MP3-NUCLEAR POWER PROGRAM – STAGE – 3

3.070 FUSION REACTOR

Institute for Plasma Research (IPR) has undertaken diversified activities which can be are broadly divided into two categories namely; 1) Immediate societal benefit program and 2) Long time energy need related societal benefit program.

3.07-100 IMMEDIATE SOCIETAL BENEFIT PROGRAMM

I PLASMA BASED TECHNOLOGIES AND APPLICATIONS

Under this category, programs making use of existing plasma technologies relevant for the societal benefits are covered. Wide ranging applications from addressing very common but effecting large population like the basic biological treatment to voluminous task of waste management has been initiated. Efforts are already made for making them available for mass population, from the perspective of addressing basic needs of the society. Contribution made toward development of new material and strengthening hardness of the existing ones have already started bringing fruits to the industry and society. Processes like skin treatment of fungal infection using plasma jet, nitriding treatment of surfaces to improve wear and tear and corrosion resistance, dying treatment of Khadi with plasma which acts as a natural dying, waste treatment using plasma pyrolysis, development of Angora wool are some of the noticeable contributions. Details of these technologies and their societal benefits are given below.

a) Atmospheric Plasma Jet for Skin Treatment

Atmospheric plasma jet developed at FCIPT was used for skin treatment under the BRNS Sponsored collaborative project titled – “Cold plasma application on human skin disease treatment” with Dr Abhijit Majumdar, IIEST as PI and Dr. S. Mukherjee as PC. Ethical permission was obtained from IPGMER- SSKM Hospital for plasma jet application on three patients with skin fungal infection (Tinea family).

Fig 1: Photograph showing application of plasma jet on skin fungal infection.

Patients were treated superficially, without anaesthesia, typically for ~ 15 minutes/ sitting/ week [Fig. 1]. After 2- 3 sittings on patients, it was found that infection did not recur even after one year. No additional medicines/ ointments are needed after applying treatment. Noticeably, no observable side effects were seen after application of plasma jet. Attempts are being made to get Ethical Permission from IPGMER hospital to treat 25 patients and introduce plasma jet treatment as a standard procedure to treat skin fungal infections.

b) Plasma Nitriding Systems in 15 Central Tool Rooms in India

Conventional nitriding is potentially very hazardous to environment due to use of poisonous chemicals like cyanides and ammonia whereas plasma nitriding process uses non-toxic & precisely controlled gas mixtures. Plasma nitriding process is hence recommended as an alternative, environmentally benign surface treatment process for improving the wear and corrosion resistance of all mechanical components prone to wear. A proposal has been send to MoS, MSME for installing plasma nitriding system in 15 tools rooms in India.

c) Khadi Treatment With Plasma, Use of Natural Dye

Investigations were carried out on Khadi using dielectric barrier discharge. The initial results obtained of natural dyeing of plasma treated Khadi were encouraging. A brief proposal was submitted to MoS, MSME (Ministry of State) for setting up a plasma treatment system to treat Khadi in an environment friendly manner.

d) Waste Treatment Using Plasma Pyrolysis

IPR has successfully developed and demonstrated the plasma pyrolysis technology for the disposal of Bio-medical waste by installing 11 numbers of plasma pyrolysis systems at various parts of India, funded by Department of Science and Technology. The Ministry of Environment and Forest and Climate Change (MoEF & CC), Govt. Of India has given approval to plasma pyrolysis technology for safe disposal of biomedical waste in India through the notification in the Gazette of India vide no. 197 of Extraordinary Part II section 3 subsections (i) and GSR No. 343E.

Recently, a fully automated system [Fig.2] has been installed and commissioned in GIFT city (Gujarat International Finance Tec City, a smart city in Gandhinagar, Gujarat) which disposes paper, plastic and STP sludge at rate of 150 kg/day.

Fig. 2: Plasma Pyrolysis System installed in GIFT City, a smart city in Gandhinagar, Gujarat, India.

IPR has also demonstrated application of plasma pyrolysis technology for safe disposal of non-medical waste and successful energy recovery. FCIPT has taken up a project from CPCB for measurement of toxic emissions using different types of plastics including PVC. It was shown that the technology safely destroys this plastic waste keeping the emissions well under the CPCB norms. Institute is planning to establish large scale plasma plant and common biomedical waste treatment facility for safe disposal/treatment of bio-medical waste. Intellectual Property Rights of this home grown technology is held by IPR through three Indian patents. IPR in collaboration with CSIR- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI) is performing a study on disposal of industrial spent solvents and chemical waste using plasma gasification/pyrolysis process.

Fig. 3: Plasma pyrolysis /gasification system for the disposal of solvent waste commissioned at CSIR-CSMCRI, Bhavnagar, India.

IPR has planned to establish 200 kg/hr plasma pyrolysis system for biomedical waste disposal at Civil Hospital Ahmedabad. In this regard an umbrella MoU has been signed between Health & Welfare Department, Govt. of Gujarat and Institute for Plasma Research. A separate MoU has also been sent to Civil Hospital and Health dept. Govt. of Gujarat to establish a Biomedical Waste Treatment Facility along with 200 kg/hr plasma pyrolysis system at Civil Hospital, Ahmedabad.

e) Artificial Intelligence Software for Automated Detection of Pulmonary Tuberculosis Footprints

In an emerging field of Artificial Intelligence (AI) worldwide, IPR has taken initiative towards development of software for helping the medical fraternity. An automated detection of Pulmonary Tuberculosis footprints in chest X Rays is carried out using this software. Capable of running on portable devices like laptop, Raspberry PI, mobile etc., the software facilitates fast, automated screening of chest X Rays, thereby ensuring prompt follow-up and treatment, even in rural areas where there is a dearth of experienced radiologists. The prototype version is ready and has been demonstrated at various exhibitions and meetings. India reports 27% of world's new TB cases. Early detection and prompt treatment can save lives.

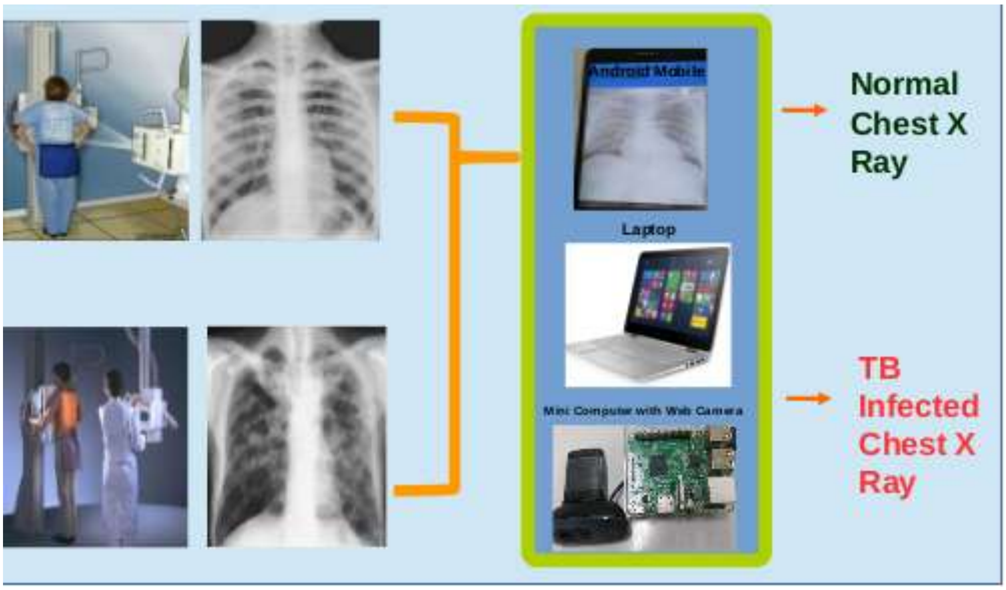


Fig. 4: Schematic showing the process involved and usage of AI software in identifying the disease.

f) 3D Simulations for Plasma Thruster

3D computer Simulations of Plasma Thrusters have been carried out in IPR. Plasma Thrusters are routinely used for attitude control & station-keeping of satellites. ISRO has so far imported these thrusters. IPR has started in-house development of this critical system. An important step is the in-house development of three-dimensional software which has just been completed. This is providing new insight into the dynamics of such Thrusters, especially oscillations in Thrust. This insight will help in design/optimization of experimental systems.

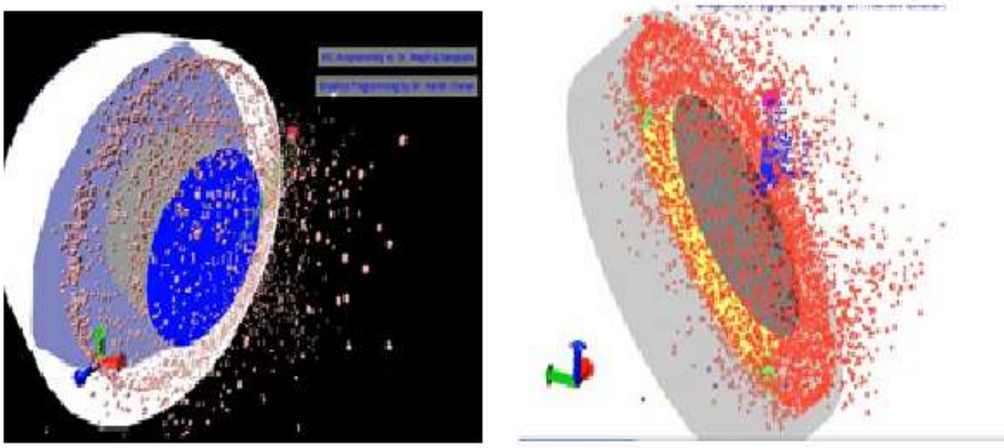


Fig. 5: Snap shots of animated 3-D simulation of plasma thruster.

g) Dusty Plasma Formulations for Biological Fluids

Application of dusty plasma formulations to processing of complex biological fluids is investigated. A strong dynamical similarity exists between flow of dust particle electrostatically suspended in the plasma (dusty plasmas) and cellular matter suspended in a biological blood plasma. The flow dynamics of suspended dust clouds is volumetrically driven by the relatively high Reynolds number plasma flow quite similar to volumetric drive of cellular matter and nutrients in the blood that is drive by the flow of biological blood plasma, essentially a liquid protein. The formulations developed for confined flow of dusty plasma and corresponding complex dynamics provide ideal modelling tools for the dynamics of the blood and various biological fluids for both their in-vitro and in-vivo processing applications. The 2D vortex flow formulation developed for dusty plasma vortex recovered in the laboratory experiments with monodispersive dust particles is being applied to understand the empirical relation applied to an innovative microfluidic based in-vitro blood plasma separation technique developed by IIT-Bombay.

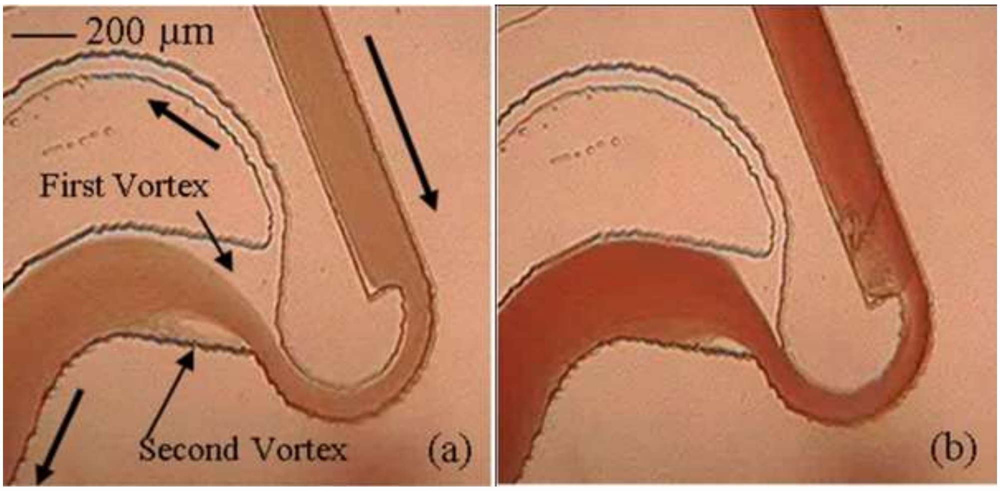


Fig. 6: In the micro device developed by IITB for blood plasma separation an expanding channel procedure is used where vortex formation in the expanding flow is utilized to separate cellular matter from the blood plasma as shown in the Fig. 1(a) and (b), showing the experiment at two difference heametocratic values.

II ADVANCED TECHNOLOGIES & APPLICATIONS

Progressing on the road map of long term societal benefit program of fusion plasma, IPR has developed many advance technologies which have benefits on both immediate and large time scales for scientific and societal applications. A brief mention of few of them is made here.

a) Regulated High Voltage Power Supply (RHVPS) for LEHIPA

An IPR-supplied RHVPS for the LEHIPA experiment at BARC has been re-commissioned for a new phase of experiments with LEHIPA. Major issues related to application as well as site conditions have been resolved. All sub-systems of RHVPS (i.e., power modules, transformers and controller) have been successfully tested and commissioned by a team of scientists and engineers from IPR. The operators have been trained for minor trouble shooting and repairs as well. A long (approx. 15 days) round-the-clock campaign has been successfully concluded. RHVPS is now fully operational with 70 kV, 12 A, in pulsed mode (1, 2 and 3 Hz). The RHVPS has been used by the BARC team for conditioning of a klystron, yielding extraction of up to 300 kW beam.

Fig. 7: Photograph of RHVPS with power modules in stacks.

b) Indigenously Developed Largest Capacity Chillers

The largest chillers ever made in India delivered to ITER. Four such chillers, each of 4 MW capacity are developed. Other major components like Plate type heat exchangers, stop log gates, piping spools, pipe supports, electrical and I&C items have also been delivered to ITER in batches.

Fig. 8: Photographs of one of the chillers undergoing pre-shipping inspection (a) and delivery of chiller at ITER site (b).

c) Indigenous Development of Vacuum Brazed Cryopump Assembly

This development will help the manufacturing of Cryopump with no risk of tube puncturing, reduction in skill dependent brazed quality and reduction in production time. These pumps IPR will supply to SAC, Ahmedabad under the MOU signed between the directors of the two institutes.

Fig. 9: The photograph of indigenously developed vacuum brazed Cryopump assembly.

d) Indigenous Development of Internal Bore Welding Torch

This development will help to mitigate the challenges of space constraints during welding and will fulfil the requirement of full penetration weld. The weld produced by this torch is qualified for the requirements of vacuum boundary as per ITER protocol mainly with respect to 100% volumetric examination and other strength parameters. With the present configuration, it is possible to approach the weld edge up to the distance 180 mm, pipe diameter of 50 mm and thickness of 1.6 mm. These ranges could be expanded as needed for the application.

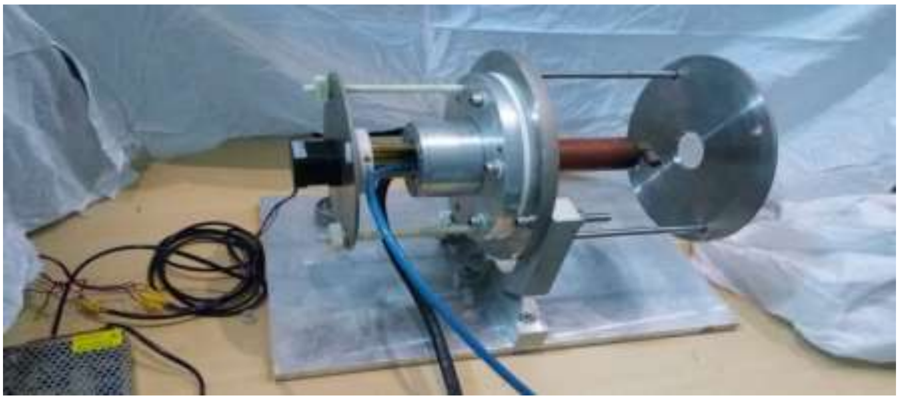


Fig. 10: Photograph showing image of internal bore welding torch.

e) Remote Handling and Robotics Technology Development

This work is primarily carried out in IPR by RHRTD division. They have upgraded the existing Remote Handling (RH) systems with respect to control and safety. The division is also involved in developing a 'one-of-its-kind' vacuum compatible inspection system. Designing and commissioning of Prototype Articulated Robotic System –II **(**PRAS-II) is the latest addition. This system has six degrees of freedom and the equipment has articulation for traversing a toroidal workspace. The system is designed to carry a maximum payload of 25 kg at 2 meter.

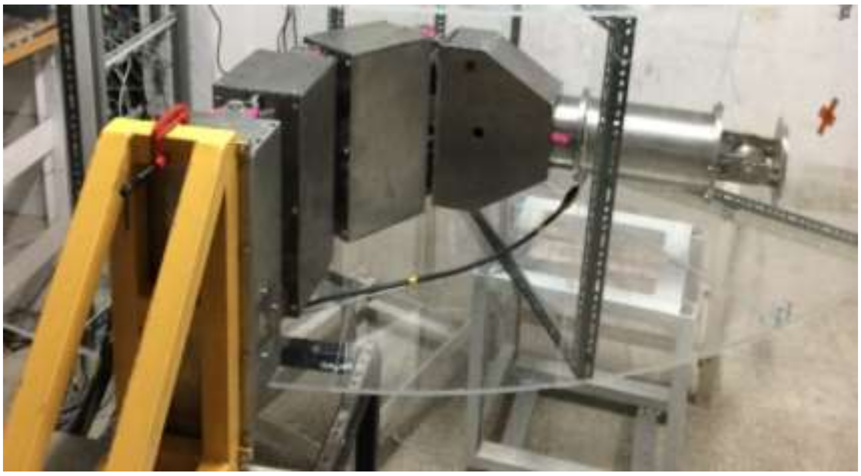


Fig. 11: The photograph showing the VR move as simulator for operator training.

f) Tetrode Based RF Amplifier Tested for 1.7 MW Power

Tetrode- based Driver and final stage High Power RF amplifiers commissioned at ITER-India lab. Successful test results obtained at up to 1.7 MW output.

Fig. 12: Photograph showing the Tetrode based system at ITER-India laboratory.

g) Liquid Metal Technologies

IPR is involved in fusion blanket technologies development such as, lead-lithium technologies, fusion materials (structural and functional) development, high temperature high pressure helium technologies and fusion fuel cycle technologies to support the development of test blanket module program in ITER.

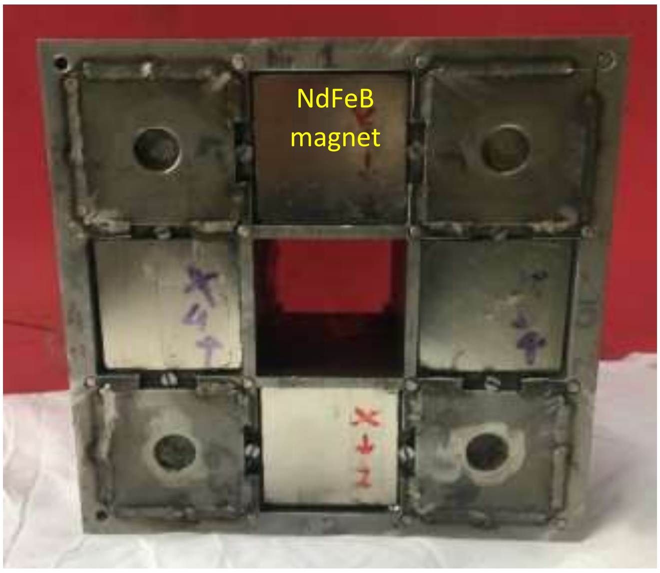


Fig. 13: Photograph of MHD flow meter based on permanent magnet developed at IPR.

Lead lithium (Pb-Li) eutectic alloy is used as a coolant as well as breeder in breeding blankets.

Fig. 14: Photograph showing panoramic view of the Pb-Li heat transfer loop.

The R&D activities at IPR are primarily focused to the development of process diagnostics such as pressure sensors, flow meter, level sensor, temperature sensor etc. and their testing in Pb-Li loops. In a recent development, high temperature compatible sensitive flow meter, using permanent magnets has been fabricated (Fig. 13). The flow meter is now being calibrated in a Pb-Li loop at an operating temperature of ~ 350^{o}C.

A Pb-Li experimental loop (Fig. 14) has been fabricated in-house and is being operated for heat transfer studies. The loop has salient safety features such as instant Pb-Li leak detection in case of pipe breakage, remote controlled operation of pneumatic valve, automatic liquid drainage from the loop to the storage tank in case of power failure, etc.

h) Space Quality Plasma Nitriding System Installed and Commissioned at ISRO Inertial Systems Unit, Trivandrum.

In order to provide wear resistant coating for intended operation of spacecraft components without degradation; plasma nitriding process was established by FCIPT-IPR for the SADA gears. This process has been qualified and life tested at subsystem level and rendered excellent performance on board in all the ISRO spacecraft geo-missions since 1998. On 3rd November 2017, a UHV plasma nitriding system of 500 mm diameter and 500 mm height was installed and commissioned at IISU Trivandrum. This system will henceforth be used to treat all spacecraft components for enhanced service life.

Fig.15: Indigenously developed plasma nitriding system for ISRO Inertial Systems Unit (IISU, Trivandrum).

i) Fusion Fuel Cycle Technologies

Tritium generated in the breeding blanket is to be extracted and stored for refuelling during the reactor operation. This process system requires tritium extraction system, storage and tritium accountancy. As a recent development, Manganese-Chloride ($MnCl_2$) modified Alumina column for Gas Chromatography (GC) System has been developed to separate and analyse very low concentration (~100 ppm) of hydrogen isotopes in carrier helium gas. The experimental set up used for this purpose is shown in Fig. 16.

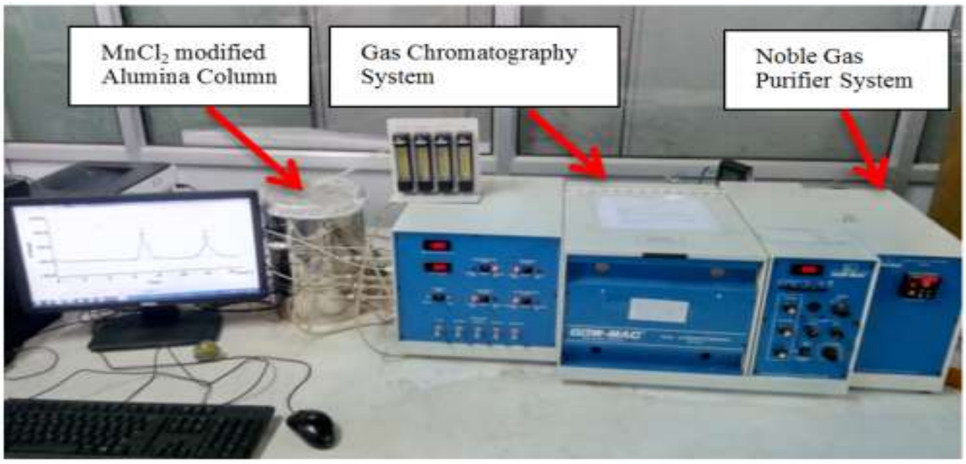


Fig. 16: Picture of the experimental set up for modified Alumina column with GC System.

III TECHNOLOGY TRANSFER AND MOU SIGNED

IPR has transferred the innovative technologies in the field of plasma and other related fields to various private entrepreneurs and to some government agencies as well. The details are given below.

a) Technology Transfer for Plasma Based Nano Powder Production

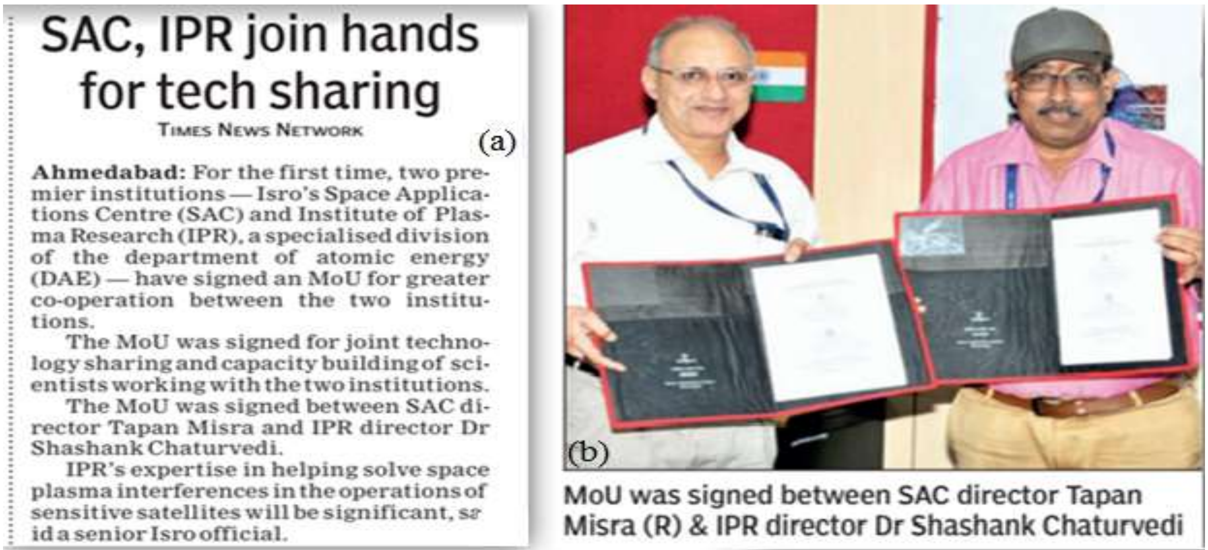
Nanotechnology is the enabling technology for next generation advanced machines and processes. IPR's efforts have been focused on developing industry specific nanotechnologies using plasma technology. One such technology is nano-powder production technology developed at FCIPT Division, IPR.

Based on the interest of Ahmedabad based company M/s Vishal Engineers & Galvanizers Pvt. Ltd. (VEGPL), a non-exclusive Technology Transfer agreement was signed by and between IPR and VEGPL on 14th June 2017 at IPR.

Fig. 17: Nanotitania production system installed at FCIPT Division of IPR in (a), and (b) photograph showing signing of transfer of Nano-powder Production Technology to M/s. Vishal Engineers & Galvanizers Pvt Ltd, Ahmedabad.

b) MoU signed between IPR and SAC-ISRO Ahmedabad and ISAC – ISRO Bangalore

Large pumping speed is required for fusion machine like ITER, an experimental fusion reactor with its cryostat having a volume of 16,000 m^3 requiring pumping speed > $5x10^5$ L/sec. Space research and many other technological areas also require large pumping speed to pump chambers of huge volumes or to handle voluminous gas loads. Large pumping speed ($3\text{-}6\ x10^5$ L/s) pumps are required to create vacuum in such huge chambers.


SAC, IPR join hands for tech sharing

TIMES NEWS NETWORK

(a)

Ahmedabad: For the first time, two premier institutions — Isro's Space Applications Centre (SAC) and Institute of Plasma Research (IPR), a specialised division of the department of atomic energy (DAE) — have signed an MoU for greater co-operation between the two institutions.

The MoU was signed for joint technology sharing and capacity building of scientists working with the two institutions.

The MoU was signed between SAC director Tapan Misra and IPR director Dr Shashank Chaturvedi.

IPR's expertise in helping solve space plasma interferences in the operations of sensitive satellites will be significant, said a senior Isro official.

(b)

MoU was signed between SAC director Tapan Misra (R) & IPR director Dr Shashank Chaturvedi

Fig.18: Image of press release in Times of India highlighting the significance of this MOM in (a) and copy of MOU displauyed by IPR director, Dr Shasahnk chaturvedi and SAC director, Mr Tapan mishra in (b).

Presently IPR has signed a MoU with SAC Ahmedabad and will be supplying SAC, Ahmedabad 9 cryogenic pumps. These are 400 mm opening pumps, with the required pumping speed of 16, 000 l/s for water vapour and 5000 l/s for Nitrogen. A lab scale model of the same is being tested for it performance at IPR. The cryo-panels of cryo-cooler based cryo-pumps not giving enough pumping speed due to deterioration in the porosity of the sorbent were treated and rejuvenated as fresh cryo-panels with fresh sorbents. IPR is carrying out the tests on such panel supplied by ISAC, Bangalore. The work involved recoating of cryopanels of commercially available cryocooler based cryopumps.

c) MoU between IPR and Health and Family Welfare Development, Govt. of Gujarat

An Umbrella Memorandum of Understanding (MoU) is signed between Institute for Plasma Research and Health and Family Welfare Department, Govt. of Gujarat (H&FWD, GOG) for cooperation on technologies and knowhow projects and any other issues to cater to H&FWD, GOG's requirements. This will involve development of systems, technologies and transfer of knowhow so achieved. Any accretion and future endeavours by way of projects or activities may be undertaken. This Umbrella MoU is signed on 16th October, 2017 and will be valid for an initial period of five years, further extendable under mutually-agreed terms & conditions.

Fig. 19: Photograph taken during signing of umbrella MOU between IPR and Health and Family Welfare Department, Govt. of Gujarat (H&FWD, GOG) for cooperation on technologies and knowhow projects and any other issues to cater to H&FWD, GOG's requirements.

IV VISITS OF DIGNATORIES AT IPR AND IPR PRESENTATION IN PARLIAMENT

a) Visit of Mr. Giriraj Singh, Honourable MoS, MSME

Mr. Giriraj Singh, Minister of State for MSME, Govt. of India, visited IPR on 10th Oct 2017 to understand first hand work related to industrial and societal applications of plasma being undertaken by IPR. The MoS was taken around at FCIPT division and shown several of the technologies developed/being developed there. The Minister mentioned that his ministry was in the process of promoting Khadi prepared with natural dyeing and expressed that scientific R&D inputs from FCIPT to determine the role of plasma technology in improving dye uptake or colour fastness would be appreciated.

The Minister had visited the IPR stall at the Parliament House Annexe, New Delhi during 28th July to 11th August 2017 and had shown interest in using plasma technologies in areas of interest to MSME such as plasma nitriding for tool rooms etc. The MoS was accompanied by Shri Sanjay Hedaoo, Director - KVIC; Shri B. N. Sudhakara, Director – MSME Development Institute, Shri Jaikrishna, PS to MoS and other members of KVIC. The visitors were initially briefed about the technologies being showcased to the MoS.

Fig. 20: In (a), Mr. Giriraj Singh, honourable Minister of State for MSME, Govt. of India, during his visit to IPR is trying to understand first hand work related to industrial and societal applications of plasma being undertaken at IPR and (b) the MoS being shown plasma nitriding process in progress.

The MoS also appreciated the work being carried out on societal applications of plasma and suggested many areas where plasma technology could possibly help. The MoS is also shown plasma treated wool and jute along with plasma nitriding in process.

b) Science Exhibition by DAE at Parliament

Institute for Plasma Research (IPR) had participated in the scientific exhibition by DAE at Parliament, New Delhi during 28th July 2017 to 11th August 2017. IPR exhibited various project activities carried out at IPR for the societal benefits viz., Plasma Pyrolysis for safe disposal of waste, Plasma treatment of angora wool and jute, Plasma Jet in biomedical applications, Nano patterning application in early detection of decease, Seed germination by plasma etc. Subsequently, Dr. Giriraj Singh, Honourable Minister of State for M.S.M.E., visited FCIPT, IPR for looking at various societal benefit projects. Based on the interaction with him, IPR has submitted few more project proposals for plasma nitriding in IGTR, waste disposal by plasma pyrolysis, jute treatment by plasma etc. IPR has also initiated an activity for setting up a common biomedical waste treatment facility including a large capacity (200kg/hr) plasma pyrolysis plant for safe disposal of biomedical waste generated in Civil Hospital, Ahmedabad.

Fig. 21: Honourable speaker of Parliament, Smt. Sumitra Mahajan (a) and Rajya Sabha MP Mrs. Renuka Chaudhari (b) at the exhibition held in Parliament.

V BASIC RESEARCH

This is well known that fundamental research remains a basic need of any institution. Last year some commendable work from this sphere of field have been reported. Basic and fundamental research in IPR covers a wide variety of subjects. It addresses issues concerning to earth's magnetosphere and fusion plasmas, even understanding dynamics of particle dust has generated tremendous interest and has become a cynosure of serious research because of its poisonous implications on fusion plasmas and space investigations. Work on surface treatment using low energy beams has progressed well; this has potential of addressing many application oriented objectives. Systems like Large Volume Plasma Device (LVPD), BETA, Flowing Plasma Device, IMPED Q-Machine, Non Neutral Plasma Device, SYstem for Microwave PLasma Experiments (SYMPLE) and Dusty Plasma have reported some interesting observations relevant to Magnetospheric and fusion plasmas. One of the noticeable observation to mention is probably the first laboratory observation of Quasi Longitudinal (QL) whistlers, this instability gets excited in earth's atmosphere when trapping of energetic particles emanating from solar flares in Van Allen Belts of earth's magnetosphere takes place. In LVPD this gets excited by reflected energetic electrons in loss cone scenario developed in +x belt region of source plasma (Fig. 22).

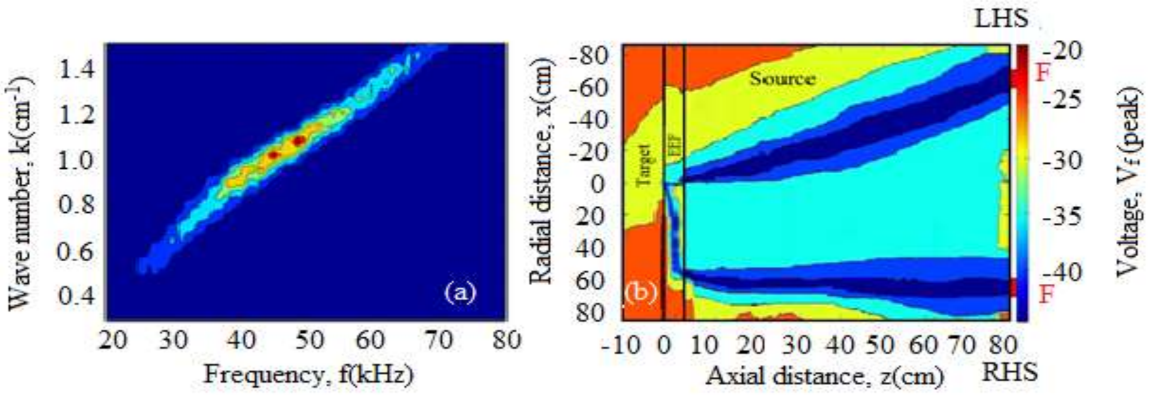


Fig. 22: (a) Joint wave number frequency spectra showing existence of QL whistlers and (b) plot of magnitude of magnetic field along field lines in $-x$ and $+x$ side halves of LVPD. 'F' represents filament locations and color bar represents the strength of peak floating potential(mimics presence of energetic electrons) in $x-z$ plane. The dark blue band in +x side represents the energetic belt with loss cone features imbedded

SYMPLE device has some developments in both phases of investigations. In Phase 1: Integration of the 3 MW, 3 GHz Magnetron with the pulsed modulator and dummy load tests and in Phase 2: Attainment of about 350 MW high power microwave (HPM) power BWO integrated with a compact driver source and design / concept validation tests of certain innovative HPM – plasma coupling schemes. A 3 MW, 3GHz, pulsed (5 µs) magnetron integrated with the pulsed modulator driver is tested successfully with a dummy load. For phase 2 operations, BWO is being developed at BARC as a combined effort by IPR and BARC and has been tested for the HPM output characteristics, with the compact pulsed power source (~500 KV, ~5 KA) specially developed for this purpose. Microwave power of ~350 MW (3.25 GHz, 40 ns) has been measured. In non-neutral plasma experiments relay based controlled baking system has been developed and integrated with a LabVIEW® application. Beside this, basic research also owns responsibility of generating a pool of trained manpower for meeting the domestic research needs of the country.

Plasma theory and simulation program in IPR, with advanced computational facility, is helping in providing interpretation to various experimental results obtained. This group has large collaborative work with institutions across the country and abroad. This group has significantly contributed in the fields namely, 1) Dusty plasma/ Complex plasma studies, 2) Laser Plasma interaction studies, 3) Nonlinear Plasma Theory and Simulation, 4) Fusion related studies and 5) Nonlinear Dynamics respectively.

3.07-101 LONG TIME ENERGY RELATED SOCIETAL BENEFIT PROGRAMME

I FUSION RESARCH

In long term societal benefit program, fusion energy is envisaged as a potential source for catering needs of the country. Progressing from the basic knowledge bank developed by operating Aditya tokamak, we progressed in operating Aditya-Upgrade. In Aditya-U, density enhancement with Hydrogen gas puff and runaway suppression in high density plasma has been studied. Plasma evolution at high spatial and temporal resolution is studied during start-up/burn-through, gas-puff and during disruption phase. Typical plasma shot (Shot no# 30628) is presenting visuals obtained using fast visible imaging video camera installed for 2D tangential viewing of different stages of plasma discharge(Fig. 23). Sizeable suppression of hard X-rays observed during repetitive gas puffed plasma discharges of plasma density ≥ 1.5 $\times 10^{19}$ m^{-3}. For phase-II operations, all 16 Minrov coils are calibrated by injecting a current to a toroidally placed hollow copper conductor. The cosine-sine coils, used for the plasma position are installed and calibrated. For phase –II operations, diagnostic systems such as spectrometer and fibers for High Z and low Z impurity monitoring, H-alpha array, Soft X-ray array, Bolometer array, Microwave interferometer, Thomson scattering, different configurations of Langmuir probe arrays, IR imaging camera, and Charge exchange are installed. A proportional–integral–derivative (PID) based feedback control system testing was carried out and has relevance for real time plasma position feedback control.

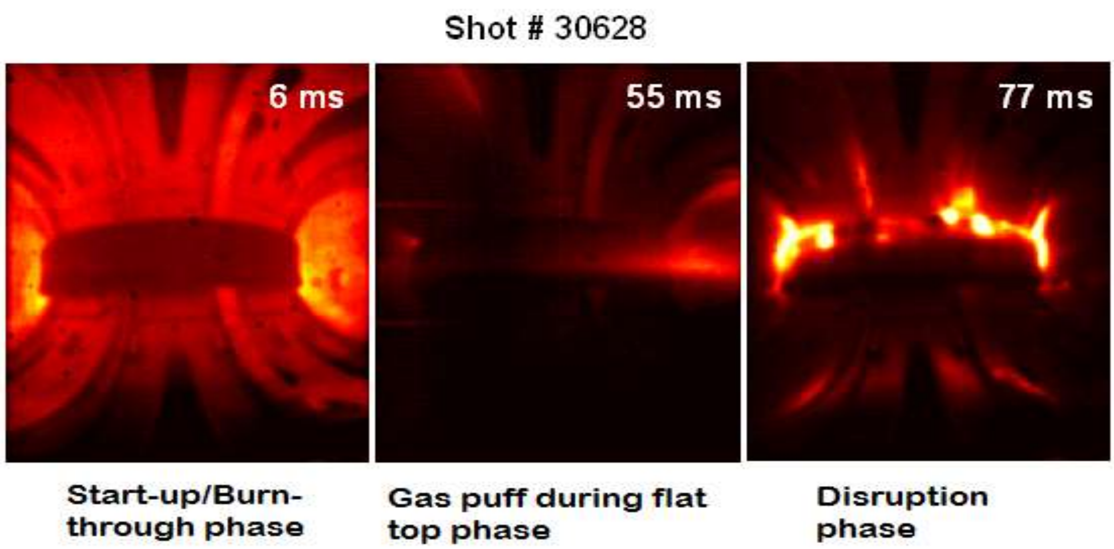


Fig. 23: Snap-shots of shot (# 30628) (a) start-up/ burn-through phase at 6 ms (b) gas puff during flattop at 55 ms and (c) Disruption phase at 77 ms.

In Steady State Superconducting Tokamak (SST-1), initiatives are undertaken towards installation of PF Power Supplies (stack of 11 power supplies). The power supply for PF-2 (Top and Bottom) coils are tested at full rating of 10 kA with short links and is interfaced to VME Data acquisition and control system. One of the auxiliary heating systems, LHCD was used for carrying out breakdown studies. It was observed that the plasma density is enhanced from 10^{11} to 10^{12} cm^{-3} using LH power. The pre-ionization of plasma using LHCD system in the absence of loop voltage is probably first such attempt in a tokamak. Previous attempts were on PLT (USA) where loop voltage was generated using the poloidal field systems and in JT60 (JAPAN), where a low loop voltage was applied from Ohmic coil system.

Pursuing further our fusion research program and exploring avenues for volumetric neutron sources, initiative for Spherical Tokamak (ST) has started. The increased fusion power, with less magnetic field makes ST a very attractive volumetric neutron source for nuclear fission fuel production. IPR is planning to design and construct a spherical tokamak indigenously with proven technologies. The pre-conceptual design of the ST machine with typical parameters of major radius (R)= 0.85 m, minor radius (a) - 0.68 m, toroidal magnetic field (B_t) of 0.3 Tesla and plasma current (I_p) of 0.5-1 MA with a heating power of 5 MW is under progress.

II DEVELOPMENT OF SPECIAL MATERIALS

a) Diverter Technology Division

Thermal Sprayed Coatings are widely used in industry for producing various kinds of coatings. Material to be coated is converted to high energy spray of hot & fine powder by continuously feeding it into the hot flame produced by high power (several kilo Watt) plasma torch. Hot flame in the form of electric arc is produced by passing high current (several hundred Amperes) through tungsten rods of the plasma spray gun. In order to achieve a sturdy low resistance electrical connection to these tungsten rods that can also withstand high temperature of the rod due to electric discharge produced by it, high purity copper is casted on these tungsten rods. Such rods are in high demand. However, due to their non-availability in Indian market, they are generally imported by the Indian industries from abroad.

In line with the "Make In India" activity, High Temperature Vacuum Furnace available at IPR is recently used to achieve simultaneous casting on total 98 nos. of tungsten rods using graphite fixtures. These tungsten rods are already tested by relevant industry and confirmed to be working satisfactorily for their thermal spray coating application.

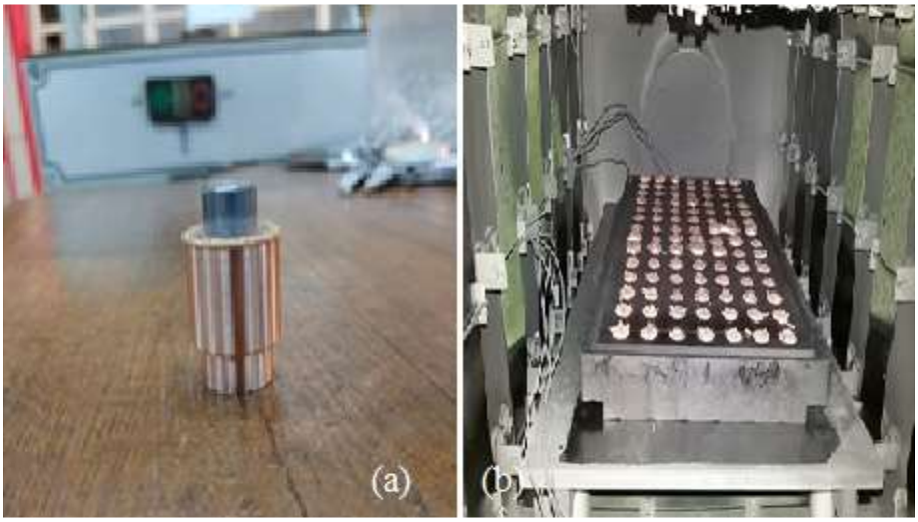


Fig.24: Photograph of copper casted tungsten rod (a) and batch production of copper casting(b).

b) Ceramic Breeder Pebbles Development:

IPR is performing R&D activities in the development of high purity lithium ceramic (Li_2TiO_3) pebbles as the tritium breeder material. The pebbles spherical (Fig. 1) shaped (~1 mm diameter) having porosity range ~10-15% for efficient tritium extraction. The production capacity has been further upgraded up to 20 kg per month with the high reproducibility.

Fig. 25: Photograph of Li_2TiO_3 powder and pebble prepared at IPR.

At every stage (powder, pellet and pebble preparation) of preparation, powder and pebbles are extensive characterized to meet the desired properties. Indigenously developed high temperature effective thermal conductivity measurement of pebble bed is currently under progress at IPR using steady state axial heat transfer method & hot wire method (fig. 2).

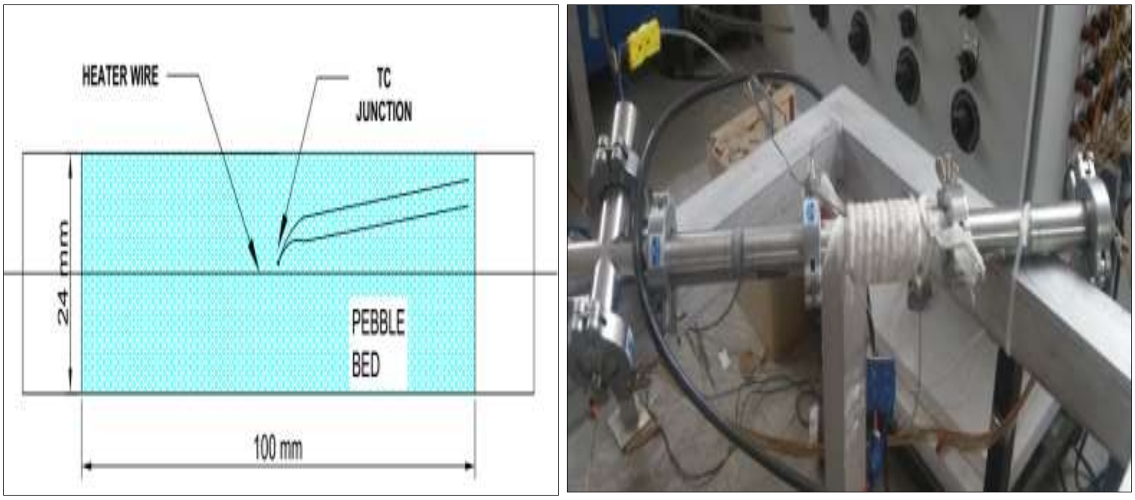


Fig. 26: Schematic (a) and the experimental setup of effective thermal conductivity measurement for pebble bed (b).

III ITER DELIVERABLES

In pursuance of meeting commitments made for ITER, IPR has delivered following items for the reported period.

a) Segments of the Lower Cylinder of the Cryostat (a 30 m dia. and 30 m tall vacuum vessel) have been manufactured in Hazira, delivered at ITER site and are undergoing sub-assembly operations in the on-site workshop. 13 segments of Cryostat Lower Cylinder components totaling 400 tons were shipped to ITER. The Base section components totaling about 1200 tons previously delivered have been welded.

Fig. 27: Base section Tier-1 sandwich structure welding completed at OTER site workshop (a) and Base section Tier-2 setup completed and cleared for welding(b).

Fig. 28: Lower cylinder Tier-1 setup completed.

b)The cryogenic lines (with multi-process pipes) manufactured in Kalol. These are one of the largest Cryolines of the ITER Cryogenic system. Several such components have been delivered at ITER site and are being installed.

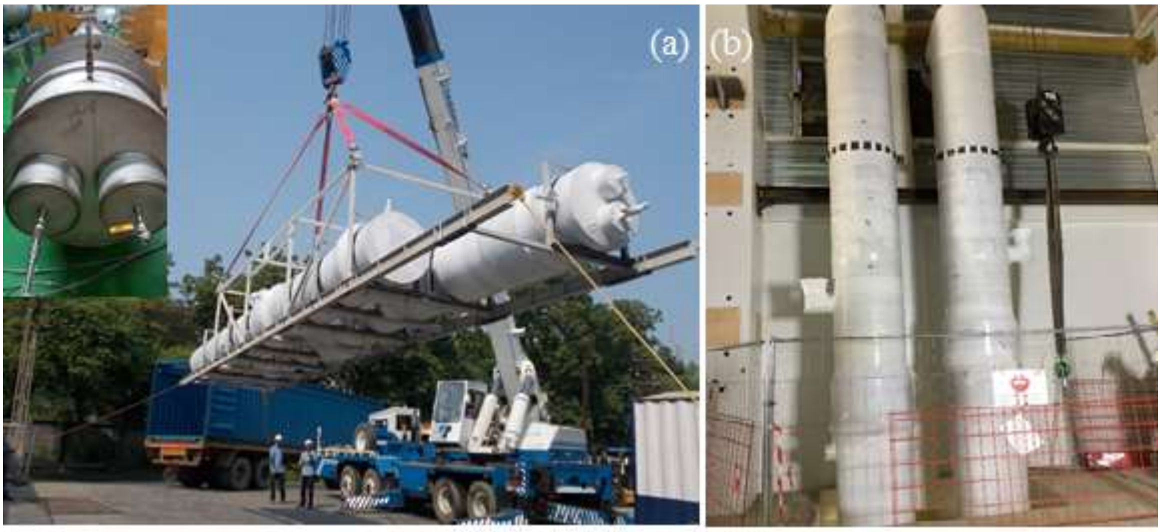


Fig.29: Cryogenic lines being loaded in the container consisting of multi process pipes (inset) in (a) and cryopgenic lines being installed at ITER site(b).

c) 6m long section (largest piece) of High Voltage Transmission line has been manufactured and successfully qualified for High Voltage DC withstand of 140 kVDC. Erection of the 13 m vertical section of the transmission line is in progress.

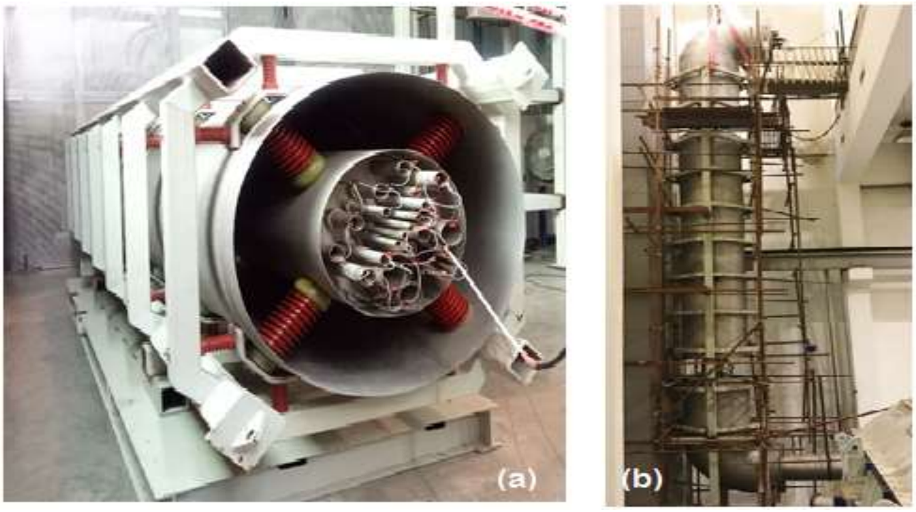


Fig. 30: Photograph showing HV transmission line prototype(a) and 13m verticl section of transmission line(b).