International Scientific Collaborations driven by Indian Science Diplomacy: The Journey of ARCI, Key Takeaways, Challenges and Opportunities

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Introduction

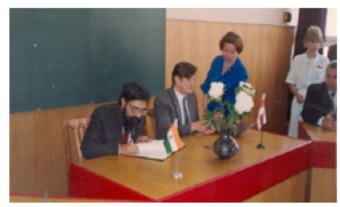
Science Diplomacy is an umbrella term often used to portray the international collaborations aimed at the formal or informal exchanges in science, engineering and technology to understand or address local or global issues. It is exciting and noteworthy that International Advanced Research for Powder Metallurgy and New Materials (ARCI) emerged as India's most extensive bilateral cooperation programme, the Integrated Long Term Programme (ILTP) on Cooperation in Science & Technology with the erstwhile Soviet Union. In the context of Science Diplomacy, it is essential to understand the overall journey of ARCI, right from its conceptualisation, objectives, the role of various stakeholders, continued journey to foster international collaborations with many other partners across the globe, portfolio of technologies inherited, accompanied challenges, present status and plans. All the aforementioned aspects are briefly covered in this article to highlight and appreciate the vital role of Science Diplomacy in the modern Indian context.

Science Diplomacy: Never Before in the Field of Materials

On 8 March 1988, an agreement was inked between India and the Soviet Union to establish the *Indo-Soviet Advanced Research Centre (ARC) for Powder Metallurgy* as a collaborative project with the Belarusian Powder Metallurgy Association (BPMA) to be implemented by the Defense Metallurgical Research Laboratory (DMRL), Hyderabad. Subsequently, on 15 October 1990, ARC was registered as a society in Andhra Pradesh, India. Owing to the political developments in the Soviet Union in the early 1990s, a multilateral agreement was signed with Commonwealth of Independent States (CIS) countries in 1993, and independent collaborations with republics like Russia, Ukraine, Moldova, and Uzbekistan were established in various areas of material technologies. Consequently, ARC was renamed 'International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)' – as it is known today – on 21 March 1994.



Signing of multilateral contracts with CIS countries



Nurturing the Newborn

With the completion of the project phase in 1995-96 and attaining a physical entity, ARCI became operational as an autonomous institution of the Department of Science and Technology (DST) with its motto of

"Translating research to technology" and transformed into one of the best materials-based application-oriented research laboratories in the country. Although the initial motivation was to develop and demonstrate powder metallurgy applications to the automotive sector, ARCI gradually evolved over the years to complement a wide range of materials and processes in line with international developments and national needs.

Conforming to its unique mandate, ARCI has selectively hosted the technologies and associated processing equipment received from the CIS countries, such as horizontal and vertical Detonation Spray Coating, single and multiple electrodes holding Electro-spark Coating, Micro Arc Oxidation, Wire-arc Spraying, High Velocity Oxy Fuel Spraying, Hydrodynamic Compaction, Blue dust (Iron ore fines) reduction, Stainless Steel Filters, Self-propagating High Temperature Synthesis, Exfoliated Graphite and a variety of oxide and non-oxide ceramic product manufacturing and others. It may be noted that some of the key technological instruments were fabricated locally and the process expertise was provided by the collaborating institutions. These technologies were broadly classified into three different pillar groups, namely (a) Powder Metallurgy, (b) Surface Engineering and (c) Ceramic Processing. Quickly realising the fact that there exists a gap between what could be readily offered and what the industry requires, ARCI vigorously pursued multi-directional R&D activities to understand the technological features and product performance aspects.

Utilising the aforementioned technologies as its primary basket, ARCI has gradually reoriented itself from an otherwise typical semi-production facility into an excellent R&D laboratory by way of indigenising each of the aforesaid technologies, benchmarking it with locally and globally available products, organising the industry workshops, demonstrating the technological and economic benefits, scale up to the industrially relevant levels, preparing the prototype systems and eventually transferring many of these technologies to a large number of Indian industries.

In the above context, the vital role of international collaborations in establishing ARCI, continued support and periodic exchange of experts as supported by International Cooperation Division at DST is the most critical factor behind the success of ARCI in translating the technologies to the Indian industry demands. At the same time, the vision, guidance and support rendered by DST, the Chairman and an expert panel of Governing Councils of ARCI and Technology Advisory Groups pertaining to each Centre of Excellence as constituted by DST, together with the dynamic and able leadership (Directors) of ARCI also played an equally important role in transforming the outcome of Science Diplomacy into the low hanging fruits readily needed for the Indian industry.



Dr K. Kasturirangan on pedal-powered hydrogen demo kit



Change of Guards: Dr G. Sundararajan (centre), Dr G. Sundaresan and Dr Y.R. Mahajan (left and right, respectively)



Dr A.P.J. Abdul Kalam at INDOSIS-1996 workshop



Dr V.S. Arunachalam (second from left) during a visit to ARCI

Success Seeding the New Challenges

As a common phenomenon to any R&D laboratory, such as ARCI, engaged in translational research with technology commercialisation as its primary target, it is apparent that the rate at which the developed technologies are transferred to the industry is directly proportional to the pace at which its technology basket gets dried up. Keeping this in mind, driven

by its strong desire to be at the forefront of the developments in materials and materials processing technologies and their effective industrial use, ARCI forayed and expanded consistently, establishing new groups of excellence in application-relevant fields such as (a) Nanomaterials and coatings, (b) Laser processing of materials, (c) Fuels cells, (d) Solar energy materials, (e) Automotive energy materials and (f) Additive manufacturing. Accordingly, several in-house R&D programs were initiated to continuously feed the technology basket of ARCI at an appropriate interval. In addition, the scout for entirely new technologies (in the Indian context) but available elsewhere on the globe at various Technology Readiness Levels (TRLs) is continued not only as a means of filling the basket and delivering various national missions but also to keep the new technological and global market avenues open to the Indian industries.



Shri Y.S. Rajan inaugurating DSC technology transferred to an entrepreneur



Dr G. Sundararajan signing a contract with ICEBT, Ukraine

Striking new international collaborations

While continuing its in-house development of materials/products/processes that the Indian industry needs, in line with its core values to work on application-centric and innovative technologies, ARCI has initiated several international collaborations with the support of DST. A few of the selected international collaborations, objectives and accomplishments are briefed below:

A joint centre for advanced nanomechanical characterisation (ANC) was established at ARCI in collaboration with **Ms. Nanomechanics Inc., Oak Ridge, USA,** in 2016. Its primary objective is to perform fundamental and applied research in small-scale mechanical characterisation that enables the development of novel test methodologies and next-generation nanomechanical testing products. The centre aims to leverage the expertise of the US partner in equipment design and ARCI in test methodology and application development. As a part of the joint centre, multiple types of equipment were sold to academic institutions, R&D laboratories, and private companies across the country. A significant achievement of the centre is the collaborative development of a high-speed nanoindentation-cum-data deconvolution tool, NanoBlitz3D+, to determine the mechanical properties of constituent phases of multi-phase materials. It was globally launched in 2019 in San Antonio, Texas, USA, during the TMS exhibition by Dr G. Padmanabham, Director, ARCI. The high-speed capability of the mapping tool has reduced the testing time for a single test from minutes to less than a second, thereby significantly



Various heat pipe heat sinks produced by an entrepreneur on a commercial scale



Simolayer Zoz-ARCI demonstration facility created at ARCI formalising alliances





Ultrafast Laser micromachining facility at ARCI (50- 100 fs, 800, 400 & 266 nm, and 100 ns, 527 nm, at 10 kHz) and the 3-D control grid created using such system

increasing the throughput. The commercialisation of this tool has resulted in a paradigm shift in indentation testing at a global level, as evidenced by the 100s of research articles published using the tool. In addition to product development, many applications also progressed. Subsequently, the product and application development efforts were amply supported by basic R&D studies, resulting in more than 25 publications with 100s of citations within a few years.

Furthermore, an ultrafast laser micro/nano fabrication and machining facility was established in the Centre for Laser Processing of Materials in 2014 through a collaborative research agreement between ARCI, India, and the **National Research Council, Canada**. This activity aims to establish a state-of-art ultrafast laser processing system and develop surface texturing of materials for automotive applications. The ultrafast laser micro/nano machining system at ARCI is equipped with some of the most cutting-edge features. This system can machine features as small as 10 μm with accuracies of 0.1 μm and without heat-affected zones. In the last few years, this system has demonstrated various applications and many others are under development.

The heat pipe is an efficient heat transfer device that works on the evaporation and condensation of fluid inside the pipe and enables to transfer large quantities of heat with a minimum temperature drop. The thermal conductivity of heat pipes is several hundred times more than copper. These devices have applications in electronic, semiconductor, electric locomotive and manufacturing industries. ARCI has developed the technology for manufacturing heat pipe heat sinks of various types in collaboration with the **Powder Metallurgy Research Institute and Luikov Institute of Heat and Mass Transfer, Minsk, Belarus**. The technology was transferred to an entrepreneur, and the industry has established a manufacturing plant for heat pipes in Hyderabad.

A joint demonstration Centre for high-energy ball mill (Simoloyer) technology was established at ARCI in 2008 in collaboration with **Zoz GmbH, Germany**. The latter is a pioneer in developing high-energy ball mills, which are being used for the development and production of nanostructured materials, oxide dispersion-strengthened alloys, electrode materials for batteries, metal matrix composites, etc. Zoz GmbH supplied CM-08 mill (1 kg/batch) at a discounted price, and ARCI extended infrastructure and manpower for demonstrating the equipment to various Indian industries. Eventually, ~5 mills were sold to various Indian industries and research institutes, which earned substantial revenue for ARCI. These mills are being extensively used by ARCI, for the development of materials needed for various projects of strategic, R&D and industrial requisites.

In addition to the aforementioned international collaborations, ARCI fostered some unique technologies in the national context, namely (a) Electron Beam Physical Vapor Deposition Technology established in collaboration with the **International Center for Electron Beam Technology (ICEBT), Paton Electric Welding Institute, Ukraine**, (b) Cold Gas Dynamic Spraying in collaboration with the **Institute of Theoretical and Applied Mechanics (ITAM), Novosibirsk, Russia,** and (c) Sol-Gel coating techniques in collaboration with **EPG, Germany,** to name a few. These unique technologies are being extended to Indian strategic and industrial sectors for reaping the potential techno-economic benefits.

Summary and Way Forward

While ARCI fruitfully enjoys a multitude of success stories, arising both out of multiple products delivered and technologies transferred to Indian industries, it continues to explore all the possible avenues to invent, incubate and collaborate strategies for continued leadership in translational research. Being a direct product of Science Diplomacy per se, ARCI will continue its relentless efforts to conceptualise and systematise national and international collaborations for the benefit of Indian industry and to leap participation in various national mission programmes of the Government of India. Concerning Indian Science Diplomacy, this article clearly illustrates the fact that the current Indian ecosystem, excellent infrastructure, and receptive and yet vibrant mindset of the citizens in the country are in favour to create and nurture more institutes,

industries and startups. Accordingly, frontier areas that need immediate attention shall be identified and carefully chosen (including semiconductors, hydrogen economy, aerospace, electric mobility, advanced manufacturing and others), and Indian Science Diplomacy to act in front to forge vital collaborations for the larger benefit of present and future generations of the country to realise the global leadership in the decade to come.

As a concluding remark, Science Diplomacy is already proven to be an exceptional tool in the hands of any nation with a promise to deliver an impactful contribution to the circular economy and political and cultural development. In the current era, Science Diplomacy shall be treated as a powerful weapon that will not create any victims but drives the multi-directional growth of the nations with a promise to transform the developing countries into developed nations by way of creating healthy and wealthy societies around them.

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