Joint R & D Centers

Convergence and Synergy

Indo-US Science and Technology Forum
The Indo-US Science and Technology Forum (IUSSTF) established under an agreement between the Governments of India and the United States of America in March 2000, is an autonomous, not-for-profit-society that promotes science, technology, engineering and biomedical research through substantive interaction among government, media and industry.
## Preface

To enable Indian and American scientists, researchers and students from academia, laboratories (both public and non-governmental) and industry to carry out joint research activities by leveraging already existing infrastructure and funding available with the partners at both sides, the Indo-US Science and Technology Forum supports linkages established through virtual networked joint centres.

The Indo-US Knowledge R & D Networked Centers and Public-Private Networked Centers aim to encourage joint project implementation on focal areas of thematic and applied research based on synergy of activities and harnessing complementary strengths of performing groups from the two countries. Knowledge R & D Networked Centers may also provide opportunities for integrating research with education, through both student and faculty exchanges. Public-Private Networked Centers, on the other hand, enables to foster academia-industry partnerships by promoting pre-commercial R & D activities having potential towards applied research and product development. These Centers are aimed to capitalize on the scientific and technological innovation and entrepreneurship in translating ideas from the bench to the market place. More information on the Networked Centers can be accessed at www.indousstf.org.

We at IUSSTF are pleased to provide a flavour of work done by some of such Networked Centers supported by IUSSTF over the years in the past across various thematic areas.

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</table>
**Indo-US Joint R & D Center on Biomaterials for Healthcare**

**Nodal Host**  
Department of Materials Science and Engineering, Indian Institute of Technology Kanpur, India

**Project Duration**  
2008 - 2011

**Resources**  
₹ 75,97,600

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**Objectives**

- To conduct research on the development of engineered Nano-biomaterials for bone tissue replacement applications.
- To develop and conduct clinical trials on Polymer based scaffold materials for cartilage tissue engineering application.
- To formulate strategies based on injection molding as well as CAD/CAM based manufacturing route to fabricate complex shaped implant materials.
- To have a focused discussion: How can Biomaterials education in India and USA be strengthened?
- Feasibility study for commercialization of successful biomaterial products with the help of private industry.
- To train next generation of scientists in an international interdisciplinary collaborative arena.

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**Lead Partners**

<table>
<thead>
<tr>
<th>India</th>
<th>USA</th>
</tr>
</thead>
</table>
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**Work plan/Methodology**

<table>
<thead>
<tr>
<th>Focus Area – I</th>
<th>Focus Area – II</th>
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</thead>
<tbody>
<tr>
<td><strong>Hard Tissue Replacement</strong></td>
<td><strong>Soft Tissue Replacement</strong></td>
</tr>
</tbody>
</table>
| IIT Kanpur and UTSA  
• Fabrication and in vitro properties of Polymeric scaffolds for bone tissue engineering (IIT, Kanpur)  
• In-vitro and In-vivo studies of polymeric scaffolds (USA)  
• In vitro and in vitro studies of functionally graded porous Ti (IIT-K)  
• In vitro studies of functionally graded porous Ti (IIT Kanpur)  
• CAD/CAM based designing of Ti based scaffolds (NFTDC)  
• CNF coated anodized Ti (Brown University)  
• HAp/Mullite, Glass Ceramic processing and in-vitro studies (IIT-K)  
• Injection molding of polymeric/ceramics based complex shaped implants (Shaping Concepts, LLC) | IIT K, IITB, NML, UTSA and Brown Univ.  
• Scaffolds for cartilage tissue engineering (IIT Bombay)  
• Designing bio-mimetic polymeric nano composites (NML)  
• Designing bio-mimetic polymeric nano composites (NML)  
• Biological evaluation of bio-mimetic nanocomposites (Brown) |

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**Accomplishments / Outcomes**

In particular, the Center oversaw the joint development of HA-based electro-conductive composites for bone replacement applications. IIT Kanpur created the composites using the spark plasma sintering route, and the research group of Amar Bhalla and Ruyan Guo at UTSA evaluated their functional properties. Using fluorescent-activated cell sorting and reverse-transcription polymerase chain reaction techniques, researchers at Brown University investigated the cellular apoptosis at genome level of -HA-based nanoceramic composites fabricated using the SPS route at IIT Kanpur.

IIT Kanpur researchers used electro-spinning techniques to develop poly (vinyl alcohol)–carbon nano fibers and poly (lactic-co-glycolic acid)–CNF hybrid bio-composites, while cardiac myocyte cell-fate processes are studied at Brown University in the context of their potential applications as synthetic patches to treat heart diseases. NML (Jamshedpur) has developed PVA based transparent hydrogels for corneal tissue engineering applications followed by Brown University’s in-vitro study of such materials. Also, IIT Bombay synthesized hydrogel scaffolds for minimally invasive cartilage tissue engineering applications. Brown researchers then investigated the cell adhesion and differentiation of chondrocyte cells in an external electric field.
Milestones achieved

- Cell culture techniques, media requirement for culturing human dermal fibroblasts and lens epithelial cells were learnt.
- Hydrogels developed at NML Jamshedpur could be successfully studied at Brown University for cell adhesion to two different cell lines: human dermal fibroblasts and human lens epithelial cells.
- Also fibroblasts adhered on PVA hydrogels were checked for their collagen and alkaline phosphatase activity.

NML-Brown collaboration: Outcomes

- Freeze-thawing can generate transparent hydrogels which are stable in aqueous medium without invoking any additional chemical agent.
- Cells respond to topographical features of the hydrogels generated as a function of composition.
- The hydrogel surfaces are more favorable for the attachment of dermal fibroblasts as compared to the lens epithelia cells.
- The secretion of proteins by the cells indicates their normal growth and proliferation within the PVA matrix.
- Addition of RGD does enhance the cell attachment density and hence the alkaline phosphate and collagen activity of the cells.

Center activities in the area of bone-tissue engineering applications

Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institution Visited</th>
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<tbody>
<tr>
<td>India</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhirendra Katti</td>
<td>IIT Kanpur</td>
<td>Univ. of Texas, San Antonio &amp; Brown Univ.</td>
</tr>
<tr>
<td>Suprabha Nayar</td>
<td>National Metallurgical Laboratory</td>
<td>Brown Univ.</td>
</tr>
<tr>
<td>C. Mauli Agarwal</td>
<td>IIT Kanpur &amp; IIT Bombay</td>
<td>Univ. of Texas, San Antonio</td>
</tr>
<tr>
<td>Deepali Dyondi</td>
<td>IIT Bombay</td>
<td>Brown Univ.</td>
</tr>
<tr>
<td>Ashutosh Dubey</td>
<td>IIT Kanpur</td>
<td>Univ. of Texas, San Antonio</td>
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<td>Sushma Kalmodia</td>
<td>IIT Kanpur</td>
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</tr>
<tr>
<td>Dhirendra Katti</td>
<td>IIT Kanpur</td>
<td>UTSA &amp; Brown Univ.</td>
</tr>
<tr>
<td>Deepali Dyondi</td>
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<td>Sanika Misra</td>
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</tr>
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<td>A. Rajyalakshmi</td>
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<td>Brown Univ.</td>
</tr>
<tr>
<td>Siddhi Gupta</td>
<td>NML Jamshedpur</td>
<td>Brown Univ.</td>
</tr>
<tr>
<td>A.K. Dubey</td>
<td>IIT Kanpur</td>
<td>Univ. of Texas, San Antonio</td>
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<tr>
<td>Alok Kumar</td>
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<td>Brown Univ.</td>
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<td>Shilpee Jain</td>
<td>IIT Kanpur</td>
<td>Brown Univ.</td>
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<tr>
<td>USA</td>
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</tr>
<tr>
<td>Rajendra Bordia</td>
<td>Univ. of Washington, Seattle</td>
<td>IIT, Kanpur, India</td>
</tr>
<tr>
<td>Justin Seil</td>
<td>Brown Univ., USA</td>
<td>IIT Kanpur, India</td>
</tr>
<tr>
<td>Teja Guda</td>
<td>Univ. of Texas, San Antonio</td>
<td>IIT Kanpur, India</td>
</tr>
<tr>
<td>Nhiem Tran</td>
<td>Brown Univ., USA</td>
<td>NML Jamshedpur, India</td>
</tr>
<tr>
<td>Erik Taylor</td>
<td>Brown Univ., USA</td>
<td>IIT Bombay, India</td>
</tr>
<tr>
<td>Alexander Turner</td>
<td>Univ. of Washington, Seattle</td>
<td>IIT Kanpur, India</td>
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<tr>
<td>Nik Hrabe</td>
<td>Univ. of Washington, Seattle</td>
<td>IIT Kanpur, India</td>
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<tr>
<td>David a. Stout</td>
<td>Brown Univ., USA</td>
<td>IIT Kanpur, India</td>
</tr>
<tr>
<td>David Stout</td>
<td>Brown University</td>
<td>IIT Kanpur, India</td>
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Publications

**Indo-US Joint R & D Center on Magnetce Resonance Technologies in Brain Cancer Imaging**

**Nodal Host**
Sanjay Gandhi Post Graduate Institute of Medical Sciences, Lucknow, India

**Project Duration**
01/11/09 - 31/07/12

**Resources**
INR 21, 71, 000

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**Objectives**

- Implement volumetric MRSI acquisition and reconstruction, MR-diffusion, and MRI-perfusion imaging, on MRI instruments at the Sanjay Gandhi Post Graduate Institute of Medical Sciences.
- Evaluate combined advanced MRI methods for diagnostic studies of brain cancer, with emphasis on untreated glioma.
- Develop a database of imaging markers for characterization of different brain lesions.
- Develop computational methods for multiparametric image-based tissue classification, for characterization of multiple tissue types associated with brain cancer, including brain edema, infiltrative tissue, cancer, and abscess.
- Develop new collaborative research and educational programs in the area of brain imaging.

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**Lead Partners**

<table>
<thead>
<tr>
<th>India</th>
<th>USA</th>
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<tbody>
<tr>
<td>Baksh Gupta</td>
<td>Andrew Maudsley</td>
</tr>
<tr>
<td>Sanjay Gandhi Post Graduate Institute of Medical Sciences, Lucknow, India</td>
<td>Miller School of Medicine University of Miami, FL</td>
</tr>
<tr>
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<td><a href="mailto:amaudsley@med.miami.edu">amaudsley@med.miami.edu</a></td>
</tr>
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<table>
<thead>
<tr>
<th>R.K.S. Rathore</th>
<th>Dan Spielman</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Radiological Sciences Laboratory, Lucas Center Stanford, CA</td>
</tr>
<tr>
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<td><a href="mailto:spielman@stanford.edu">spielman@stanford.edu</a></td>
</tr>
</tbody>
</table>

**Work Plan/Methodology**

The specific activities undertaken in the project period was as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Tasks</th>
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<tbody>
<tr>
<td>Oct. 2009</td>
<td>Project Approval. Finalized development and evaluation of the volumetric MRSI sequence on 3T GE MRI (Spielman). Finalized licensing issues for installing this sequence in the GE MRI in Lucknow. Final specification of clinical research plan, and completion of human research approvals (Gupta). Exchange of ideas and information to design image analysis methods (all PIs).</td>
</tr>
<tr>
<td>Feb 2010 to Sept 2010</td>
<td>Installation and testing of MRSI acquisition and processing software at SGP/GIMS. Visits of Dr. Maudsley and Mr. Sheriff to Lucknow, India, for software installation and testing, and training. The MRSI and MRI methods were evaluated using studies in phantom objects and normal volunteer subjects. Final definition of multiparametric image analysis methods and instruction on incorporation into the MIDAS software environment (Maudsley, Spielman, and Rathore).</td>
</tr>
<tr>
<td>Nov. 2010</td>
<td>Initiation of MR studies in patients referred with evaluation of brain tumor (Gupta). The MRSI sequence was added to the routine brain tumor imaging protocol. Development of image analysis methods for diffusion and perfusion (Rathore). Ongoing support and software development for data processing and image display in the MIDAS package (Maudsley).</td>
</tr>
<tr>
<td>Feb. 2011</td>
<td>Gupta visit to Miami for the purpose of reviewing the existing data, performing an initial data analysis, planning of additional development projects and publications.</td>
</tr>
<tr>
<td>July 2011</td>
<td>Ms. Roy visit to Miami and Stanford for the purpose of completing integration of data processed in Lucknow into the MIDAS database, and for planning of additional processing and analysis software.</td>
</tr>
<tr>
<td>Mar. 2012</td>
<td>Maudsley visit to Lucknow. A final review and analysis of all data was carried out for evaluating the efficacy of the multiparametric imaging methods was initiated. A manuscript describing this work was drafted.</td>
</tr>
<tr>
<td>July 2012</td>
<td>Alperin visit to Lucknow. Additional MRI methods were implemented for the purpose of measuring intra-cranial pressure in patients with brain cancer.</td>
</tr>
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</table>

**Accomplishments / Outcomes**

Completion of MR studies of 94 subjects, including 7 of normal controls. Of these 56 studies were selected for analysis as confirmed glioma and being of adequate quality in all imaging studies for analysis. The image data was incorporated into the database used for data processing and analysis at the University of Miami site. Several software developments were implemented to deal with specific requirements of the acquired data.

The following figure illustrates the primary image parameter maps that were obtained. Data was obtained from a subject with histology-proven glioblastoma (GBM).

**Scientific Outcomes:**

- The ROC analysis indicated that DCE-MRI derived relative CBV is most efficient for the aim of glioma grading, and that a combination of parameters from DCE-MRI, DTI, and whole brain MRSI enables classification of gliomas into high and low grade with accuracy near to the classification based on histopathology.

- The finding supports the use of a multiparametric MR protocol for tumor diagnosis. Additional findings support the use of the volumetric whole-
brain MRSI method for improved sampling of brain tumors relative to standard MRS methods provided by the MR instrument manufacturers.

The study demonstrated the value of multiparametric MR data acquisitions and comprehensive data processing approaches enabling combination of MRS and multiple MRI features, benefit for aiding visual clinical diagnosis.

Cross-sectional images at six slices through the brain out of the full volume image data for different MRI maps: a) T2 MRI; b) T1-post contrast MRI; c) NAA; d) Creatine; e) Choline; f) Lactate; g) apparent diffusion (ADC); h) Fractional Anisotropy; and i) cerebral blood volume (CBV).

Bilateral Cooperation and Interactions: Exchange of information, imaging technology, and a unique set of data obtained for an important clinical group of patients.

Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute visited/proposed</th>
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<tbody>
<tr>
<td>R.K. Gupta</td>
<td>SGPGIMS, Lucknow</td>
<td>University of Miami</td>
</tr>
<tr>
<td>Bhaswati Roy</td>
<td>SGPGIMS, Lucknow</td>
<td>University of Miami</td>
</tr>
<tr>
<td>Professor A. Maudsley</td>
<td>University of Miami</td>
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</tr>
<tr>
<td>Sulaiman Sheriff</td>
<td>University of Miami</td>
<td>SGPGIMS, Lucknow</td>
</tr>
<tr>
<td>A. Maudsley</td>
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<td>SGPGIMS, Lucknow</td>
</tr>
<tr>
<td>N. Alperin</td>
<td>University of Miami</td>
<td>SGPGIMS, Lucknow</td>
</tr>
</tbody>
</table>

Publications

1. A report entitled “Utility of Multiparametric 3T MRI for Glioma Characterization” has been submitted for publication.
2. A report on MRS findings in the normal-appearing regions of the brain in tumor patients is in preparation.
3. Software is being developed to measure temperature from the MRSI data. This will be applied to the data acquired under this project and if there are significant new findings this will be developed into a report.
4. An additional finding of the MRSI measurement was detection of increased glycine in a subset of patients. The potential diagnostic value of this finding is unclear, and therefore an analysis will be carried out to test for any association of glycine with the other imaging measures.
5. The data acquired under this project has been made available to Dr. R. Stoyanova (Miami University) who is comparing the extents of tumor volume measurement derived from MRI and the volumetric MRSI. This measurement has potential impact for planning of radiation treatment.

Software Generated

1. Import image data for the parameter maps derived from perfusion imaging into the image database system developed at the University of Miami. This data was provided in a custom data format developed at the IIT Kanpur site.
2. Transfer of data to image display programs for manual image segmentation of brain lesions. This functionality was needed to modify brain tissue segmentation maps to add an additional image feature corresponding to the unidentified (i.e., tumor, edema, and necrosis) tissue and was needed to correct errors in a brain mask caused by the presence of a lesion, and to improve the metabolite signal normalization in the presence of a lesion.
3. Incorporation of an additional tissue type, namely that describing the brain tumor, into three processing and analysis programs of the MIDAS package.
4. Apply spatial transformations to T1 and perfusion maps, which were acquired in a different image orientation.
5. Apply additional preprocessing to the raw MRSI data to account for differences in the data order obtained from the GE scanner at SGPGIMS.
6. Some modifications to existing programs has taken place to incorporate differences in the data and analysis methods for this project, including changes to the MRS analysis to include lactate, and glycine.

Visit of Dr. Maudsley to Lucknow in April 2012
**Nodal Host**
S. N. Bose National Centre for Basic Sciences, JD Block, Sector III, Salt Lake, Kolkata-700098

**Project Duration**
2007 - 2010

**Resources**
₹ 18, 40, 380

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**Objectives**
- To develop a theory to understand the common features between correlated electron oxides and other compounds of transition metals and organic charge-transfer solids (CTS).
- Superconducting CTS have nominally quarter-filled bands and aside from the common band fillings these inorganic systems share two other common features with the organic CTS: strong electron-electron interactions, and (ii) lattice frustration.
- Thus superconducting CTS in all cases have lattice structures that are anisotropic triangular. The inorganic systems that we identified, such as LiTi2O4, MgTi2O4, CuIr2S4 and CuRh2S4, are spinels and the present research activity of this joint center had been focused on spinels.

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**Lead Partners**

<table>
<thead>
<tr>
<th>India</th>
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</thead>
</table>
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S.N.Bose National Centre, Kolkata | Hongtao Li  
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**Work Plan/Methodology**
In order to incorporate orbital degeneracy, frustration, and the possibility of Peierls order in multiple directions the following Hamiltonian had been considered for a checkerboard lattice with doubly degenerate metal orbitals at each lattice site.

\[ H = H_{SSH} + H_{OO} + H_{ee} \]

\[ H_{SSH} = \sum_{i,\gamma,\gamma',\gamma''} t_{\gamma,\gamma'}^{m} (1 + \alpha_{\gamma} \Delta_{i,i+a}) (d_{i,\gamma}^{\dagger} d_{i+a,\gamma''}) \]

\[ + h.c.] + \frac{1}{2} \sum_{i} K_{SSH} \Delta_{i,i+a}^{2} \]

\[ H_{OO} = \frac{g}{2} \sum_{i,\gamma,\gamma'} Q_{i,n_{i,\gamma'} - n_{i,\gamma}} + \frac{1}{2} K_{OO} \sum_{i} Q_{i}^{2} \]

\[ H_{ee} = U \sum_{i,\gamma} n_{i,\gamma} n_{i+1,\gamma} + \frac{U'}{2} \sum_{i,\gamma,\gamma'} n_{i,\gamma} n_{i,\gamma'} \]

The Hamiltonian consists of (i) $H_{SSH}$ that contains the kinetic energy and the inter-ion electron-phonon (e-p) coupling, (ii) an orbital-ordering (OO) term $H_{OO}$, and (iii) electron-electron interaction $H_{ee}$ that includes short-range e-e interactions within each site.

Treating OO and e-p interactions using a standard self-consistent approach derived from the equations:

\[ \frac{\partial\langle H \rangle}{\partial Q} = 0 \]

\[ \frac{\partial\langle H \rangle}{\partial \Delta_{i, i+a}} = 0. \]

The self-consistency equations were used iteratively given an initial starting distortion. In the infinite system the OO or the bond distortion would occur for infinitesimally small coupling constants $g$ and $a$. In finite-size clusters, however, due to the finite-size gaps between successive energy levels, nonzero coupling constants are required before the symmetry-broken state appears. We, therefore, consider $g$ and $a$ close to the minimum values needed for the broken-symmetry state to occur. We performed calculations for lattices up to 16 x 16 (256 atoms with 512 orbitals).
Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanusri Saha-Dasgupta</td>
<td>S.N Bose Centre</td>
<td>University of Arizona</td>
</tr>
<tr>
<td>Soumyajit Sarkar</td>
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<td>D.D. Sharma</td>
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<td>Sumit Mazumdar</td>
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<td>Sumit Mazumdar</td>
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</tr>
<tr>
<td>R. Torsten Clay</td>
<td>Mississippi State University</td>
<td>S.N Bose Centre</td>
</tr>
</tbody>
</table>

Publications


Software generated:
Software had been generated to solve the model Hamiltonian incorporating orbital degeneracy, frustration, and the possibility of Peierls order in multiple directions.

Indo-US Joint R & D Center on

Climate Change and its Impact on the Ecosystem of the Arabian Sea

Objectives

- Strengthen and enhance INDO-US collaboration and cooperation in oceanographic research and long-term monitoring.
- Encourage and promote interdisciplinary research and excellence in oceanographic and climate change sciences of the Arabian Sea through optimal use of expertise, resources and technology.
- Create an environment that will encourage scientific curiosity about the oceans and cross-cultural exchange of ideas especially among students and young scientists.
- Inspire and develop a new generation of researchers to investigate climate change issues of relevance to the Indian Ocean and human populations around them.

Nodal Host
National Institute of Oceanography, Goa- 403 004, India

Project Duration
2008 - 2010

Resources
₹ 12, 82, 050
Lead Partners

<table>
<thead>
<tr>
<th>India</th>
<th>US</th>
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</thead>
</table>
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Pt. Joint Centre  
National Institute of Oceanography  
Dona Paula, Goa  
sgpm@nio.org | J. I. Goes  
Senior Scientist  
Bigelow Laboratory for Ocean Sciences  
180 McKown Point, W. Boothbay Harbor, ME 04575, USA  
joges@bigelow.org |

Work Plan/Methodology

<table>
<thead>
<tr>
<th>Training of students/exchanges</th>
<th>Pre-cruise meetings:</th>
</tr>
</thead>
</table>
| **Year I**  
One student got trained in USA. The training was useful in isolation of harmful algae and bio-optical characteristics of this various harmful algae. |  
Two US scientists taken part in pre-cruise meeting of planning of the Noctiluca studies in the field. |
| **Year II**  
Two students were trained in grazing and ocean color remote sensing to apply Noctiluca detection from space. |  
• Two Indian scientists taken part in the pre-cruise planning in the USA and processing of the data in USA.  
• Three USA Scientists has taken part in the pre-cruise meetings in India. |

Science plan during cruise:

**Study of reference area and bloom area**

Bloom area is marked by ocean color images and reference studies are occupied in the bloom free area. The main transects were fixed in the bloom area covering entire bloom area.

**Physical Parameters**

Data on wind speed, wind direction, air pressure and air temperature for all stations were recorded on board Sagar Sampada and Sagar Kanya (Figs.). Temperature and salinity was recorded by CTD (Seabird Electronics Inc., USA) system.

**Chemical parameters**

**Nutrients:** Water samples from depths based on water column characteristics were collected from different stations using CTD for the estimation of dissolved oxygen, pH and nutrients (Nitrate, Nitrite, Phosphate and Silicate). The other parameters used were Yellow substance (C-DOM), Bio-optical Studies, Bio-optical Profiling (IOP Characterization), Biological studies (Phytoplankton Taxonomy, Pigments by HPLC method, Primary Productivity, Microbial studies; Nutrient cycling, new and regenerated production, Photosynthesis versus light measurements, Remote Sensing (Satellite data processing, Chl a Retrieval from IRS P4 OCM) and Sediment trap and new production.

**Accomplishments / Outcomes**

Shipboard and satellite data shows that *Noctiluca miliaris* blooms are becoming an increasingly important component of phytoplankton communities of the Arabian Sea. Phytoplankton cell density, chlorophyll a (chl a) concentration and pigment data collected during a series of five cruises in the northern Arabian Sea in the Northeast Monsoon (NEM, Nov–Jan) and the Spring Intermonsoon (SIM, Mar–May) since 2003 contradicted the established notion that winter blooms mainly consist of diatom communities. Recent data show that following the NEM and well into the SIM, phytoplankton populations are dominated by the dinoflagellate *Noctiluca miliaris* Suriray (synonym *Noctiluca scintillans* Macartney). In the SIM they were often in association with the well-known blooms of the diazotroph *Trichodesmium* sp. Large blooms of *N. miliaris* have also begun making their appearance annually in the Gulf of Oman and off the coast of Oman.

The study uses NASA’s recently developed product of merged SeaWIFS and Aqua-MODIS chl a data to investigate the temporal evolution and spatial extent of these taxonomically validated blooms.

*N. miliaris* blooms are becoming an annual and widespread feature in the Arabian Sea proceeded by diatoms-dinoflagellates communities and followed by extensive blooms of *Trichodesmium* (Paper accepted by Chinese Journal of Oceanology and Limnology, 2010). High Bacterial abundance and production in *N. miliaris* Bloom areas compared to non-bloom areas. The wide variations in Total Bacterial
Counts (> 10 fold) are highly unusual from any open-bacteria (Paper accepted by Chinese Journal of Oceanology and Limnology, 2010).

Primary production is only C source in any open ocean and production rates vary from BLOOM to NON BLOOM areas indicates seasonal fast changing conditions in the NE Arabian Sea as the bloom ages and declines.

Noctiluca miliaris, a conspicuously large heterotrophic dinoflagellate containing green symbionts of the prasinophyte Pedinomonas noctilucae, has only been observed in the northern Arabian Sea. Since that time expansive blooms have been observed during the winter monsoons. Community composition predicted by the model compares well with coincident microscopic observations (Paper communicated to Geophysical Research Letter, 2010).

Other accomplishments

Dr. S. G. Prabhu Matondkar and Dr. J. I. Goes attended workshop at IIT Kanpur during 7th to 9th December 2008 and made presentation on Joint Centre activities and scientific programme.

Arranged workshop for training on bio-optics in NIO, Goa during 15th to 19th December 2008

inherited by Dr. A. Mitra, Executive Director, INDO-US Science and Technology Forum, New Delhi which was attended by other participating institutions.

Planned and executed cruise on Sagar Kanya (SK-256) during 9/02/2009 to 23/02/2009 period as the first phase of the active bloom.

Planned and arranged Sagar Sampada cruise (SS-263) during 26/02/2009 to 13/03/2009 period as the second phase of the bloom study which was attended by participating organizations.

Arranged post cruise meeting at Space Application Centre, Ahmedabad for discussions of results in between US and Indian collaborators.

Planned and arranged third bloom phase cruise SK-258 (18th to 30th April 2009) where all the Indian collaborators has participated.

Planned/ arranged cruise on Sagar Sampada (SS-273) during 5th to 13th March 2010 for study of fourth phase of bloom.

One day workshop at Ahmedabad on 20th January 2010 for discussions and presentations by participating organizations.

Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surabhi Pednekar</td>
<td>Ph.D. Student, NIO, Goa</td>
<td>Bigelow Laboratory for Ocean Sciences, Marine Institute n Port Aransas Texas, University of Maine</td>
</tr>
<tr>
<td>Sushma G. Parab</td>
<td>Post.doc Fellow, NIO, Goa</td>
<td>Bigelow Laboratory for Ocean Sciences, Horn Point laboratory, Boston University</td>
</tr>
<tr>
<td>J. G. Prabhu Matondkar</td>
<td>Scientist F PI Joint Centre, NIO, Goa</td>
<td>Bigelow Laboratory for Ocean Sciences, University of Southern California</td>
</tr>
<tr>
<td>R. M. Dwivedi</td>
<td>Scientist , Co-PI, SAC, Ahmedabad</td>
<td></td>
</tr>
</tbody>
</table>

USA

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute visited</th>
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</thead>
<tbody>
<tr>
<td>J. I. Goes</td>
<td></td>
<td>National Institute of Oceanography, Goa, Space Application Centre, Ahmedabad, India</td>
</tr>
<tr>
<td>R. H. do Rosario Gomes</td>
<td>Bigelow Laboratory for Ocean Science</td>
<td></td>
</tr>
<tr>
<td>Colin Roessler</td>
<td>Co-PI, SAC, Ahmedabad</td>
<td></td>
</tr>
<tr>
<td>Jeremy Wendell</td>
<td>Ph.D. Student, NASA</td>
<td></td>
</tr>
<tr>
<td>Jenna Campbell</td>
<td>Ph.D. Student, Texas University</td>
<td></td>
</tr>
<tr>
<td>Pat Gillet*</td>
<td>Scientist, Horn Point laboratory, Cambridge</td>
<td></td>
</tr>
</tbody>
</table>

* Travelled on other projects; ** Travelled by CSIR funding

Publications


Objectives

- Research in the area of biomass related COPD (Chronic obstructive pulmonary disease) and other lung diseases in non-smokers by utilizing the cohort set up in rural Pune, India, to decrease the burden and mortality of environmental lung diseases.

- Improve the understanding of COPD in non-smokers and help develop novel prevention and therapeutic strategies directed to the affected population in future.

Work Plan/Methodology

- Organize a joint meeting between the US and Indian partners, with the objectives of: meeting each other, identifying the key priority research questions, understanding the research expertise of the collective group, designing appropriate study methodology and planning the research studies to be undertaken.

- Collecting particulate matter samples from indoor homes in India that use biomass fuel for in vivo animal exposure studies and in vitro cell culture studies to generate pilot data to help and understand the potential biological mechanisms of how biomass fuel smoke particle mediate biological responses.

- Breysse and Diette visit to India and assist in building up a system (particulate cyclone collector) to help collecting particulate matter samples from homes using biomass fuel for cooking. The collected particles to be shipped to IGIB and Johns Hopkins for characterization and mice model studies to study the effect on innate immune response, lung function and carcinogenicity. (Time duration: 6-12 months.)

- Designing of epidemiological and basic research studies to develop the research in the area of biomass related COPD and other lung diseases in non-smokers by utilizing the cohort set up in rural Pune, India to decrease the burden and mortality of environmental lung diseases.

- Submission of research proposal to appropriate funding agencies in USA, India and other places interested to fund such an initiative. Potential funders aimed to target were: The Welcome Trust, The Bill Gates Melinda Foundation, The Bloomberg Foundation, WHO and NIH. Grant applications to be submitted to different agencies.

Accomplishments / Outcomes

Objective 1: met by meetings and brainstorming.

Objective 2: The principal finding is Indoor air particulate matter collected from rural Indian homes that use biomass as cooking fuel causes potent neutrophilic inflammation that is mediated through Toll-like receptor signaling.

Objective 3: Work is in progress. Ammeting was held in Feb 2012

Objective 4: The Indian and US groups have already leveraged the Indo-US center to successfully apply for a Fogarty basic biomedical grant from the NIH, USA. There also plans for grants with WHO, Gates Foundation, and Wellcome Trust.

Conclusions

- Both samples induce inflammation and airway restriction.

- Cow dung PM elicits a greater pulmonary response than wood PM.

- Study would have substantial public health
implications for establishing guidelines that could improve the health of billions of individuals who are exposed daily to biomass smoke.

Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Anurag Agrawal</td>
<td>IGIB</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>Rajesh Pandey</td>
<td>IGIB</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>Anurag Agrawal</td>
<td>IGIB</td>
<td>Joint meeting at ATS</td>
</tr>
<tr>
<td>Sundeep Salvi</td>
<td>CRF</td>
<td>Joint meeting at ATS</td>
</tr>
<tr>
<td>Veena Muralidharan</td>
<td>VRHC</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>Sneha Limaye</td>
<td>CRF</td>
<td>Johns Hopkins</td>
</tr>
<tr>
<td>Jesse Negherbon</td>
<td>Johns Hopkins</td>
<td>CRF</td>
</tr>
<tr>
<td>Shyam Biswal</td>
<td>Johns Hopkins</td>
<td>CRF, IGIB</td>
</tr>
<tr>
<td>Shyam Biswal</td>
<td>Johns Hopkins</td>
<td>CRF, IGIB</td>
</tr>
<tr>
<td>Patrick Breysse</td>
<td>Johns Hopkins</td>
<td>CRF</td>
</tr>
</tbody>
</table>

Publications


Objectives

- Research for development of practical guidelines for road and airport pavement construction.

Highway and Airport Pavement Engineering

Nodal Host
Indian Institute of Technology, Kharagpur – 721302

Project Duration
10 Oct. 2006 - 31 Mar. 2010

Resources
₹ 30,82,400
Work Plan/Methodology
- Identify two typical modified asphalts (IIT-KGP, IIT-M) based on their availability and demonstrated potential including one crumb rubber modified binder.
- Conduct tests for characterization of these asphalts (IIT-KGP, IIT-M).
- Prepare samples and test samples with different amounts and types of asphalt, including one with unmodified (control) asphalt (IIT-KGP, IIT-M) needed for mix designs to determine the optimum asphalt content.
- Conduct additional testing (IIT-KGP, IIT-M, WPI, UTEP) needed to validate the performance of the designed mixes.
- Using test data to simulate pavements with pavement design software to predict cracking and rutting (WPI, UTEP).
- Recommend appropriate amount and type of modified asphalt (IIT-KGP, IIT-M, WPI, UTEP).
- Prepare samples using aggregates and asphalt (UTEP, WPI).
- Conduct state of the art testing (such as dynamic modulus, creep compliance and indirect tensile strength of three commonly used dense graded mixes and accelerated testing on mixes to relate test parameters with performance) (WPI, UTEP).
- Generate master curves for mixes (UTEP, WPI).
- Analysis of data and usage in flexible pavement design procedures to simulate appropriate conditions (IIT-M, IIT-KGP).
- Evaluation of the effect of mix properties on thickness (IIT-M, IIT-KGP).
- Recommend appropriate thickness and design procedures (Develop models relating rutting, fatigue and thermal cracking test parameters to the corresponding performances) (IIT-M, IIT-KGP, UTEP).
- Recommend optimum asphalt content (IIT-M, IIT-KGP).
- Conduction of state of the art testing (such as accelerated testing) on appropriate number of samples.
- Relate performance to mix properties.

<table>
<thead>
<tr>
<th>Evaluation of Modifier A</th>
<th>Evaluation of Modifier B</th>
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<tbody>
<tr>
<td>Control Mix with Aggregate 1, no modifier</td>
<td>Test Mix with Aggregate 1 and modifier</td>
</tr>
<tr>
<td>Test Mix with Aggregate 2, no modifier</td>
<td>Test Mix with Aggregate 2</td>
</tr>
<tr>
<td>a b c d</td>
<td>e f g h</td>
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</tbody>
</table>

Note: Aggregates 1 and 2 may or may not be the same; a through h represents the different concentrations (percentage of mix or asphalt binder) of the modifier.
**Accomplishments / Outcomes**

**On Binders**
- Enhanced pavement service life (resistance to rutting) twice when compared to unmodified asphalt binder by use of polymer modified asphalt binder.
- Higher viscosity values of unaged (Styrene butadiene styrene-Polymer Modified Bitumen) PMB-40, PMB-70 and (crumb rubber modified bitumen) CRMB-55.
- Higher bitumen content is needed in case modified binders compared to unmodified binder.
- Varied rheological characteristics of bitumen binders collected from different sources.
- Alternative method to simulate short term and long term aging by RTFO and PAV of some modified binders was developed with normal oven.
- Evaluation of the impact of polymer modified binder on the structural performance of asphalt pavements.
- The MEPDG has been utilized to determine the effect of polymer modified binders on the life of asphalt pavements.
- Evaluation of life cycle cost of mixes with and without modified binders.

**On Bituminous Mixes**
- Significantly higher Rutting resistance of asphalt concrete mixes with unmodified asphalt binder.
- Approx. 4.8 times resistance of Styrene butadiene styrene polymer modified asphalt binder mix of that offered by an unmodified binder mix during laboratory rutting studies.
- Utilization of waste plastic and other modified asphalt reduced the life cycle cost of pavement when compared to unmodified asphalt binder. However pavement with SBS polymer modified asphalt binder resulted in lowest life cycle cost among the alternatives considered in this study.
- Reduction in air voids below (3%) resulted in higher rutting compared to higher air voids (more than 7%) irrespective of type of binder used in the bituminous mix. However modified binders have shown higher resistance to rutting compared to normal binders.
- Comparable performance characteristics of VG-40 binder mix.
- Higher fatigue life of the dense bituminous mixes with small increment in binder content above optimum binder content.
- Evaluation of Dynamic Modulus (E*) for BC (Bituminous Concrete) which increases with increase in frequency and vice-versa.

**Research outcome**
- State of the art report on modified binder.

**Exchange Visits**

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute Visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Amaranatha Reddy</td>
<td>IIT Kharagpur</td>
<td>IIT Madras, Chenlla</td>
</tr>
<tr>
<td>Ajit Krishna Singh</td>
<td>M.Tech Student, IIT Kharagpur</td>
<td>The University of Texas ElPaso</td>
</tr>
<tr>
<td>A. Veeraragavan</td>
<td>Ph.D Student, IIT Madras</td>
<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>S. Anjan Kumar</td>
<td>Ph.D Student, IIT Madras</td>
<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>Rajib Mallick</td>
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<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>Cassie Jonathan James</td>
<td>MS Student (WPI)</td>
<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>O'Sullivan Karen Anne</td>
<td>MS Student (WPI)</td>
<td>IIT Kharagpur, Kharagpur</td>
</tr>
<tr>
<td>Vivek Tandon</td>
<td>University of Texas ElPaso</td>
<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>S. Natarajan</td>
<td>University of Texas ElPaso</td>
<td>IIT Madras, Chennai</td>
</tr>
<tr>
<td>Varnali Krishna</td>
<td>MS Student University of Texas ElPaso</td>
<td>IIT Madras, Chennai</td>
</tr>
</tbody>
</table>

*: Additional student – for consideration

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**Workshops/Training Programs**

**Indo-US Workshop on Recent Advances in Pavement Engineering**


**Publications**

4. Siddagangaiah, Anjan Kumar (PhD student), Veeraragavan, A (IIT-Madras), and Mallick, Rajib B (WPI). *Permanent Deformation Behaviour of Modified Asphalt Mixes - Use Of Polymer And Recycled Waste Materials*, IIT, 11th International Conference on Asphalt Pavements, organized by the International Society of Asphalt Pavements in Nagoya, Japan, August 2010:
9. Ajit Krishna Singh, Amaranatha Reddy M. *A Alternate to Superpave Aging Methodology for Bitumen Binders Communicated to Journal on IRC*

**Book : Road Design, Construction and Management: Challenges and Solution**

Even though the principles of pavement engineering are well established, quite often the adoption of even the best principles result in roads that do not survive widely differing soil and environmental conditions and unpredictable traffic conditions. Problems can be more complicated when concepts of sustainability and life cycle cost among the alternatives considered in this study.

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**Highway and Airport Pavement Engineering**

**Book : Road Design, Construction and Management: Challenges and Solution**

Even though the principles of pavement engineering are well established, quite often the adoption of even the best principles result in roads that do not survive widely differing soil and environmental conditions and unpredictable traffic conditions. Problems can be more complicated when concepts of sustainability and life cycle cost among the alternatives considered in this study.

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**Publications**

4. Siddagangaiah, Anjan Kumar (PhD student), Veeraragavan, A (IIT-Madras), and Mallick, Rajib B (WPI). *Permanent Deformation Behaviour of Modified Asphalt Mixes - Use Of Polymer And Recycled Waste Materials*, IIT, 11th International Conference on Asphalt Pavements, organized by the International Society of Asphalt Pavements in Nagoya, Japan, August 2010:
9. Ajit Krishna Singh, Amaranatha Reddy M. *A Alternate to Superpave Aging Methodology for Bitumen Binders Communicated to Journal on IRC*
Intelligent Transportation Systems Technologies

Joint R & D Centers | Convergence and Synergy

Intelligent Transportation Systems Technologies

Lead Partners

<table>
<thead>
<tr>
<th>India</th>
<th>US</th>
</tr>
</thead>
</table>
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| NEXTRANS Center, Purdue Univ.,  
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| Srinivas Peeta  
NEXTRANS Center, Purdue Univ.,  
peeta@purdue.edu |

Objectives

- Public and private partnership to develop sustainable programs in research and education.
- Evaluation of automated traffic data collection techniques (sensors, loops, video, cell phones, etc.) that will work for traffic conditions with heterogeneity and lack of lane discipline, data monitoring and archiving and traffic modeling using these data for various ITS applications.
- Development of state-of-the-art ITS based traffic monitoring centers at each of these institutions.
- Increase the number of students and faculty involved in the undergraduate, graduate, and professional programs of the IUIC-IST consortium members.
- Increase the quality and quantity of the transportation workforce by providing international educational opportunities.
- Disseminate JC research results to Indian/US transportation agencies.

Activities planned

ITS is, by definition, a multidisciplinary activity which requires researchers from a variety of fields to work collaboratively including transportation engineering, electrical engineering, communications, signal processing, image processing, software and hardware engineering etc. India has a deficit of experienced professionals so the experience of the US investigators will be of great benefit as their knowledge will be helpful during the ITS implementation stage in US.

Conversely, traffic in many cities of USA is becoming more heterogeneous due to relatively large increases in freight-related traffic. Consequently, the current ITS systems need to be made more robust in order to accommodate the wide variety of vehicles on the roads. This challenge is analogous to the one faced by Indian transportation professionals who manage a transportation system with a wide variety of vehicle types with widely varying operating capacities. Therefore, the experience of Indian researchers in this area will be invaluable to their US counterparts.

Automated data collection is a basic need for any successful ITS implementation. As is widely known, none of the existing data collection technologies are developed for the heterogeneous and less lane disciplined traffic such as the one existing in India. A collaborative research project will be undertaken whereby promising technologies such as inductive, Radar, Infrared, and Video will be analysed for monitoring heterogeneous traffic. Based on the preliminary study, two test beds - one in India and one in the US - will be identified.

The performance of various data collection techniques will be evaluated. Modification/Development of data collection techniques that can work under heterogeneous conditions will be explored. The significant R&D initiatives in developing detectors that can work under mixed traffic conditions, both intrusive such as loop detectors and non-intrusive including video and radar detections.

The algorithms and models will be developed by the Indian researchers to characterize the heterogeneous traffic conditions that will be extremely useful for US researchers who are only now experiencing significant heterogeneity in their traffic streams. Because these models will better account for the variability and complexity of traffic, the prediction models developed will be more accurate.

Work Plan/Methodology

The overarching theme of the center is related to ITS data, including monitoring, collection and archiving, and the ways in which this data can be used to solve transportation problems. The JC will leverage the existing ITS test sites (concentrating on urban arterials) and ITS modeling capabilities at the participating universities. Following are the research areas which the collaboration will focus on:

- Evaluation of automated traffic data collection techniques (sensors, loops, video, cell phones, etc.)
- Data monitoring and archiving techniques;
- Modeling of transportation system with ITS data.
The above activities will involve a significant amount of faculty and student exchange. Specific activities for collaboration include:

- Test bed identification and selection of data collection technologies
- Evaluation of data collection technologies
- Data quality control and archiving
- Traffic modeling for ITS applications
- System integration
- Evaluation of ITS systems
- Dissemination of findings
- Traffic modeling for ITS applications

Accomplishments / Outcomes

**IITM–UNL:** A test bed is set up in the Rajiv Gandhi Salai in Chennai, India, with various traffic detectors that are sending data in real time to the ITS laboratory. Real time data monitoring is established using wireless and GPRS communication and data archiving is under development. The following off the shelf products are being evaluated and calibrated for Indian conditions: Radar Detector – Smartsensor, Infrared Detector – TIRTL, Video Sensor – Collect-R, and Image processing – Trazer. The following new sensors are being developed: an inductive loop detector (ILD) specifically suited for the less lane-disciplined and heterogeneous traffic conditions, a bluetooth sensor unit and video image processing tools.

Using these data, traffic models are being developed. The models will be used in the development of methods and technologies to regulate the movement of road vehicles.

**IITB–Purdue:** An area of common interest was explored and finalized with Prof. Srinivas Peeta at Purdue University. Mr. Caleb Ronald Muniguty, Research Scholar at IIT Bombay has shown interest in the above study. The broad objective of the study would be to bring out a robust simulation model catering to the needs of mixed traffic conditions which can be thought of to be vehicle type dependant. Specifically, the focus would be on the critical analysis of the lateral movements by vehicle type and to bring out the influential variables. Later, the lateral movement decision and execution models would be developed which will form a critical component in the development of the simulation model.

In the case of a general urban network, the challenge is to identify the route choices and departure time based on the time at which the vehicles have been observed at the counting stations. In the case of such large and complicated urban networks, the trip-based information for at least a sample of the vehicle population obtained from license plate studies or Bluetooth surveys could aid in increasing the observability of O-D pair flows. A proper methodology to integrate the different data sources to be developed to increase the reliability of estimation.

### Exchange Visits

<table>
<thead>
<tr>
<th>Name of the Scientist/Student</th>
<th>Affiliation</th>
<th>Institute Visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gireesh Devi Rangasam</td>
<td>Assistant Professor Dept. of Civil Engg. IIT Madras, Chennai</td>
<td>Univ of Nebraska Lincoln</td>
</tr>
<tr>
<td>Abhiram Madhav</td>
<td>Assistant Professor Dept. of Civil Engg. IIT Madras, Chennai</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Arunabh Bhattacharya</td>
<td>Professor Dept. of Civil Engg., IIT Bombay Mumbai</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Kavitha R.</td>
<td>Doctoral Student Dept. of Civil Engg., IIT Madras, Chennai</td>
<td>Purdue University</td>
</tr>
<tr>
<td>Neeraj Ram Kanda</td>
<td>Dual Degree Student Dept. of Civil Engg., IIT Madras, Chennai</td>
<td>Univ of Nebraska Lincoln</td>
</tr>
<tr>
<td>USA</td>
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<td></td>
</tr>
<tr>
<td>Srinivas Peeta</td>
<td>Professor Dept. of Civil Engg., Purdue University</td>
<td>IIT Madras</td>
</tr>
<tr>
<td>Laurence R. Walli</td>
<td>Professor University of Nebraska Lincoln</td>
<td>IIT Madras</td>
</tr>
<tr>
<td>Scott Sorensam</td>
<td>Graduate Student University of Nebraska-Lincoln</td>
<td>IIT Madras</td>
</tr>
</tbody>
</table>

**Objective**

- To promote exchange of researchers between the participating institutes.
- To establish a proof-of-concept of microwave processing of materials specifically metal powders, metal-ceramic composites.
- To understand phenomenology of particulate consolidation through the microwave heating and investigate and develop unique microstructural formulations exploiting unique advantages of microwave heating.
- To characterize the properties of microwave sintered composites vis-a-vis their conventionally sintered counterparts.
- To enhance the properties of microwave sintered composites through alloy design and tailoring the compositions.
- Education and training in microwave processing of materials.
- To render assistance to industry and research institutes in microwave sintering and operational details of equipment design and set-up.

**Resources**

- **₹ 30, 82, 400.00**
**Lead Partners**

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<thead>
<tr>
<th>India</th>
<th>USA</th>
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<tbody>
<tr>
<td>Anish Upadhyaya (PI)</td>
<td>Jiann Yang (Jim) Michigan Technological University</td>
</tr>
<tr>
<td>Dept. of Materials and Metallurgical Engineering, IIT Kanpur</td>
<td><a href="mailto:hwang@mtu.edu">hwang@mtu.edu</a></td>
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<tr>
<td>Pradeep Goyal (Co-PI)</td>
<td>Dinesh Agrawal (PI) Microwave Engineering &amp; Processing Center, The Pennsylvania State University</td>
</tr>
<tr>
<td>Pradeep Metals Ltd., Industrial Microwave Research Center (IMRC, Mumbai)</td>
<td><a href="mailto:dkaol@psu.edu">dkaol@psu.edu</a></td>
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</table>

**Work Plan/Methodology**

- Fabrication of fine micro structured various metal-ceramic composites through microwave sintering and powder metallurgy.
- Investigation and development of unique microstructural formulations exploiting unique advantages of microwave heating.
- Characterization of the properties (microstructural, mechanical, tribological) of microwave sintered composites via a variety of conventional sintered counterparts.
- Further enhancement of the properties of microwave sintered composites through alloy design and tailoring the compositions.
- Education and training of students affiliated with the participating Institutes.
- Executing exchange of researchers between the participating institutes for conducting experiments and technological/ scientific discussions.

**Summary Collaborative Activities done at IIT Kanpur:**

- Liquid Phase Sintering of 2712, 6711 and 7775 Aluminum Alloys and their Properties (IIT/K + PSU)
- Microwave Heating of Stainless Steels (IIT/K + PSU)

**Activities at Industrial Microwave Research Center, Mumbai:**

- Kick-off meeting of the Center: Held on 18 July, 2008 and the primary objective was to apprise to and interact with Indian industries and other R&D centers about the objectives of the IMRC and educate them about the microwave materials processing.
- Sintering of Stainless Steel: Held in collaboration with IIT Kanpur and MPEC, USA.
- Workshop on Microwave Steel making: Held on February 27, 2009.
- Microwave Steel making (IMRC + MTU)
- Bulk Metal Heating & Heat Treatments (IMRC)
- Visits to MPEC and Michigan Tech. University: By Dr. Shivanand Borkar from 20th October to 17th Nov. 2008.
- Metal Ore pretreatment in Microwave (MTU+IMRC + IIT/K)
- Upgrade of Microwave Facility at IIT/K and IMRC/Mumbai

**Accomplishments / Outcomes**

The research focus has been towards investigating the sintering aspects of ferrous and non-ferrous materials and major findings are summarized as follows:

- Microwave Heating of Stainless Steels
- Microwave Sintering of Bronze
- Microwave Sintering of W-Ni-Fe Alloy

Both ferrous and non-ferrous alloys can be successfully processed through microwave sintering. As compared to conventional heating, microwave sintering results in significant reduction in the processing time ranging from 70-90%.

**Conclusions**

- Microwave heating can effectively produce cracks in the silicate matrix of the high grade metal sulphide ore.
- Heating to temperatures of 400 °C in air/argon reported no mass loss of the sample, important for processing conditions, if microwave pretreatment of the ore was employed to produce cracks, as the mass loss results in gas production mainly in the form of SOx.
- By heating to temperatures in excess of 800 °C in air/argon mass loss is reported from the formation of voids in the metallic bearing phases of the ore.
- Localized melting occurs within the silicate matrix forming a flux containing all elements found in that region of the sample. As metallic phases heat to high temperatures, the heat is transferred to the neighboring silicate causing it to melt engulfing the metallic bearing within it. This is not good from a mineral processing standpoint as the thermal runaway occurring within the ore causes the economically valuable minerals to be further trapped by the silicate matrix.

**Exchange Visits**

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Shivanand A. Borkar (Co-PI)</td>
<td>Penn State / Michigan Tech</td>
</tr>
<tr>
<td>Avijit Mondal (Student)</td>
<td>Penn State</td>
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<td>Anish Upadhyaya (PI)</td>
<td>Penn State / Michigan Tech</td>
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<tr>
<td>Dinesh Agrawal (PI)</td>
<td>Mumbai</td>
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<td>Jiann Y. Hwang (Co-PI)</td>
<td>Mumbai / Kanpur</td>
</tr>
<tr>
<td>Matthew Andrise (Student)</td>
<td>Mumbai / Kanpur</td>
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**SEM image the silicate flux formed during heating in air to 970 °C**

EDS analysis performed on the mid-portion of the silicate flux.
Publications

Under Review:

Conference Presentations: (International and National)
2. A. Mondal, A. Upadhyaya and D. Agrawal (2009), "Microwave Sintering of W-Cu, W-Ni-Cu and W-Ni-Fe Alloys", 17th International Plansee Seminar, 25 to 29th May, Reutte, Austria. (Poster)
Nanomaterials for Energy

Lead Partners

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</table>

Objectives

- A new cohort of globally engaged researchers in nanotechnology and energy with appreciation for diverse professional and international cultures.
- Creation of joint research programs of both academic-academic and industry-academic types leading to new discoveries at the interface between nanotechnology and energy.
- Enhancement of collaborative use of cyber infrastructure research and educational resources such as nanoHUB.org and thermatHUB.org.
- Organization and hosting of summer schools and related tutorial materials offered annually to attract strong participation from industrial and academic participants.
- Strengthening of links between academics and global technology companies with R&D centers in the US and India.

Work Plan/Methodology

- Information to be made available on the web and also through personal interactions to all possible applicants from JNC/ICMS, Purdue and GE.
- Based on the discussions among the PIs and the Co-PIs involving colleagues from both sides, the suitability of a prospective visitor is evaluated and the concerned is invited.
- After scrutinizing the work proposal and obtaining concurrence from the host, a bilateral or a trilateral exchange visit is formally approved by the PIs.
- The joint Centre members also assist in logistics related to visa, travel and stay. Usually, the exchanges produce publication(s) based on the joint work carried out. This serves as a report of the visit.

Accomplishments / Outcomes

- Metal-semiconductor superlattice thermoelectrics
  To understand the microscopic aspects of ScN, ZrN, and HfN relevant to the thermoelectric properties of nitride metal/semiconductor superlattices, the electronic structure was determined, vibrational spectra and thermal properties using first-principles calculations based on density functional theory with a generalized gradient approximation of the exchange correlation energy. There had been found a large energy gap in the phonon dispersions of metallic ZrN and HfN, but a gapless phonon spectrum for ScN spanning the same energy range, this suggests that a reduced thermal conductivity, suitable for thermoelectric applications, should arise in superlattices made with ScN and ZrN or ScN and HfN. To obtain an electronic energy band gap of ScN comparable to experiment, a Hubbard correction with a parameter U (≥3.5 eV) was used.

- Exfoliated graphite/graphene materials for enhanced interfacial transport
  There is a catalyst-free synthesis of cantilevered carbon nanosheet extensions, or petals, from graphite fibers by microwave plasma CVD. Results reveal that the petals grow from the fiber surface layers while preserving graphic continuity from fiber to the petals. Subtraction of Raman signatures from pristine and decorated fibers reveals a convolution of two underlying peaks at 2687 and 2727 cm⁻¹ that are consistent with profiles of multilayer graphene flakes between 5 and 25 layers. Such structures offer the possibility of minimizing interfacial losses in transport applications, improved interactions with surrounding matrix materials in composites, and a route toward substrate independence for device applications.

- Liquid nanosolder for electrical contacts and thermal interfaces
  An easy and elegant method of CNT nanocircuit fabrication using a metal organic precursor of Pd, namely, Pd hexadecanethiolate, is presented. This precursor directs the self-assembly of cantilevered carbon nanosheet extensions, or petals, from graphite fibers by microwave plasma CVD. Exfoliated graphite/graphene materials for enhanced interfacial transport
  There is a catalyst-free synthesis of cantilevered carbon nanosheet extensions, or petals, from graphite fibers by microwave plasma CVD. Results reveal that the petals grow from the fiber surface layers while preserving graphic continuity from fiber to the petals. Subtraction of Raman signatures from pristine and decorated fibers reveals a convolution of two underlying peaks at 2687 and 2727 cm⁻¹ that are consistent with profiles of multilayer graphene flakes between 5 and 25 layers. Such structures offer the possibility of minimizing interfacial losses in transport applications, improved interactions with surrounding matrix materials in composites, and a route toward substrate independence for device applications.

- Liquid nanosolder for electrical contacts and thermal interfaces
  An easy and elegant method of CNT nanocircuit fabrication using a metal organic precursor of Pd, namely, Pd hexadecanethiolate, is presented. This precursor directs the self-assembly of individual CNTs spanning a gap between Au electrodes. This is achieved by first patterning the precursor along the edges or the gap electrodes, as it enables direct patterning by e beam. Further, thermal activation of the precursor at 250 degrees C leads to metatllization and the ohmic electrical contact between the CNTs and the electrodes beneath. A resistive fuse action of the soldered joints is observed as well.

Integration of carbon nanotubes for solar, thermal and lighting applications

- Interaction of single-walled carbon nanotubes with electron-donor and acceptor molecules causes significant changes in the electronic and Raman spectra. Electron-donating molecules such as tetraethylsilane and alkane cause...
changes opposite to those caused by electron-withdrawing molecules such as nitrobenzene and tetracyanoethylene. Thus, a proportion of the semiconducting SWNTs become metallic ultimately predicting the thermo-mechanical behavior of metal hydride powders and compacts. **Behavior of Attolitre water droplets**

Working with a biased atomic force microscope (AFM) tip in the tapping mode under ambient atmosphere, attoliter (10^-18 L) water droplet patterns have been generated on a patterned carbonaceous surface.

**Au Nanoparticle-PDMS Composites**

A simple, green synthesis technique for preparing Au nanoparticle-PDMS composites is described. The solid solution nature of the PDMS combined with the surface properties of the nanoparticles imparts unique properties to this composite. We demonstrate the utility of this material for water purification and for chemically-triggered storage and release of compounds toward-drug delivery applications.

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### Publications


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### Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Bhuvana</td>
<td>JNCASR</td>
<td>Purdue University</td>
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<tr>
<td>G.U. Kulkarni</td>
<td>JNCASR</td>
<td>Purdue University</td>
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<tr>
<td>U. Waghmare</td>
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<td>Purdue University</td>
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<tr>
<td>N.S. Waghmare</td>
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<td>Purdue University</td>
</tr>
<tr>
<td>Narendra Kuma</td>
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<tr>
<td>Kyle Smith</td>
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<td>Timothy Fisher</td>
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<td>Kevin McMullen</td>
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<td>Timothy Fisher</td>
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<tr>
<td>Adina Scott</td>
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<td>JNCASR</td>
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Nodal Host
Indian Institute of Technology, Bombay

Project Duration
Year 2007-10

Resources
₹ 22, 63, 560

Lead Partners

<table>
<thead>
<tr>
<th>India</th>
<th>USA</th>
</tr>
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<tbody>
<tr>
<td>Chandra Venkataraman, Department of Chemical Engineering, IIT Bombay</td>
<td>Pratim Biswas, Department of Energy, Environmental &amp; Chemical Engineering, Washington University in St. Louis</td>
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<tr>
<td>Anurag Mehra, Virendra Sethi, A.K. Suresh, Department of Chemical Engineering, IIT Bombay</td>
<td>Da-Ren Chen, Washington University in St. Louis</td>
</tr>
<tr>
<td>Jayesh Bellare, A.Q. Contractor, A.K. Suresh, Department of Chemical Engineering, IIT Bombay</td>
<td>R. Axelbaum, The University of Iowa, USA</td>
</tr>
<tr>
<td>A. Kaginalkar, Centre for Development of Advanced Computing, Pune</td>
<td>S.H. Ehrman, University of Maryland, USA</td>
</tr>
</tbody>
</table>

Accomplishments / Outcomes

Aerosols routes for production of nano-sized controlled-release drug particles.
- Development of a mathematical model from first principles approach to study lung deposition of aerosolized drugs (at IIT Bombay).
- Design nano-sized drug carriers of appropriate sizes to be delivered into deep lung for systemic use (at IIT Bombay and WUSIL).
- Validation of model predictions by available experimental data. (at WUSIL and IIT Bombay).

Rational design of pulmonary delivery systems for biocompatible nanoparticles.
- Aerodynamic size of droplets and structural damage to liposomes measured by drug leakage (at IIT Bombay).
- Experimental system design and training on electrospray for aerosolization of liposome suspensions (at WUSIL).
- Development of electrospray based aerosolization system for liposome suspension (at IIT Bombay).
- Successful establishment of flame and furnace aerosol reactors for inorganic nanomaterial synthesis at IIT Bombay in collaboration with Washington University.

High-temperature aerosol routes for nanoparticle synthesis: Preparation, characterization and applications
- Development of high temperature aerosol reactors (FLAR, FUAR) for gas phase Nanoparticle synthesis.
- One step synthesis and characterization of nano-sized crystalline calcium phosphate using FUAR setup for their application as bone substitute material.

Modeling atmospheric transport of aerosols and nanoparticles
- The latest version of STEM model (STEM 2K3, Tracer version) had been ported in parallel mode on a multi-core Linux system at C-DAC, Pune and coupling of WRF model to generate meteorological conditions for driving the chemical transport model.
- The STEM emission pre-processor module is redeveloped in the study domain over the Indian region.
Publications


Silk Protein Matrix for Cell Based Tissue Engineering

**Objective**

- Measurements of mechanical properties of different types of engineered pure silk and blended for tissue engineering applications constructs.
- Biomechanical, biochemical, immunohistochemical, and structural analysis of the cartilaginous tissue construct formed in vitro upon culture of chondrocytes in the fibrin/chitosan 3D scaffolds.
- Optimization of bovine joint chondrocyte cell seeding density on cell viability, morphology and biochemical properties of 3-D engineered cartilage constructs.
- Osteogenic and adipogenic differentiation of rat bone marrow cells on non-mulberry and mulberry silk gland fibrin 3D scaffolds.
- Design of novel hybrid protein by combining specific domains of mulberry fibrin and sercin to be used as new biomaterial.

**Work Plan/Methodology**

**Silkworm Collection**

The 5th instar larvae of Indian tropical tasar silkworm *Antheraea mylitta* were collected from local tasar silk farms and *Bombyx mori* silkworm cocoons from Debra Sericulture farm, West Midnapore, West Bengal, India. The posterior silk glands of fully-grown 5th instar larvae were dissected for extraction of silk protein fibroin using established methods (Mandal and Kundu, 2008, Kundu et al., 2008) i.e. the glands were washed in distilled water to remove the traces of sercin, then squeezed with fine forceps to extrude out the protein. The protein was collected as aliquots and kept in –20°C.

**Preparation of silk protein fibroin aqueous solution:**

- From non-mulberry silkworm A. mylitta silk glands
- From mulberry silkworm B. mori silk cocoons
- Scaffolds preparation and treatment
- Tissue Culture
- Digestion of scaffolds
- Biochemical assays
- Live dead assay
- Collagen assay by hydroxyproline assay
- Histology (Alcian blue staining)
- Immunohistochemical staining
- Biomechanical testing

**Accomplishments / Outcomes**

*In-vitro* tissue engineering of cartilage had been studied using chondrocytes and 3D porous scaffolds. Cartilaginous constructs were formed from SF scaffolds seeded with varying initial cell densities. The biochemical content of native cartilage matrix molecules increased with cell density and concomitantly, biomechanical properties of the engineered tissue also demonstrated enhanced load-bearing properties for the seeded constructs compared to non-seeded scaffolds. The results indicate the importance of cell seeding density in the development of cartilaginous tissue.

SF protein and chitosan-blended polyelectrolyte complex porous scaffolds are also being studied for cartilage tissue engineering in vitro. The scaffolds seeded with chondrocytes were incubated and analyzed for biochemical, biomechanical and histological properties. Blended scaffolds modulated production and deposition of extracellular matrix molecules, sulfated glycosaminoglycan and type II collagen, and also enhanced compressive properties. These results suggest a possible benefit of tissue engineering with material blends.

**Formation of new biomaterials from novel hybrid proteins combining specific domains of mulberry fibroin and sercin has produced recombinant silk-sericin like proteins. Silk sercin gene design and cloning, protein expression in bacteria, recombinant protein purification and macrophage response studies have been conducted to examine the direct activation of the innate immune response by such materials.**

- Rat bone marrow stem cells cultured on 3D scaffolds made up of non-mulberry and mulberry silk gland fibrin for 28 days under static conditions in osteogenic and adipogenic media respectively led to induction of differentiation. Proliferation and spreading of fibroblasts and bone marrow cells on silk scaffolds were observed to be dependent on scaffold porosity as revealed through confocal microscopic observations. Histological analysis shows osteogenic differentiation within silk scaffolds resulting in extensive mineralization in the form of deposited nodules as observed through intense Alizarin Red S staining. Similarly, adipogenesis was marked by the presence of lipid droplets within scaffolds on staining with Oil Red O. Real-time
PCR studies reveal higher transcript levels for osteopontin (Spp1), osteocalcin (Bglap2) and osteonectin (Sparc) genes under osteogenic conditions. Similarly, upregulated adipogenic gene expression was observed within A. mylitta and B. mori scaffolds under adipogenic conditions for Peroxisome proliferator activated receptor gamma (PPARγ2), lipoprotein lipase (LPL) and adipocyte binding protein (aP2) genes. The results suggest suitability of silk fibroin protein 3D scaffolds as natural biopolymer for potential bone and adipose tissue engineering applications.

The scaffold is mechanically robust and show homogenous pore distribution with high porosity and interconnected pore walls. Low immunogenicity of fabricated silk scaffolds as estimated through TNF release indicates its potential as future biopolymeric graft material.

- The biomechanical properties of scaffolds are also a regulatory factor for indwelling cells. Thus, the static and dynamic mechanical properties of porous scaffolds fabricated from mulberry and non-mulberry SF proteins have been compared.

- Human Embryonic stem cells (ESCs) can generate in vitro a variety of cells including those of neural crest. A suitable culture condition for these stem cells to proliferate and differentiate in non-mulberry SF scaffolds is being developed. Constructs are being examined for morphology, expression of specific proteins, and biomechanical properties. The results will help to define the 3-D microenvironment of scaffolds based on SF appropriate for differentiation of ESCs into specific cell types.

Pictographs of live/dead staining of scaffolds with initial seeding of (A, B) 25 million cells/ml, (C, D) 50 million cells/ml, or (E, F) 100 million cells/ml. Scale bars are 500 mm (A, C, E) and 100 mm (B, D, F).

### Exchange Visits

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>S. C. Kundu</td>
<td>IIT Kharagpur</td>
<td>UCS and Tufts University</td>
</tr>
<tr>
<td>Ms Nandana Bhardwaj</td>
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<tr>
<td>Ms Sarmista Talukdar</td>
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<tr>
<td>Ms Banani Kundu</td>
<td>IIT Kharagpur</td>
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<td>USA</td>
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<td>Robert L. Sah</td>
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<td>David L. Kaplan</td>
<td>Tufts University</td>
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Indo-US Joint R & D Center on Cell Targeted Diagnostics and Therapeutics Using Nanomaterials

Nodal Host
Amrita Centre for Nanosciences & Molecular Medicine (ACNSMM), Kochi, Kerala

Project Duration
July 2010 to July 2012

Resources
₹ 44, 93, 825

Objectives
- Have distinguished scientists from both sides to travel to the other country and provide tutorial lectures and facilitate the joint research by students
- Support the mobilities of PhD students so that they can benefit from the interactions with faculty and resources of the other country
- Create a cadre of trained professionals in this emerging field
- Cell targeted generation of various tissues by simulating the micro-nano environment and delivery of appropriate biomolecules (chemokines, growth factors, differentiation factors etc.)
- Diagnostics and therapeutic targeting of cancer.

Lead Partners

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<tr>
<th>India</th>
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<tbody>
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<td>Shanit Nair</td>
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<td>Oral &amp; Maxillofacial surgery, Univ. of Texas Health Sciences Center, Huston</td>
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Work Plan/Methodology
- Use electrospun micro-nano fibers to regenerate tissues such as bone and cartilage.
- Use gel based matrices for cartilage and cardiac tissue engineering.
- Electrospinning scaffolds for sustained release of drugs for oral cancer.
- Systems biology studies to predict the effects of specific molecules on gene expression (with Cellworks).

Accomplishments / Outcomes

Giridharan work at Rice: Development of locally implantable nanoparticle based gel system for interferon delivery (Objective c)- prepared a novel locally implantable gel based interferon delivery system, wherein IFN is better stabilized and released in a sustained manner over a period of ~ 21 days.

Praveen’s work at Stanford: Microfluidic device assembly & Gradient generation of vascular growth factors (Objective a and b)
- Microfluidic devices were fabricated to study the following ECM cues:
  - Concentration of soluble growth factors.
  - Shear stress induced by fluidic motion.
  - Interaction with substrate-bound ligands.
For Osteochondral Tissue Engineering (Objective a and b) - Electrospinning of 3D Engineered Protein Nanomaterials (Objective a and b) - Electrospinning is a known technique that can be used to impose fibrous structure on our material. For this, we need to know what kinds of fibers are produced by electrospinning the elastin-like proteins, and what fiber diameters we can achieve under reasonable conditions.

**Experiments Conducted:**
- HFP is frequently used to electrospin collagen, but also used to electrospin elastin. However, it is highly toxic. So, the aim is trying to optimize the conditions with water and, ethanol/PBS.
- Increasing flow rate, measured in µL/min, and conditions with water and, ethanol/PBS.
- Is highly toxic. So, the aim is trying to optimize the conditions with water and, ethanol/PBS.
- increasing fiber thickness.

**Distinct fiber radius from each condition over a range from 50 to 1000 nm. After a hydration cycle, scanning electron microscopy will be done to confirm fiber size. Then by the use of imaging software to calculate a mean and standard deviation for fiber diameter.

**Hydrated gels (2.5%) will be evaluated for mechanical stiffness using compressive rheology. Solution of the spun gel will be assessed by taking a time course of hydrated mass. We will keep the gel at 37°C to prevent dissolution.**

**Nitya’s work at UConn Health Centre: Scaffolds for Osteochondral Tissue Engineering (Objective a and b) - Electrospinning of 3D Engineered Protein Nanomaterials**

**Patrick’s (Stanford) work at Amrita: Electrospinning of Acidic Hyaluronic Acid composite hydrogel**

**Amrita’s Collaboration with Cellworks: Combination of small molecule inhibitors for cancer therapy (Objective c)**

**Delivery of multiple small molecules for cancer therapy using nanoparticle delivery systems, the small molecules of interest and Cellworks conducted the computational analysis**

**to understand the concentration and sequence of each of these molecules for efficient cancer therapy. Validation of results with bioinformatics to validate the results of Cellworks.**

**Heilshorn work with Cellworks: (Objective a and b)**

Investigating how cells respond to exposure of certain enzymes that may be used as therapeutic triggers. For example, the Heilshorn laboratory has developed a novel biomaterial that degrades on demand in response to the enzyme urokinase plasminogen activator (uPA). They have used these biomaterials to create 3-D patterns within tissue engineering scaffolds that deliver multiple biomolecules with distinct spatial and temporal release profiles. The Cellworks team was able to recapitulate these experimental results using their computational simulation of fibroblast cells and to predict several signaling antagonists that may block the secretion of the uPA inhibitor without damaging the cells. The Heilshorn laboratory is now experimentally testing these signaling antagonists to determine if they do indeed enable the uPA enzyme triggering to occur in the presence of cells.

**Tony’s work with Cellworks: (Objective a and b)**

Exploring the effects of a model inflammatory cytokine, tumor necrosis factor-alpha (TNF-α), as well as of known osteogenic growth factors, including bone morphogenetic protein (BMP)-2, BMP-4, BMP-7 and transforming growth factor-beta1 (TGF-β1), on bone regeneration. The specific objectives of this collaboration are:

To elucidate the effect of increased TNF-α signaling (e.g., 10-100 fold increase) on osteogenic gene expression in an osteoblast and in a fibroblast, as well as in the following co-cultures: macrophage-fibroblast, macrophage-osteoblast, osteoblast-fibroblast, and osteoblast-osteoclast. The specific osteogenic genes monitored were: RUNX2, BMP-2, osteocalcin, osteiriX, type 1 collagen (COL1A2), and alkaline phosphatase (ALP).

To determine the effect of increased BMP-2 signaling (e.g., increase by 4 fold) on osteogenic gene expression in an osteoblast and in a fibroblast.

To predict potential input signals that would stimulate increased production (i.e., at least a 3 fold increase) of the osteogenic growth factors BMP-2, BMP-4, BMP-7, and TGF-61, by native bone cells, including: fibroblasts, macrophages, osteoclasts, and osteoblasts.

**Other Accomplishments**

**Rice Seminars by Dr Tony Mikos conducted at Amrita:**

**U Conn Seminars by Dr. Lakshmi at Amrita:**
- Injectable lactoferrin gel as a novel osteogenic material
- Development of osteo-conductive scaffolds for bone regeneration

**Course in Nano Bioengineering in planning between Partners**

**Joint Course in Nano Bioengineering in planning between Partners**

**Joint Course in Nano Bioengineering in planning between Partners**

**Exchange Visits**

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<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Institute Visited</th>
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<tbody>
<tr>
<td>Nitya</td>
<td>Student</td>
<td>Stanford</td>
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<tr>
<td>Patrick</td>
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<td>Amrita and Cellworks</td>
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<tr>
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**Publications**

1. Research Publications generated and / or planned:


ii. Patents in preparation (to be filed and requires some additional data in process):  
2. A distributed nanostructured scaffold for growth of vascularized tissue, Binulal Sathay, Shantikumar Nair and Antonios Mikos  
3. Micro-nano scaffolds for cartilage tissue applications, Erica Levorson, Antonios Mikos, Krishnaprasad Chennazhi and Shantikumar Nair, in preparation

iii. Any other outcome emanated:  
1. NanoBio 2012 conference in Feb 2012 was a seminal international conference that highlighted the accomplishments of the JC.  
2. Both Stanford and Rice team visited Cellworks and initiated preliminary studies to investigate the systems biology aspects related to tissue engineering.