IISc;

RECOGNISING the long-standing collaboration and cooperation between IISc and the CIs of HBNI;

NOTING the plans of DAE and IISc to establish new campuses at Chitradurga in close proximity to each other;

REALISING that while continuing the existing programmes as of present, there is ample scope of further expansion of the existing collaboration and cooperation, IISc and HBNI, collectively referred to as "Partner Institutes".

HEREBY agree to create a long-term institutional partnership in education and research, including undertaking of collaborative research in areas of mutual interest supported by funding through DAE, according to the broad framework set forth in this Memorandum of Understanding (MoU).

2. Objective

To create a long-term institutional partnership in education and enhance collaborative research in the areas of mutual interest, both in extent and scope by using the medium of faculty and research students enrolled in the partner institutes.

3. Modalities of Cooperation

3.1 Researchers from both the Institutes will jointly formulate projects in areas of interest and for the first phase, the following areas have been identified:

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(i) Thermal Loops and Associated Science
(ii) High Frequency, High Voltage and High Power Technology
(iii) Materials for Future Fission and Fusion Reactors

This list will be expanded as the co-operation proceeds. A brief outline of these three projects is given in Annexure 1. For every joint project formulated, a detailed project report will be prepared and duly signed by Principal Investigators (PIs) from the partner Institutes after necessary internal approvals. PIs will submit the Project report to the Dean, HBNI who, after evaluation of the project including its expected outcome by the concerned specialist group, will recommend it for funding to Joint Secretary (R&D), DAE. These projects will be processed for approval by DAE as independent projects. On approval of the project for funding by DAE, addenda to this MoU will be signed by the signatories to this MoU with the project report forming an annex to the addenda.

3.2 A student registered under a supervisor for a Master's or Doctoral programme in one Partner Institute (hereinafter referred to as Parent Institute) may have a co-supervisor from the other Partner Institute, as per the provisions of the academic rules and procedures of the Partner Institute. The Partner Institute may consider enacting specific rules to facilitate this process.

3.3 A Master's or Doctoral student in one Partner Institute may carry a part of the course work in the other Partner Institute. The Partner Institute offering the course will issue a transcript of the grade obtained in the course attended. This may be used for credit transfer subject to the rules of such transfer at each participating institute.

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3.4 The Parent Institute shall be responsible for paying to the Partner Institute the tuition fee, if any, for participation of its students in the course work conducted at the Partner Institute.

3.5 The exchange of faculty for lectures and research for short periods shall be encouraged by both Partner Institutes.

3.6 A mechanism shall be formulated to identify research areas of mutual interest and for possible funding for the same from BRNS and/or third-party sources.

3.7 The issues related to Intellectual Property Rights (IPRS) with regard to the outcomes of the collaborative research and the outcomes of project/thesis work carried out under the joint supervision of the faculty from the Partner Institutes shall be governed by the provisions of law for the time being in force.

4 Implementation

4.1 This MoU becomes effective from the later of the dates on which it is signed by the Partner Institutes and will be valid for an initial period of ten years. The total funding for the project and scope as identified under the first phase is expected to be within 100 crores and the total funding for the collaboration will be limited to Rs 150 crores. The agreement may be extended by mutual consent. Any commitments made under this MoU before its lapse will be fulfilled.

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4.2 For implementation of this MoU, the following will be the contact persons:

- From HBNI – Dean, HBNI
- From IISc – Divisional Chairman, Division of Mechanical Sciences

Signed on 19th day of April 2012

For and on behalf of
Homi Bhabha National Institute

Director

Ravinder Puri
Dean

For and on behalf of
Indian Institute of Science

P. Balaram
Director

Registrar

Annexure 1a

Thermal Loops and Associated Studies

In this area, the following facilities and associated research are planned:

1. Thermal Test Loop
2. Laboratory Scale R&D

1. Thermal Test Loop:

The heart of the thermal hydraulics loop will be the energy generation system. The energy generated will be used to heat a fluid in the primary loop (molten salt etc). The primary loop, in turn, will be transferring heat to a secondary loop (e.g. high pressure CO_2) which will be used for power generation through a turbo-expander. The scale of the test loop will be about 50-100 kWe (secondary loop power output).

Some features of the facility and broad issues to be studied

The proposed facility will form a unique integral test facility for nuclear power plants. It will be designed to simulate the thermal-hydraulic phenomena that may occur during the normal operation of such plants and also for new and innovative power generation systems with various passive safety systems. It will simulate the reactor heat generation, safety systems and control systems. It will also be equipped with a state-of-the-art control room and several advanced instruments. The following are some of the important issues planned to be studied:

Primary loop:

For the primary loop, the first choice to be made is that of the simulated heat source. Normally, electrical resistance elements are used. We would like to focus on molten salt as a primary coolant. In this respect, molten fluoride salt coolant has been planned to be studied, in line with the Innovative High Temperature Reactor (IHTR) being designed in India. One of the potential molten salts which can be considered for setting up of the loop is FLiNaK (mixture of fluoride of Li, Na and K). Issues to be considered in this study include material and design related matters for piping, pumping device and heat exchanger between primary and secondary loops.

Secondary loop:

Closed Cycle high pressure CO_2 Brayton cycle will be considered for the secondary loop. This cycle can operate at temperatures in the range 500-700°C. Very high cycle efficiencies (>50%) are achievable with these cycles. Since fully supercritical CO_2 Brayton cycle system (operating pressures between 70 bars and 170 bars) needs significant R&D work on the component level as well as on the system level, we would like to start with a subcritical (or trans-critical) cycle operating in the range of 20-80 bars (approximately), which can also yield significantly high cycle efficiency compared to air Brayton cycles in the same pressure and temperature ranges. Development of appropriate expansion device (turbo-expander), compressor and heat exchanger will be important parts of research initiative.

2. Laboratory scale R&D

Development of computational tools and fundamental experiments:

Research in computational tools include advanced numerical methods, new two-phase flow models, constitutive models, and multiphase computational fluid dynamics (CFD) codes. Through computational studies and fundamental experiments, studies of heat transfer, phase change, coolant dynamics, molten salt flow, and various phenomena related to thermal loop and reactor safety can be studied.

Fundamental studies with molten salts: In addition to the test loop, we propose to have a R&D laboratory to carry out studies on a smaller scale. In this respect, molten fluoride salt coolant has been planned to be studied. One of the potential molten salts identified is FLiNaK (mixture of fluoride of Li, Na and K). Under the purview of DAE-IISc collaboration, the following studies are planned to be taken up at the laboratory scale:

1) Heat transfer and pressure drop studies are required to be carried out for various geometries like circular tube, tube bundles, pebbles bed, etc. As the operating temperature of the fluid is high, the effect of thermal radiation and natural convection shall also be examined as the fluid is transparent.

2) Development and testing of high temperature instruments capable of reliable service for prolonged period in heat transfer systems for measurement of various parameters (flow, pressure, pressure drop, level, oxygen content, electrical conductivity, etc).

3) Development and testing of high temperature components like- compact heat exchanger, CO_2-molten salt heat exchanger with conversion of water into steam pump, valves, etc. Laboratory scale studies will be done for components and system functionality in the salt environments, life cycle tests, and reliability tests.

4) Studies on corrosion behaviour of potential structural materials under intimate contact with molten salt mixtures.

5) Study of super-critical CO_2 power cycle with high temperature coolant from the primary loop. Thermodynamic studies and optimization through modelling with respect to the higher efficiency power cycles will be carried out.

Annexure 1b

Programme on Materials

Homi Bhabha Centre for Energy Research under the auspices of Indian Institute of Science will undertake long term programme of research addressing issues on structural materials for future generation energy system operating under nuclear fission and fusion environment with emphasis on development as well as issues of reliability and safety. The programme will be cantered primarily on two themes -- one is concerned with the design, development, performance evaluation, validation and understanding mechanisms of degradation with aging for newer materials of future generation power reactors to withstand higher temperature and high radiation flux for longer durations. The other theme will be concerned with the theoretical modelling and experimental evaluation of the materials behaviour exposed simultaneously to higher temperatures, radiation flux and state of stress.

The Centre would initiate basic and applied work, under the first theme, on developing two classes of materials. One of the classes would be based on bulk carbon, SiC and their composites which are suitable for extreme temperature environment but lack toughness. The other class of materials would be newer alloy systems which have the potential for structural applications under high temperatures and radiation environment. Refractory metal based alloys and nano dispersed steels and other alloys are the example of the other class of materials. Understanding the strengthening and processing mechanisms and long terms stability under extreme conditions would be the major effort. It would also be addressing the issues related to qualification for use in nuclear environment.

The other major effort would be studying the long term stability of materials under the non equilibrium conditions of high radiation flux. This requires basic understanding of defect generation and their interaction, diffusion, phase stability and transformation. A large programme covering these aspects will embrace both careful experiments and a state of art computational materials science approach. This knowledge is crucial not only for assessing life of materials and components in power plant but also for designing future power plants. Besides utilizing normal techniques, this would require development of small scale testing system and protocols because the experimental coupons that will be available may often be limited in dimension.

A large infrastructure and good experienced faculty already exists at the Indian Institute of Science for materials characterization and will be available for the programme. However, few augmentations are needed. Since interaction of materials with radiation and resulting effects of defect creation and chemical segregation occur at atomic level, it is proposed to establish a National Atom Probe facility under the centre which can explore chemistry and structure at atomic level. Such a facility is limited in the country and a need is felt by large number of scientists. It is also proposed to set up a Gleeble

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facility where simultaneous effect of temperature and stresses can be studied. Such a facility is also helpful in developing process flow sheets for newer alloy systems.

Although during the initial stages the work is planned to develop computational materials science for studying the effect of irradiation and carry out few irradiation tests on chosen alloy and characterize these by post irradiation examination. It is planned to carry out realistic experiments in due course of time by setting up an in situ experimental facility with dual beam accelerator (10-13 kV transition metal beam line and 3 kV He beam line) which can yield high dpa and hence suitable for accelerated radiation damage experiments. The details of these would be worked out in due course and financial estimates would be submitted.

Annexure 1c

High Frequency, High Voltage and High Power Technologies

In this area, we wish to take up research on the following topics:

1. Computational and Experimental Studies on Electromagnetic Interaction Problems.
2. RF CMOS integrated circuits
3. Sources for Terahertz radiation

1. Computational and Experimental Studies on Electromagnetic Interaction Problems

It is envisaged to consolidate the efforts of researchers from IISc and BARC towards an integrated software platform that can be used for wave-particle, beam-wave and wave-plasma interaction. Such multi-domain problems involving partial differential equations are addressed in a different scale and for a different set of problems under an existing activity in IISc. A team of researchers will be set up to develop this platform.

Under this activity, a range of problems pertinent to BARC will be addressed using approaches ranging from empirical methods to and numerical techniques such as finite element method and finite difference time domain methods. Some of the problems that may be addressed include coupled problems involving Maxwell equations for handling the liquid metals and design of pumps etc for reactors. Charged particle dynamics may be analyzed in time domain along with suitable particle in cell simulations. Design approaches for RF structures, closing and opening switches, various measurement probes, pulse transformers, and other components will be incorporated.

In this context, the interaction of radio frequency electromagnetic waves with plasma is a hot topic of research, which is of interest to DAE for their ongoing Tokomak fusion reactor development for power generation. It is proposed to establish experimental research capabilities to conduct research in this area. This would require equipment to generate plasma and RF separately, and fabrication of various interaction geometries to enhance their interaction. RF components such as ultra wideband antennas will be required in this context. A test facility will be set up to evaluate their performance in the time domain.

In addition, IISc has expertise in field computation in ion trap and electron optics structures. We can help in developing software for simulation of ion motion in such structures. Some free/commercial codes are presently available in this direction. However, we will try to develop a package that would address problems specific to BARC at the high power and high field problems.

The main objective of this activity would be to develop capabilities for theoretical and numerical modeling of various interaction and design problems. Some key experimental validations at reasonable low power levels will be attempted. Manpower development will be another key aspect.

2. RF CMOS Integrated Circuits

IISc has established research on RF signal processing blocks such as low noise amplifiers, mixers, and voltage controlled oscillators. Based on an ongoing funded research activity, we are developing a CMOS RF transreciever for the 2.4GHz ISM band for the IEEE 802.15.4 standard. The receiver consists of a 2.4GHz LNA, down-conversion mixer, 2.4GHz frequency synthesizer, analog channel select filters, variable gain amplifier (VGA) and analog to digital converter (ADC) to down-convert from RF to IF of about 3MHz. The digitized IF data is further processed and digital bits are extracted by a custom digital processing block. The transmitter consists of a Power amplifier and a frequency synthesizer which can be FM modulated with the data to be transmitted. The Noise figure of the LNA is about 3dB which is adequate for our application. Much lower noise figures of less than 2dB can also be achieved at the cost of increased power. These circuits can be easily customized to target lower frequency bands like 1GHz and higher bands of up to 3GHz by appropriately modifying the LNA and the frequency synthesizer.

We plan to develop subsystems such as LNA, mixer at frequencies ranging from 100's of MHz to several GHz, partially catering to the needs of BARC/DAE

3. Terahertz Sources

Sub-millimeter wave radiations, mostly unexplored until 1990's, are fast becoming an exciting field of research, due to its fascinating properties and immense potential applications in several fields of science and technology. The term Terahertz technology was first reported in the literature in the 1970's to represent the frequency spectra of the present interest. As the name suggests, these broadly encompass the electromagnetic spectrum from 300 GHz to 3 THz. This frequency range corresponds to wavelengths ranging from 1mm to 1μm, approximate photon energy in the range 1.2 to 12.4eV, and equivalent blackbody temperature between 14 and 140 K. This new discipline can definitely benefit from developments in areas such as microwave, optics, nanotechnology, and micromachining, among others.

Terahertz waves possess some interesting properties. These are non-ionizing radiations. Terahertz radiation has major use in spectroscopy, imaging, remote sensing and bio-medicine. THz radiation can pass through objects and substances which block light like clouds, smoke, paper, clothing and even walls but is extremely sensitive to water. It can be used to detect diseases and cancer. For medical purposes, one major advantage that terahertz radiation has over conventional X-rays is that THz waves penetrate living cells without damaging them.

The research initiatives in IISc in the area of RF MEMS will be extended to fabricating THz sources (e.g., micromachined folded waveguides) and other devices operating at THz frequencies. The objective is to set up characterization facilities to enable design and develop a device capable of generating Terahertz signals that could be used in a portable system for non-intrusive sensing and imaging. Specifically we would like to explore the use of scaled down (in size) waveguides fabricated using microfabrication, nanostructures thin films on non-linear transmission lines, beam-wave interaction devices, etc for THz sources Such systems are useful in security and safety imaging applications, and will be of interest to DAE. Specifically explosive detection capability of such components and systems will be investigated.