Development of Plasma Torches for Waste Management and R&D on Fusion reactor's materials

Pakistan Tokamak Plasma Research Institute (PTPRI)
Pakistan Atomic Energy Commission

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Nuclear Fission program of Pakistan

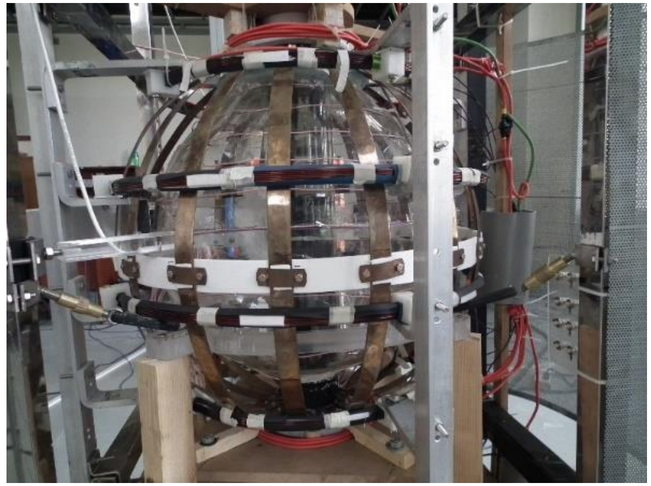
- Pakistan started its nuclear fission power program in 1971 with CANDU type power reactor
- Currently fission power plants are contributing a total sum of 3500 MW of electricity in national grid
- Several Cancer Hospital and Agricultural center are also serving the nation
- In parallel there are two research reactor for the training of young engineers and scientists

Nuclear Fusion Program of Pakistan

- Established in 2007 named "NTFP – National Tokamak Fusion Program"
- Renamed as "PTPRI – Pakistan Tokamak Plasma Research Institute" in 2020
- Vision: Tokamak as fusion energy source and a mean of innovative technological development for Pakistan
- Small training facility has been established
- Research publications and M. Phil / M. S students projects
- Part of three (03) IAEA-CRP (Coordinated Research Projects)
- Expansion to Medium sized Tokamak in progress
- Technological infrastructure in key areas of fusion power
- Multi-dimensional links with the international community
- Joining of ITER and world's mega projects of DEMO
- Support of IAEA and CERN to interact ITER as non-Member

Tokamak Devices at PTPRI

GLAST – 1

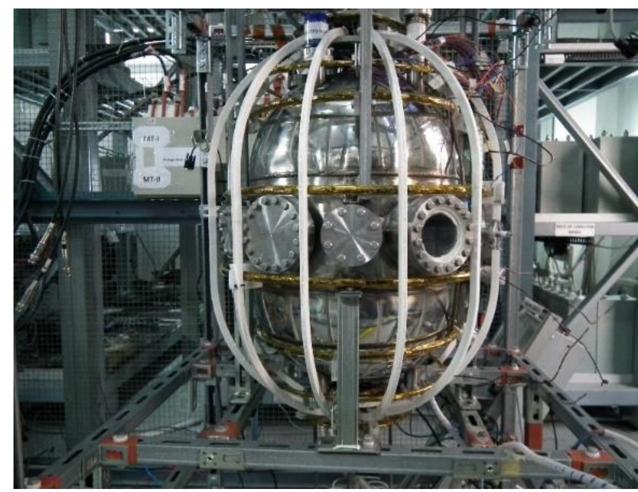


GLAST – 2

GLAST – 3

First plasma
6:30 pm 28th June,2012

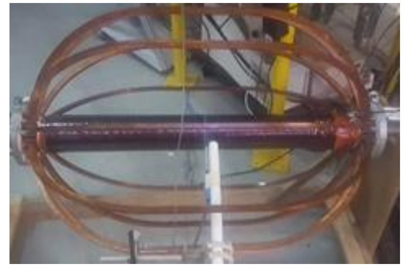
MT – 1



MT – 2

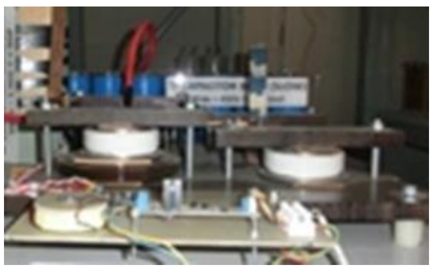
Indigenous Development at PTPRI

Vacuum vessels



Magnetic Field Coil Systems (0.33 – 1.0 Tesla)

DC Power Supplies (10kV – 20kV)



Power switches (~MW, ~mS)

IGBT gate drive controller

Trigger controller

Microwave (2.45Ghz, 3kW)

Rogowski Coils

3 – D Magnetic Probes

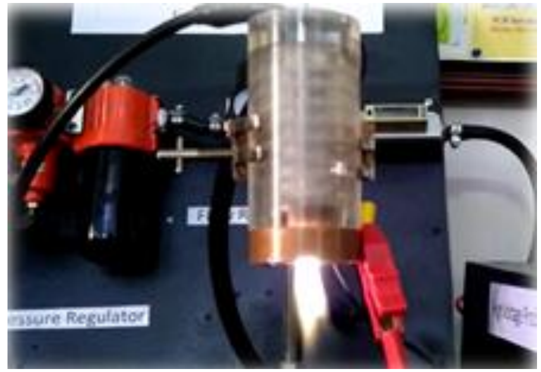
Langmuir Probes

Optical diagnostics

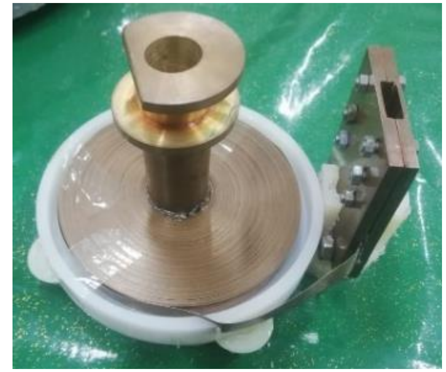
Data acquisition (20 – 100 Channels)

Technological Application Projects at PTPRI

Low Temperature Plasma
(DC and RF for coating, cleaning)



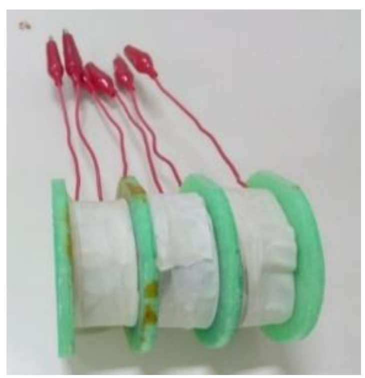
Plasma torch (250W, 500C)
(For waste management)



HTS coil
(DC magnetic field ~ Tesla)

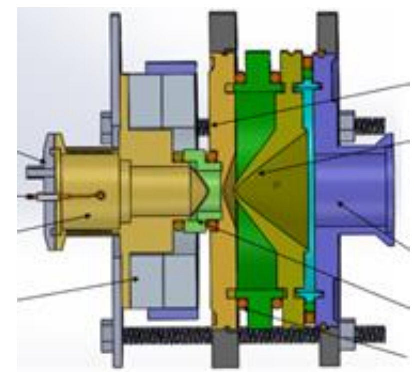
Lithium Evaporator

High power RF mono-pulse Generation (2.45GHz)



Eddy current probe
(Metallic Cracks)

High Frequency / H Voltage
(Biomedical / agricultural)



Prototype NBI system (~1 kW)

Fission-Fusion Synergic R&D Activities

- Development of plasma torches for waste management
- R&D on fusion Reactor’s materials

Plasma Torches for Waste Management

- Radioactive waste management is one of the major challenges faced by the nuclear industry
- One of the solution is the vitrification of waste (transformation into compact glassy slag) through high power plasma torches
- Plasma torches (temp. up to 10,000 Celcius) can reduce volume of low and intermediate level radioactive waste
  - by 50 times as compared to the untreated waste
  - over 10-times that of pre-compacted waste
  - by a factor of at least 2 for previously super-compacted wastes
- Decreased storage requirement for nuclear repositories, minimum risk of contamination and eliminates the need of pre-disposal processes like segregation, pre-treatment, incineration compaction etc.
- Large saving in financial expenditures with min. risk

Development of Prototype Plasma Torch

Specifications

Power: 250 Watts

Flame Temperature: ~500 ^{o}C

Design Features

- •Compact design having tangential entry of gas flow
- •Copper anode with nozzle shape and half cone angle of 30°
- •Tungsten cathode of 3.2 mm dia. at center of anode
- •Swirling effect for maximum exit velocity and laminar flow
- •Strong flow circulation at a swirl number of 1.73
- •Vortex flow constraints the plasma at center of anode for maximum stability
- •Rectified DC breakdown voltage of 4kV
- •Breakdown and plasma flame formation at the cathode tip

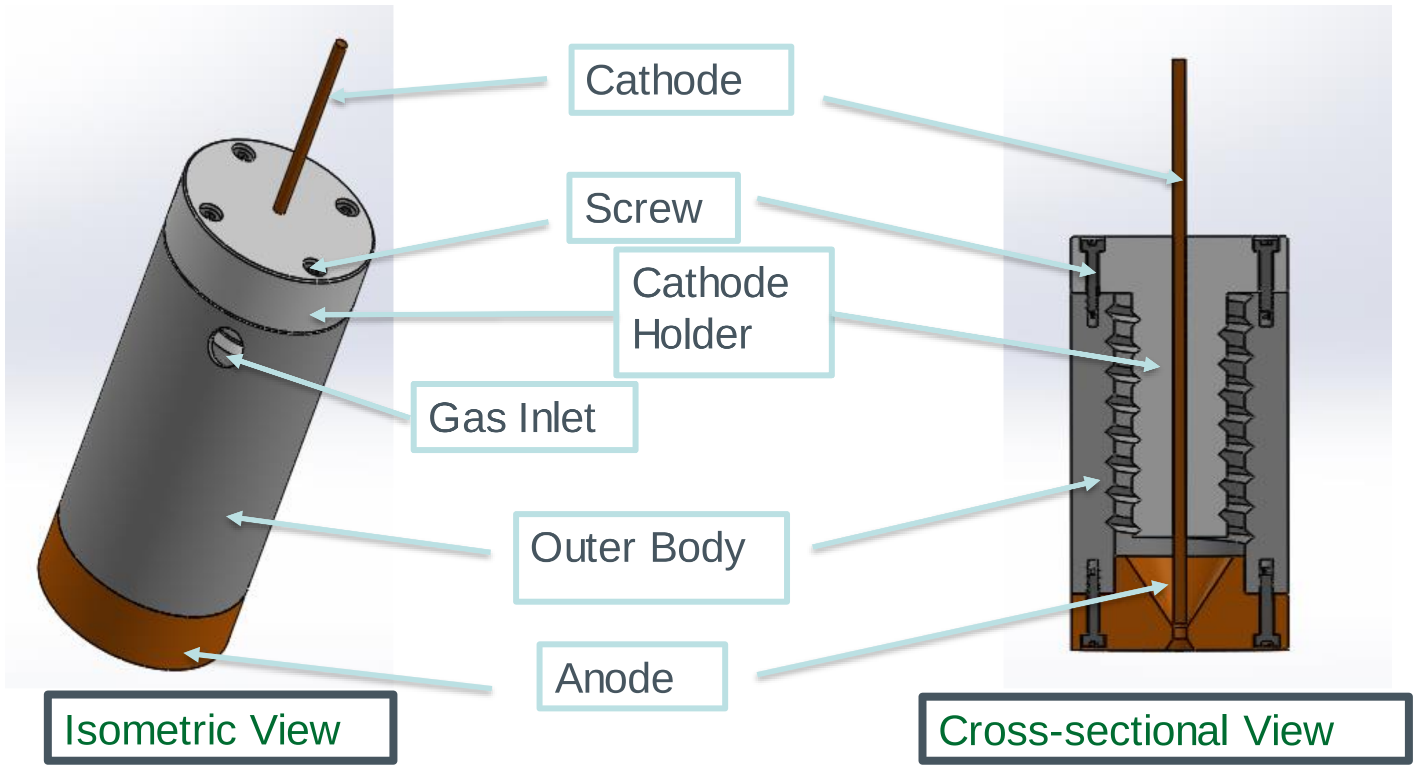
Design Parameters

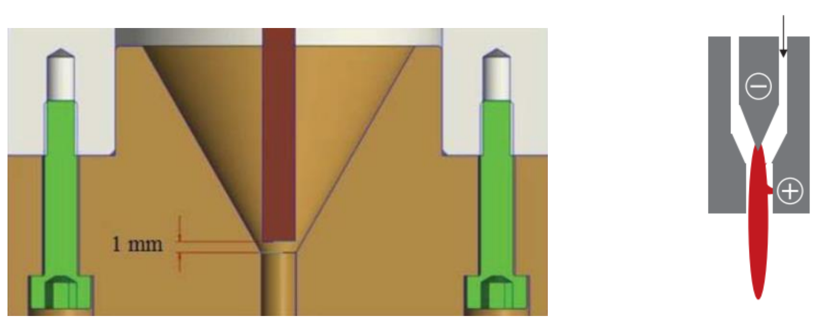
Parameters	Specification
Type of plasma	DC – APP
Power	0.25 kW
Current	62 mA
Voltage	4 kV
Atmosphere/pressure	Atmospheric
Gap between electrodes	5 mm
Gas flow rate	25 L min^{-1}

Parameters	Dimension (mm)
Tungsten cathode	3
Copper anode	
Inner diameter	3.2
Outer diameter	50
Nozzle cone angle	60
Height	25
Torch body	
Inner diameter	30
Outer diameter	50
Gas inlet diameter	6
Height	80
Perspex cathode holder	
Rod diameter	22
Cap diameter	50
Height	80
Helical annular space	
Groove depth	2
Groove width	4
Groove pitch	8

Components	Specification
Step-up transformer	
Power	250 VA
Input voltage	230 V@50 Hz
Output voltage	4000 V
Diode	
Model	HVM12
Peak reverse voltage	12,000 V
RMS voltage	8400 V
DC blocking voltage	12,000 V
Rectified current holder	350 mA
Capacitors	
Model	H1423M
Rated voltage	450 V
Capacitance	470 µF
Resistor	
Resistance	1 kΩ

Design Schematics



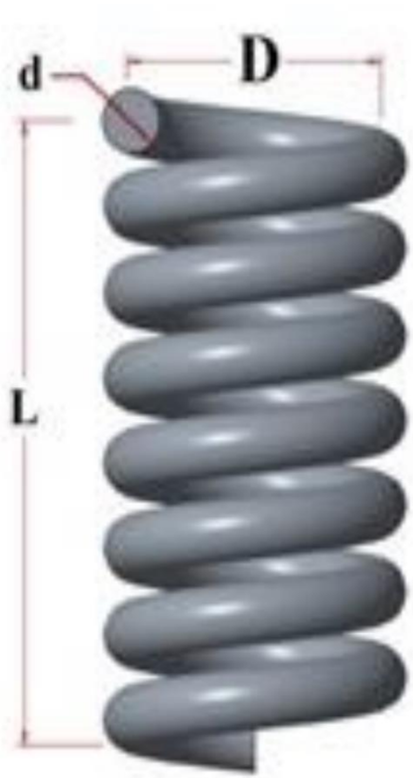


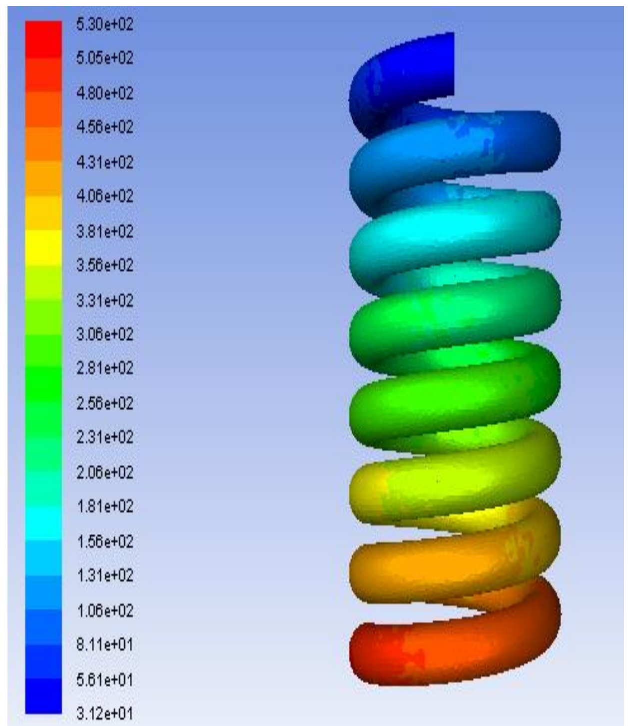
Breakdown region in the conical anode at swirl termination

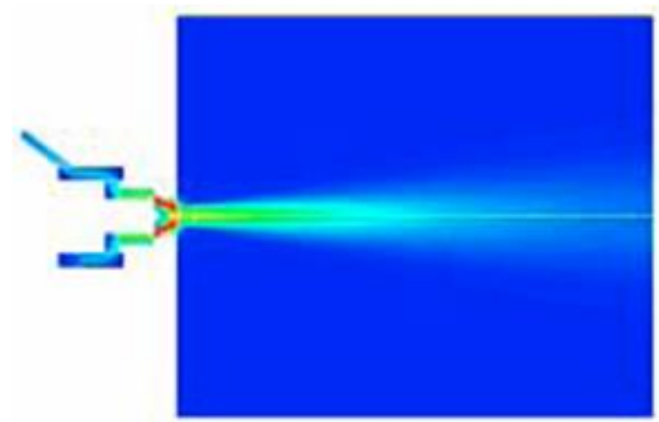
Computational fluid dynamics (CFD) on ANSYS

D = Coil Dia = 26mm
D = Wire Dia=6mm

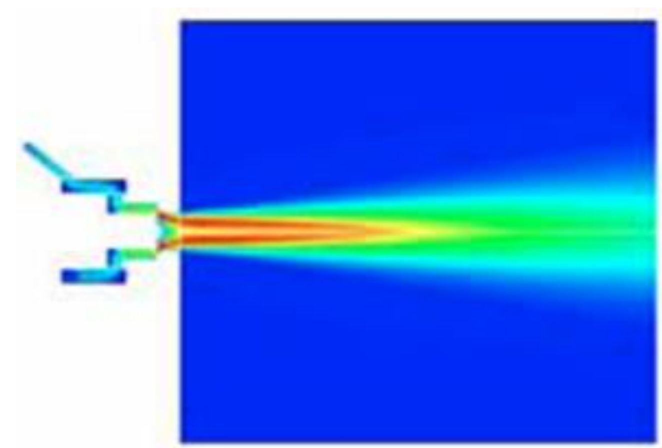
Coil straight length = L = 57mm
Number of turns = 7





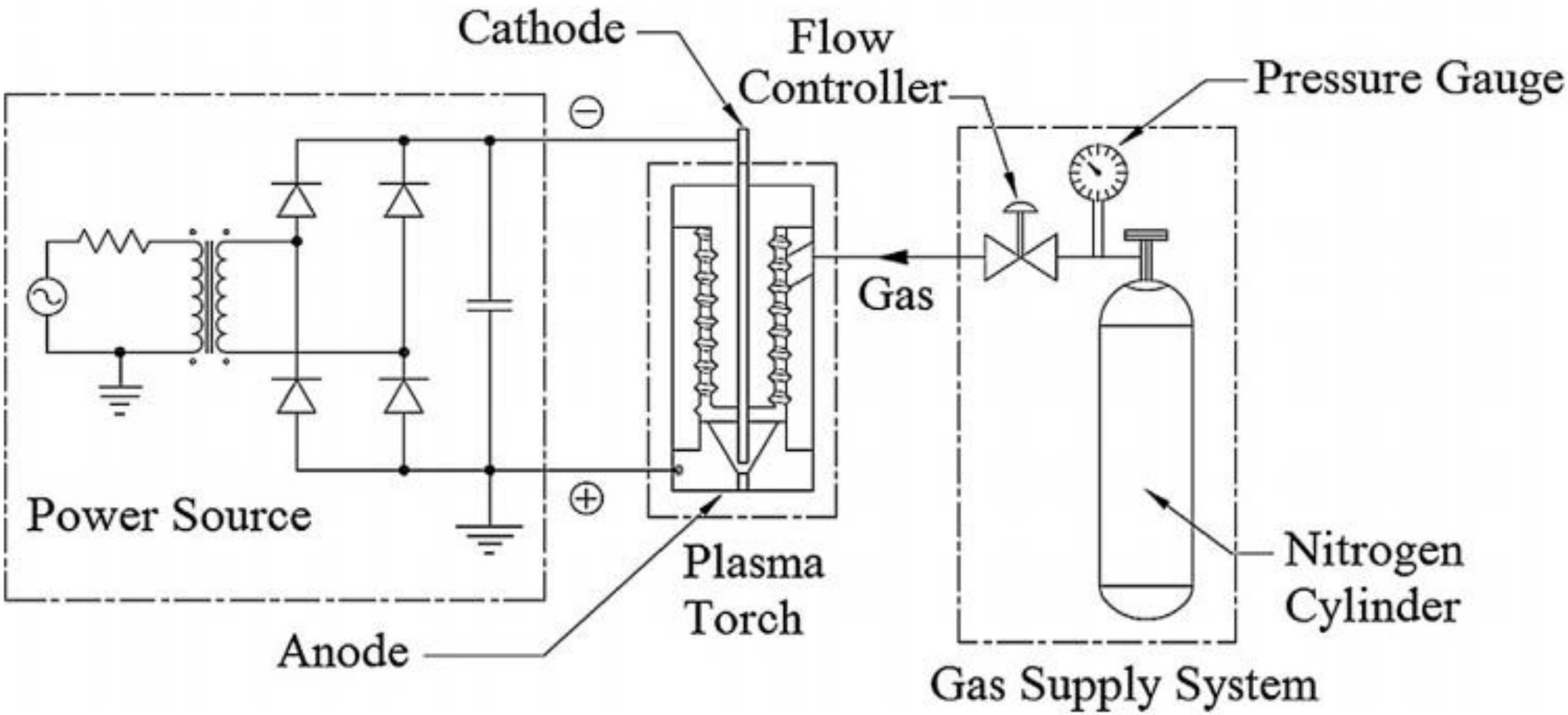


No-swirl flow torch

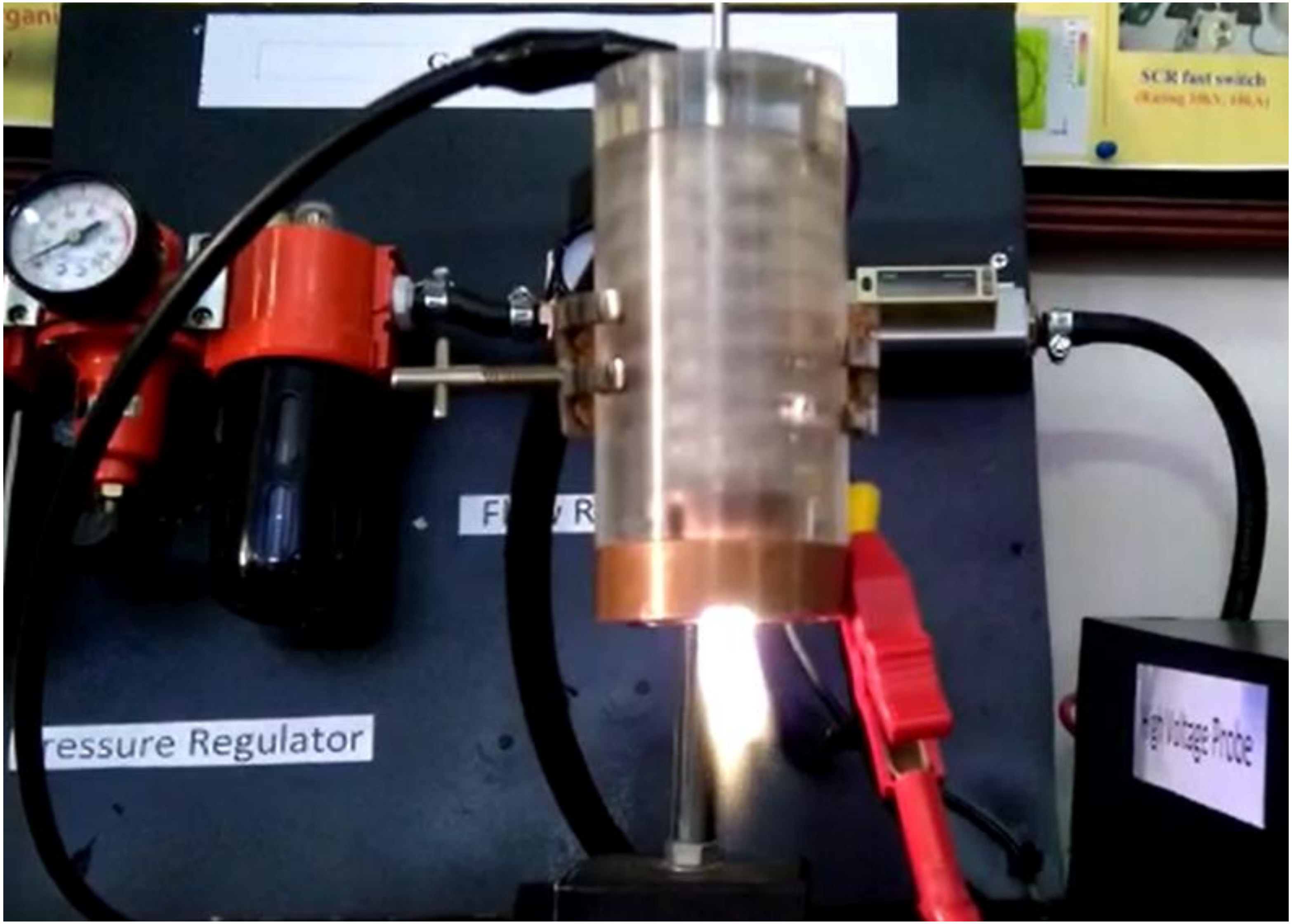


Swirl flow torch

Experimental Layout



Plasma Torch at PTPRI



Future Targets

- A 3kW plasma torch is in fabrication phase
- Technological infrastructure for high power torches
- Enhancement of power from 3kW to 100kW in three steps
- Establishment of Plasma Medical Waste Treatment Facility (3-4 Torches, ~ 20-30kW per torch)
- Development of Plasma based Radioactive Waste Treatment Facility (3-4 Torches ~ 50-100kW per torch)
- Applications of plasma torches in other technological areas (bio-medical, agricultural, industrial etc.)

R&D on Fusion Reactor's Materials

- Technological challenges of fusion energy are intimately linked with the availability of suitable materials capable of reliably withstanding the extremely severe operational conditions of fusion reactors.
- Materials for DEMO and commercial reactor materials are being designed and investigated to meet the requirements
- We have also started R&D activities in this important area
- We have ion sources "Tandem accelerator (10 MV, 25 MeV) and Ion Implanter (120 MeV)" and research reactors
- Besides, we have SEM (Scanning Electron Microscope), EDS (Energy Dispersive Spectroscopy), XRD (X-ray Diffraction), AFM (Atomic Force Microscopy), XPS (X-ray photoelectron)
- Some basic studies have been done on Tungsten, Molybdenum and Inconel alloys

Conclusions

- Excellent initiative by IAEA on the subject
- Multi-dimensional efforts is the need of time to synergize Fission – Fusion
- IAEA should force the member states to work on fast track on this extremely important aspect
- Joint working teams of Fission-Fusion scientists / engineers should be formed by IAEA in member states