# CPR's Research Projects & Collaborations – Way Forward

S H Saw[1,2], and S Lee[1,2,3]

[1]Inti International University, Nilai Malaysia

[2]Institute for Plasma Focus Studies, Melbourne, KL, Singapore

[3]University of Malaya, KL, Malaysia

# Introduction 1/2

- The Centre for Plasma Research at INTI International University was conceived in July 2007 and set up in November 2007 with the hosting of the Universal Plasma Focus Laboratory Facility (UPFLF) and in January 2009 the installation of INTI PF, a 3 kJ plasma focus machine donated (in 2008) to INTI IU by Nanyang Technological University (Plasma Sources and Application Centre, a part of Natural Sciences and Science Education Academic Group)
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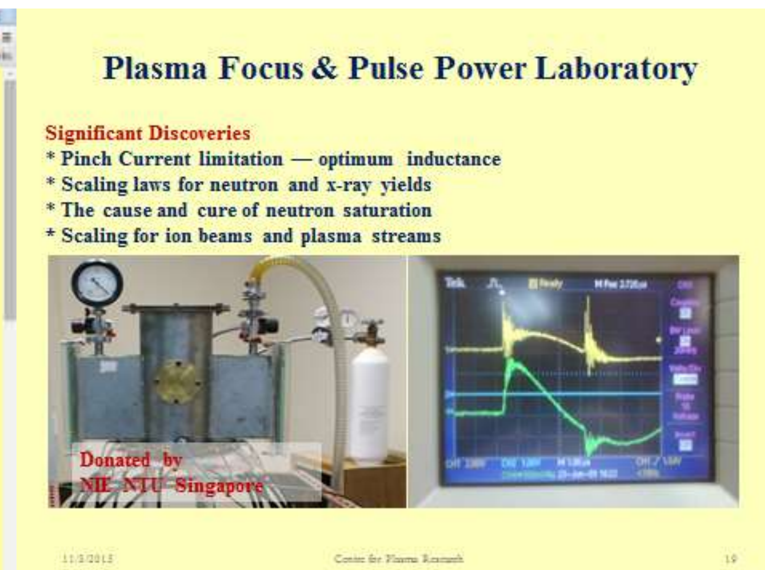


# Appointment of Adjunct Professor Dr. Lee Sing – November 2007


# Launching of the Universal Plasma Focus Laboratory

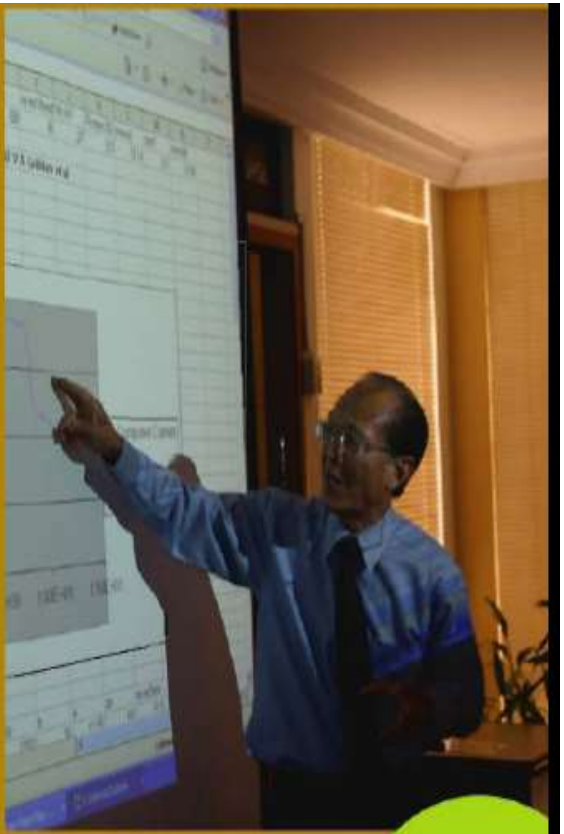
Professor Dr. Lee Sing, a renowned authority on plasma research, was appointed Adjunct Professor of INTI International University College (INTI-UC). He will developed a universal plasma focus laboratory facility at INTI-UC and assist researchers to use this facility.

Welcoming Prof. Dr Lee Sing was Professor Dr Lee Fah Onn (no relation), President of INTI-UC; Dr Saw Sor Heoh, Associate Vice-President, Teaching and Learning, INTI-UC; and other staff of the university college.

"There was a time when it was said that a third of the plasma focus machines in the world was developed with the assistance of Malaysians," said Prof. Dr Lee Sing in his address. "With this rich tradition in plasma focus research, it is logical for more Malaysians to go into focus research.

"When this opportunity arises to assist one of my former students (Dr Saw) to start research at INTI-UC, I really look forward to doing something well within my experience and expertise."

Professor Dr. Lee Sing, who holds a PhD from The Australian National University, is a visiting professor at the University of Malaya and an adjunct professor at the National Institute of Education, Nanyang Technological University. He was the founding president of the Asian African Association for Plasma Training.



*Prof Dr Lee Sing introduces plasma focus at INTI-UC*

# INTI PF from NIE-NTU Singapore

**Group Photo taken after successful 1st shot – 23 June 2009**

# Introduction 2/2

- Since then many series of Laboratory Experiments have been conducting using INTI PF.
- Many series of Numerical Experiments using UPFLF have since been successfully carried out on INTI PF and plasma focus machines in Argentina, Germany, USA, Chile, Malaysia, Singapore, Russia, China, Pakistan, India, Estonia, Italy, Iran, Syria and the International Centre for Dense Magnetised Plasmas (ICDMP), Poland.
- This has resulted in in more than 170 papers, including 84 published papers most in top level ISI physics journals such as Applied Phys Lett, Phys of Plasmas, IEEE Trans Plasma Sci, J Fusion Energy, J Applied Phys, and 53 plenary/keynote/ review lectures at international conferences.

# CPR Research Facilities

- Universal Plasma Focus Laboratory Facility at Centre for Plasma Research INTI International University

- 3kJ INTI Plasma Focus Machine (a UNU/ICTP Plasma Focus Facility) – donated by Nanyang Technological University Singapore
  - Current Measurement System
  - Voltage Measurement System
  - Magnetic field Measurement System
  - SXR Measurement System
  - Faraday cup Measurement System
  - Time of Flight (TOF) Measurement System

## Universal Plasma Focus Laboratory Facility

**Most powerful simulation** model for PF, **most widely used internationally.**

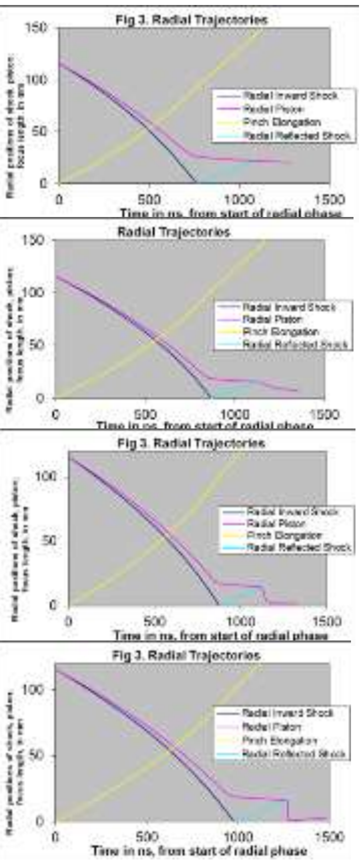
200 scientists trained in 9 international workshops.

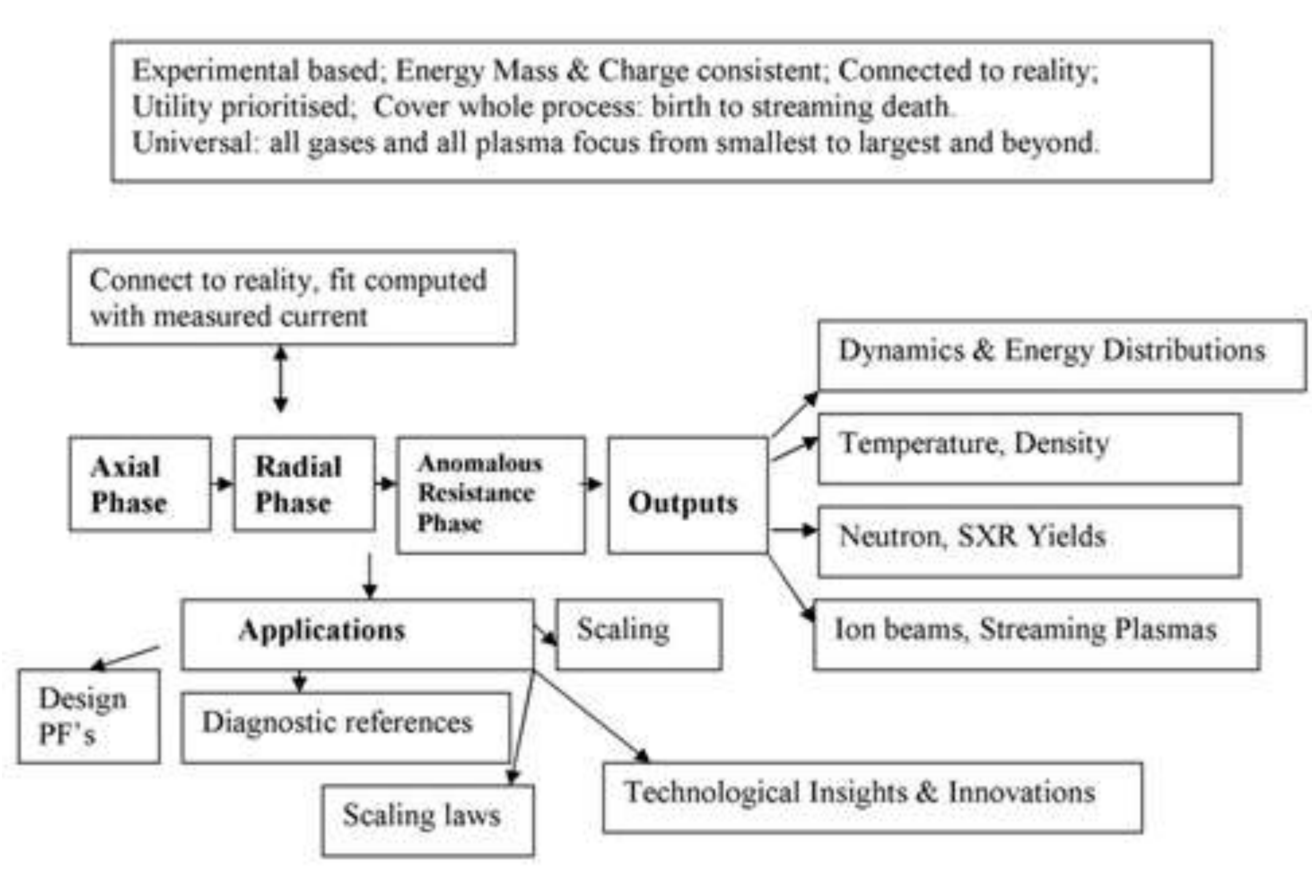
**Frontier Papers**: PF limitation effects **Appl. Phys. Lett. 92, 021503 (2008)**

Global PF scaling laws **J Fusion Energy 27 292-295 (2008), Phys Plasmas (2012, 13)**

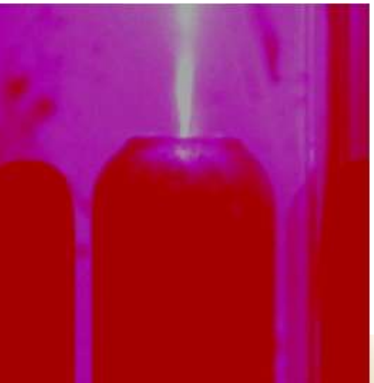
Overcoming existing scaling deficiencies - **Appl Phys Letts - 95, 51503(2009)**

**Radiative Cooling and Collapse-J Fusion Energ (2013), Phys Plasmas (2015)**



# INTI PF – 3kJ



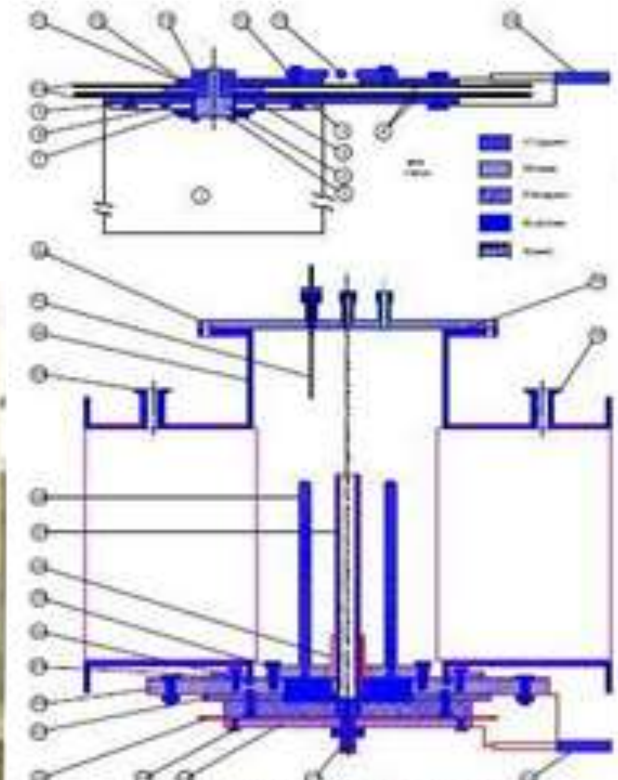
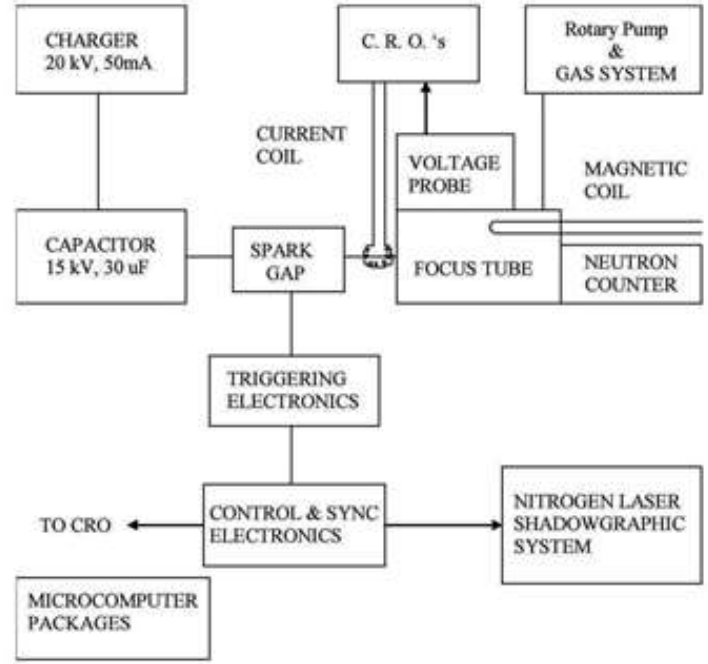


Fig 2: Design of the UNU/ICTP PFF

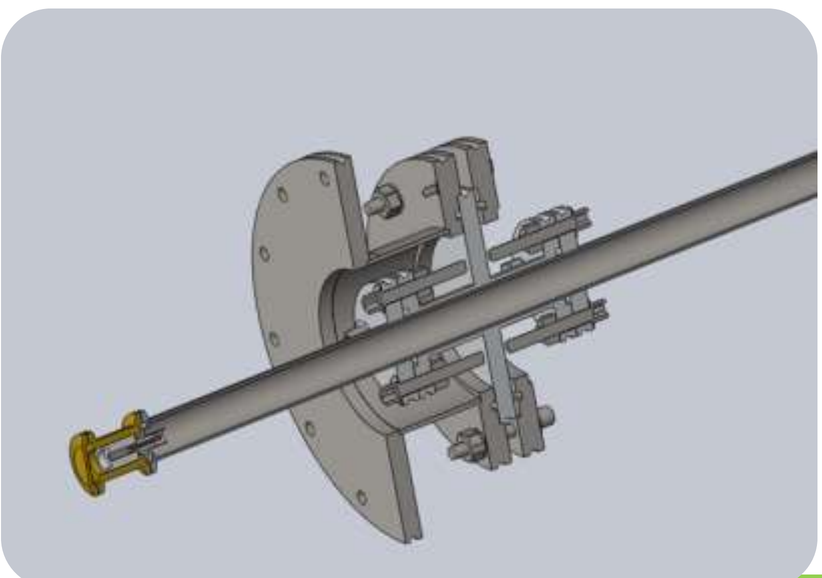


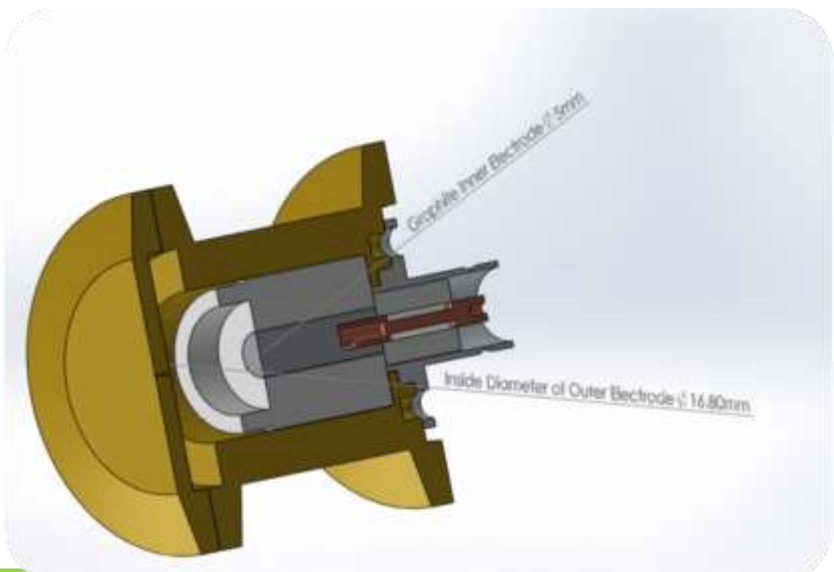
# Diagnostics Systems

- Current Measurement System
- Voltage Measurement System
- Magnetic field Measurement System
- SXR Measurement System
- Faraday Cup Measurement System
- Time of Flight Measurement System

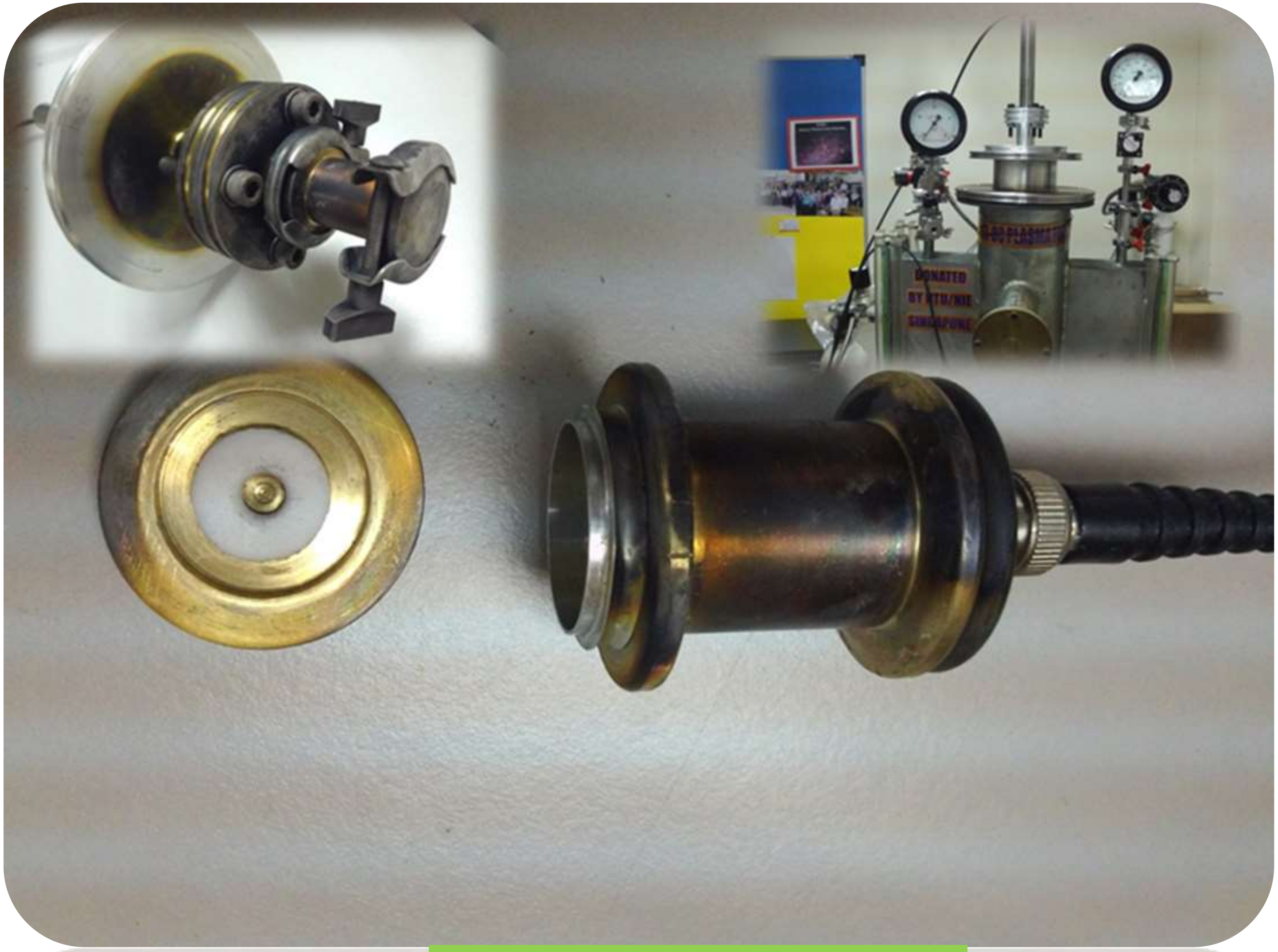
# INTI PF FC Drawing

- **This is an adjustable faraday cup. The distance between faraday Cup to plasma focus anode tip is adjustable by means of a stainless steel tube from outside of the vacuum chamber.**

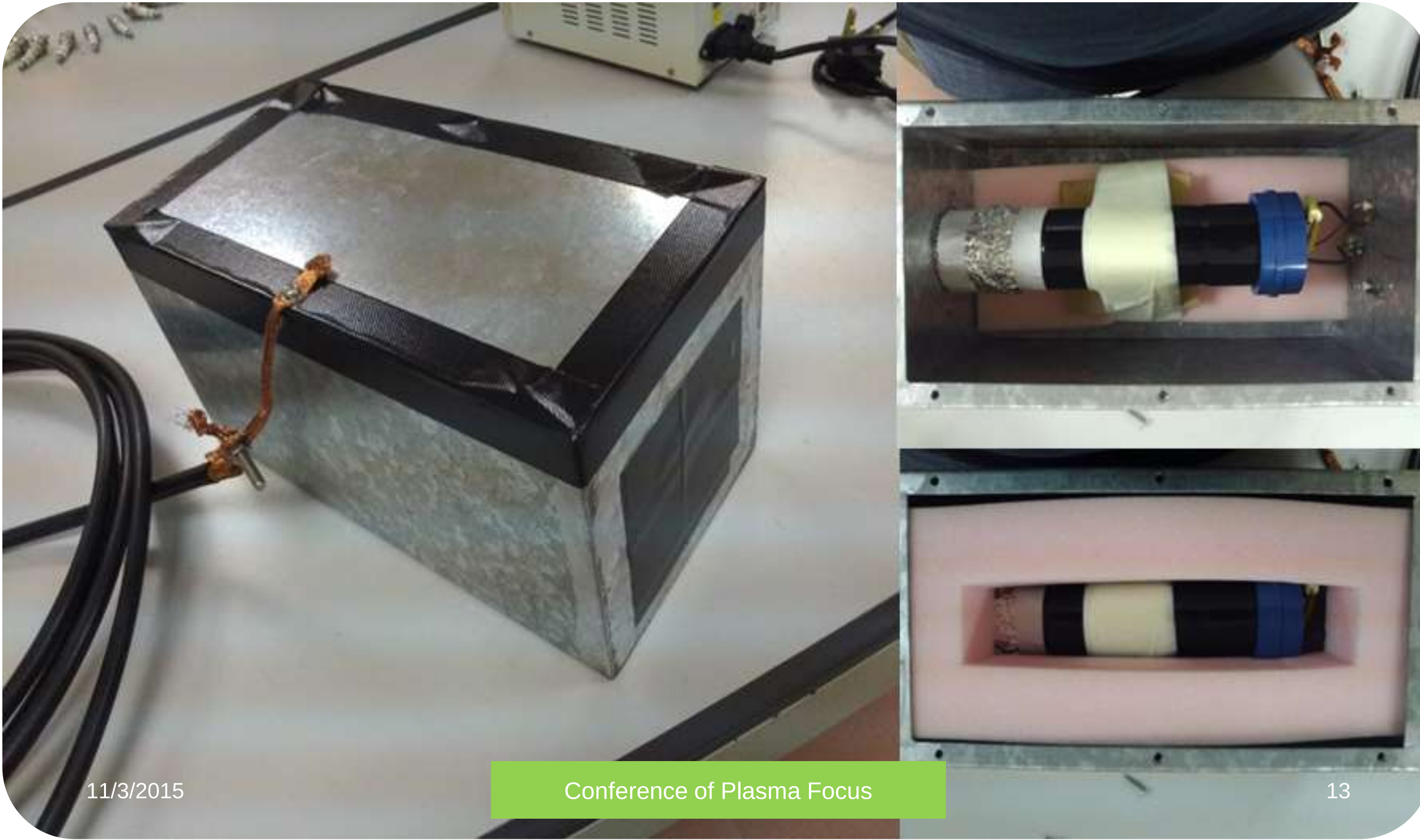




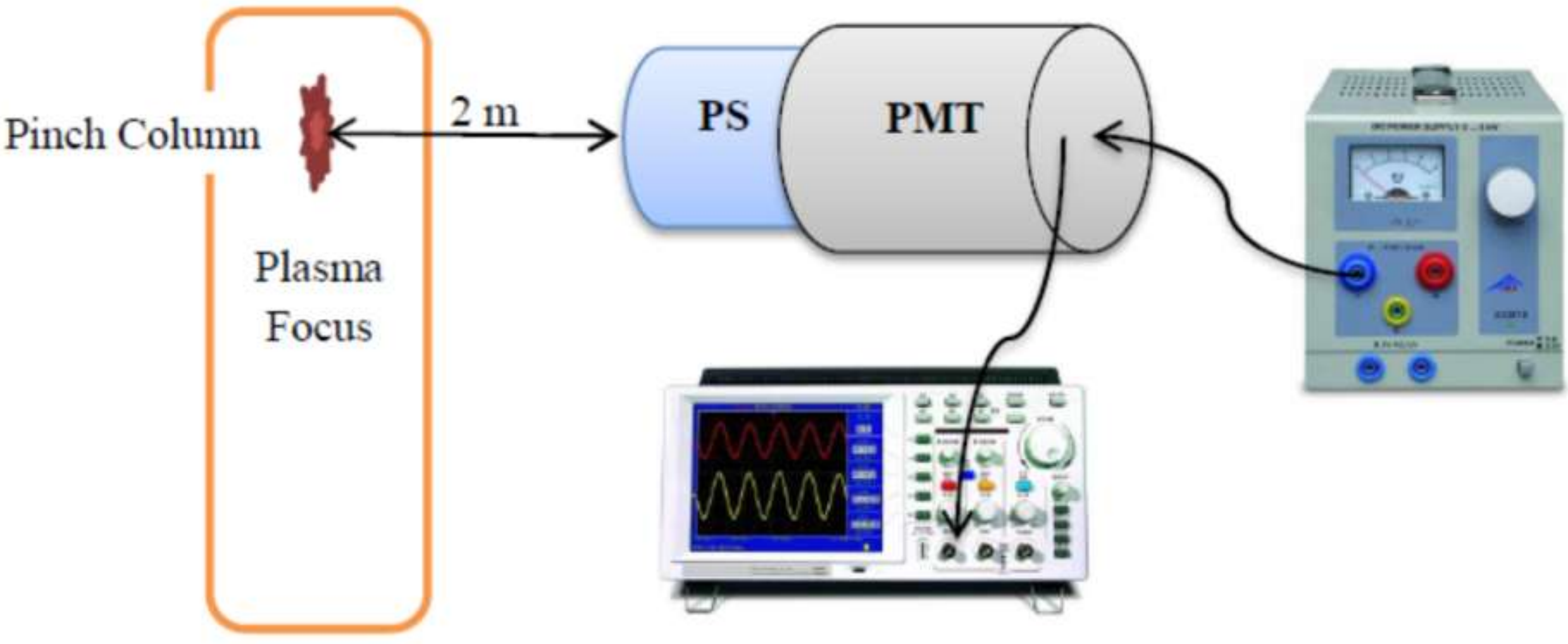
# INTI PF FC Construction



# Photomultiplier-Scintillator System for INTI PF



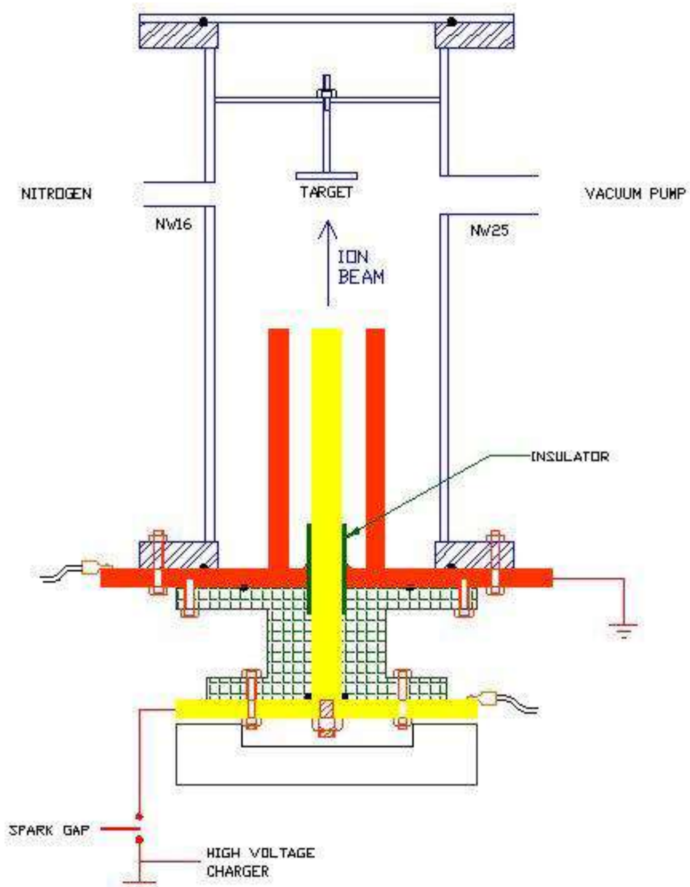
# Photomultiplier-Scintillator System for INTI PF



# New Research Facilities

- 3kJ INTI Plasma Focus Facility for Nitriding of Materials – INTI IU construction in-progress

- 160 kJ Dual PF for materials synthesis and damage research – Patent in-progress




30 µF, 15 kV capacitor from Azad University, Tehran, Iran

THE STUDY OF SURFACE TREATMENT OF LOW ALLOY STEEL USING ION BEAM IMPLANTATION WITH PLASMA FOCUS

Project investigators: Teh Thiam Oun, Lee Sing, Saw Sor Heoh, Yuvaraj Rengasamy, Chiat Chin Jiun

Faculty: Centre of Plasma Research

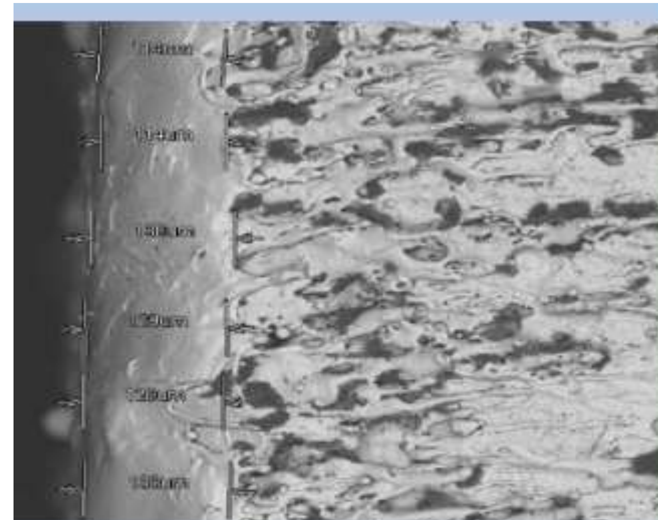
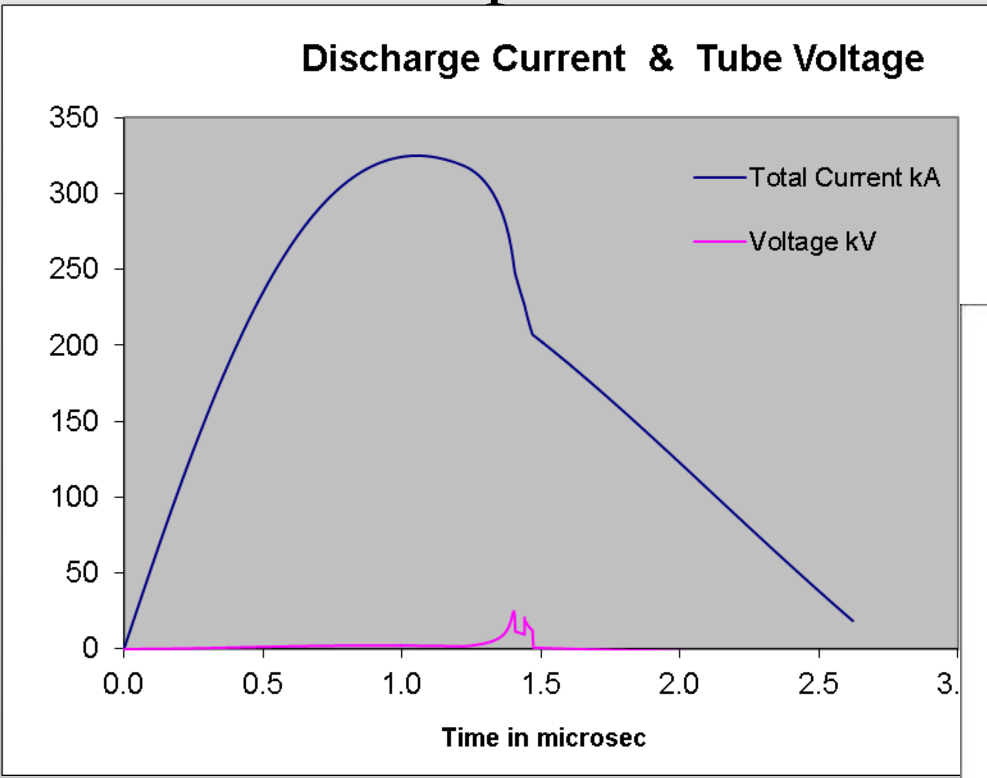


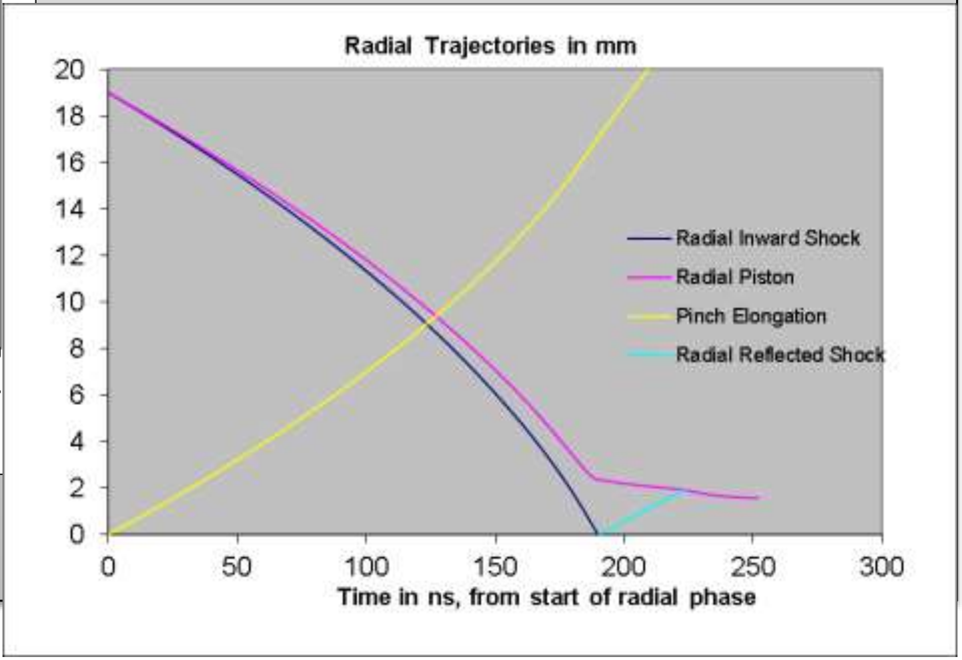
Figure 2: Cross sectional view using SEM.

- A thin nitride layer has been observed on the surface of the target after treatment in the plasma focus machine.
- EDX analysis showed the presence of nitrogen on the surface.
- Micro Vickers hardness testing at 10 gram loading showed that the hardness has increased from a value of 300 to 800 HV on the Vickers scale at the surface.

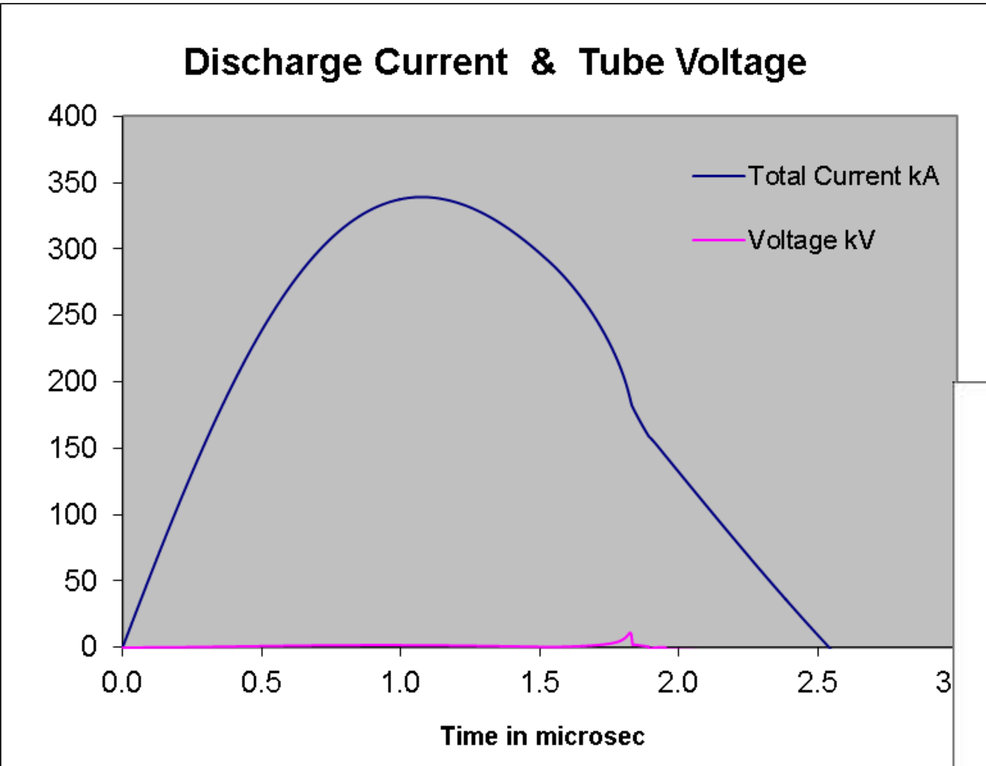
# New concept: SFM vs FFM:
# PF operated near time-matched-FFM



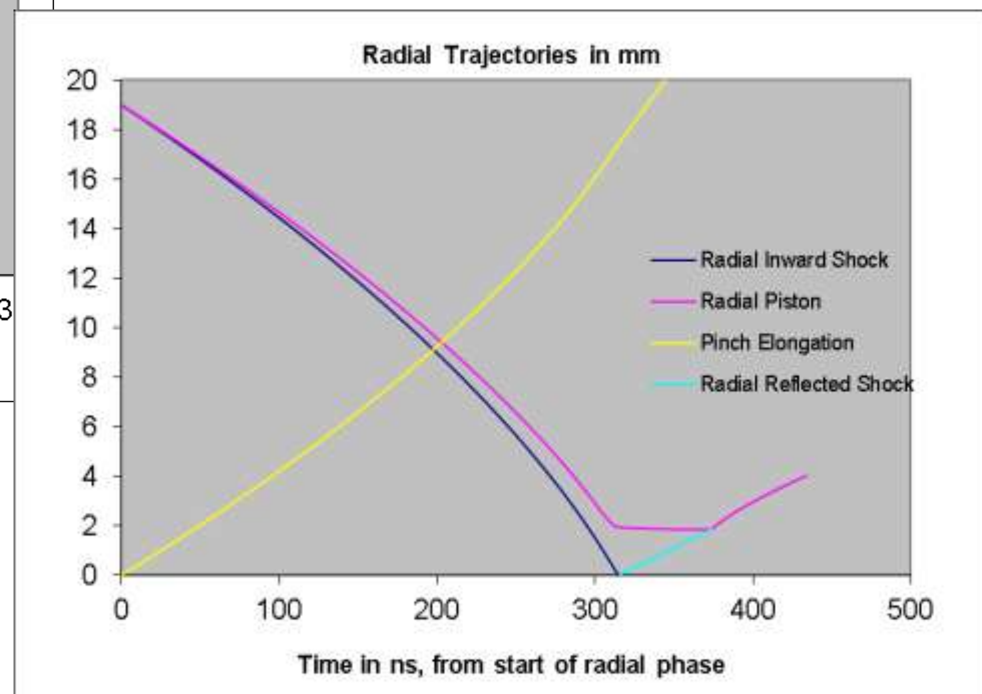

| Lo | Co | b | a | zo | ro mOhm |
|---|---|---|---|---|---|
| 20 | 28 | 4.1 | 1.9 | 5 | 2.3 |
| massf | currf | massfr | currfr | Model Parameters | |
| 0.0635 | 0.7 | 0.16 | 0.7 | | |
| Vo | Po | MW | A | At-1 mol- | Operational |
| 11 | 3 | 20 | 10 | 1 | Parameters |



# PF operated at higher pressure- SFM




| | | | | | |
|---|---|---|---|---|---|
| Lo | Co | b | a | zo | ro mOhm |
| 20 | 28 | 4.1 | 1.9 | 5 | 2.3 |
| massf | currf | massfr | currfr | Model Parameters | |
| 0.0635 | 0.7 | 0.16 | 0.7 | | |
| Vo | Po | MW | A | At-1 mol- | Operational |
| 11 | 6 | 20 | 10 | 1 | Parameters |



# DuPF- PF operating in dual mode

- One set of capacitors
- One set of electrodes- FFM
- A second set of electrodes - SFM

# FFM electrodes and main collector Assembly of DuPF with 170 kg weight

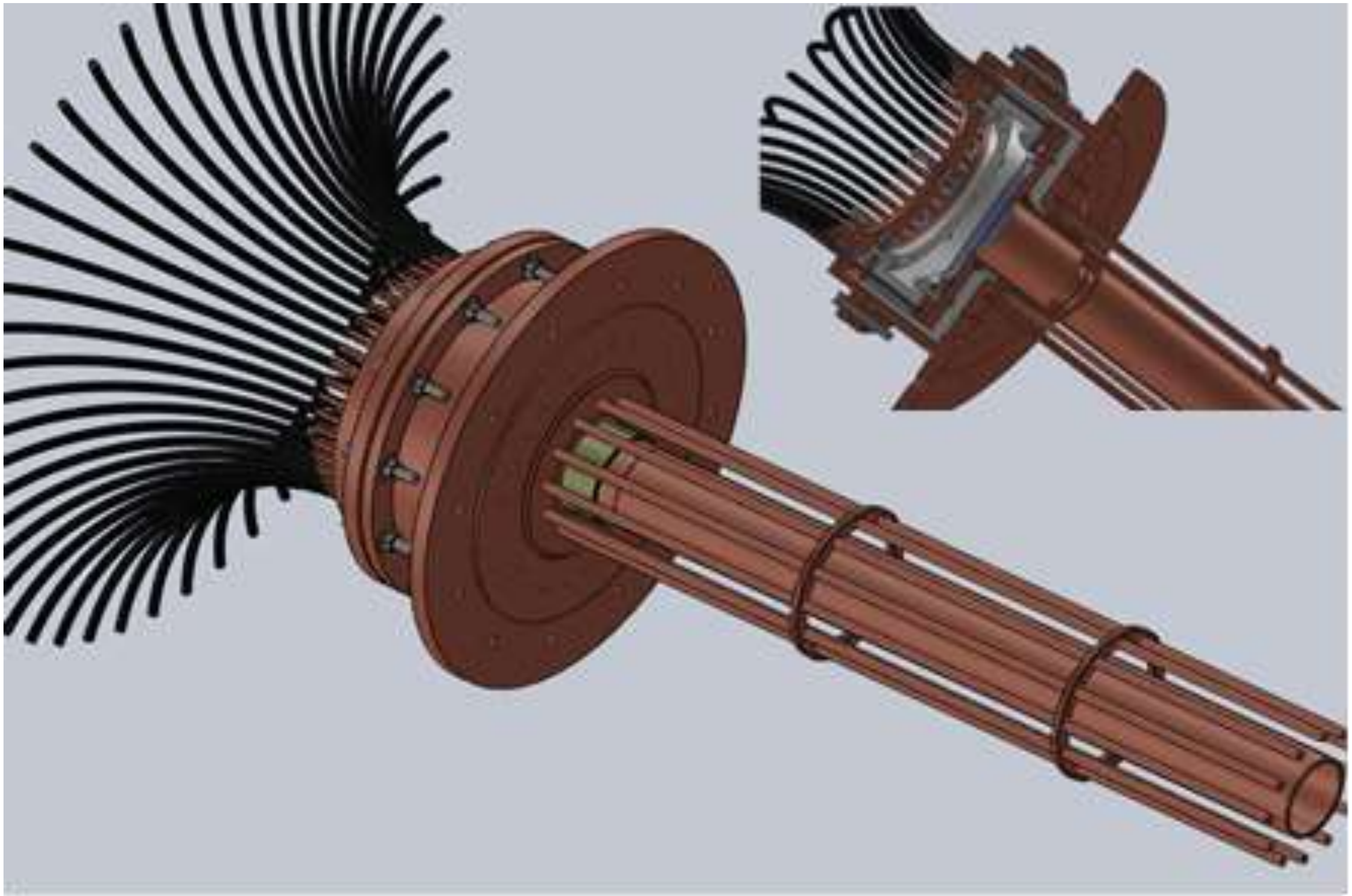


Figure 1. FFM electrodes and maincollector Assembly of DuPF with 170 kg weight

# Design Drawings- SFM electrodes and main collector Assembly of DuPF with 197 kg weight

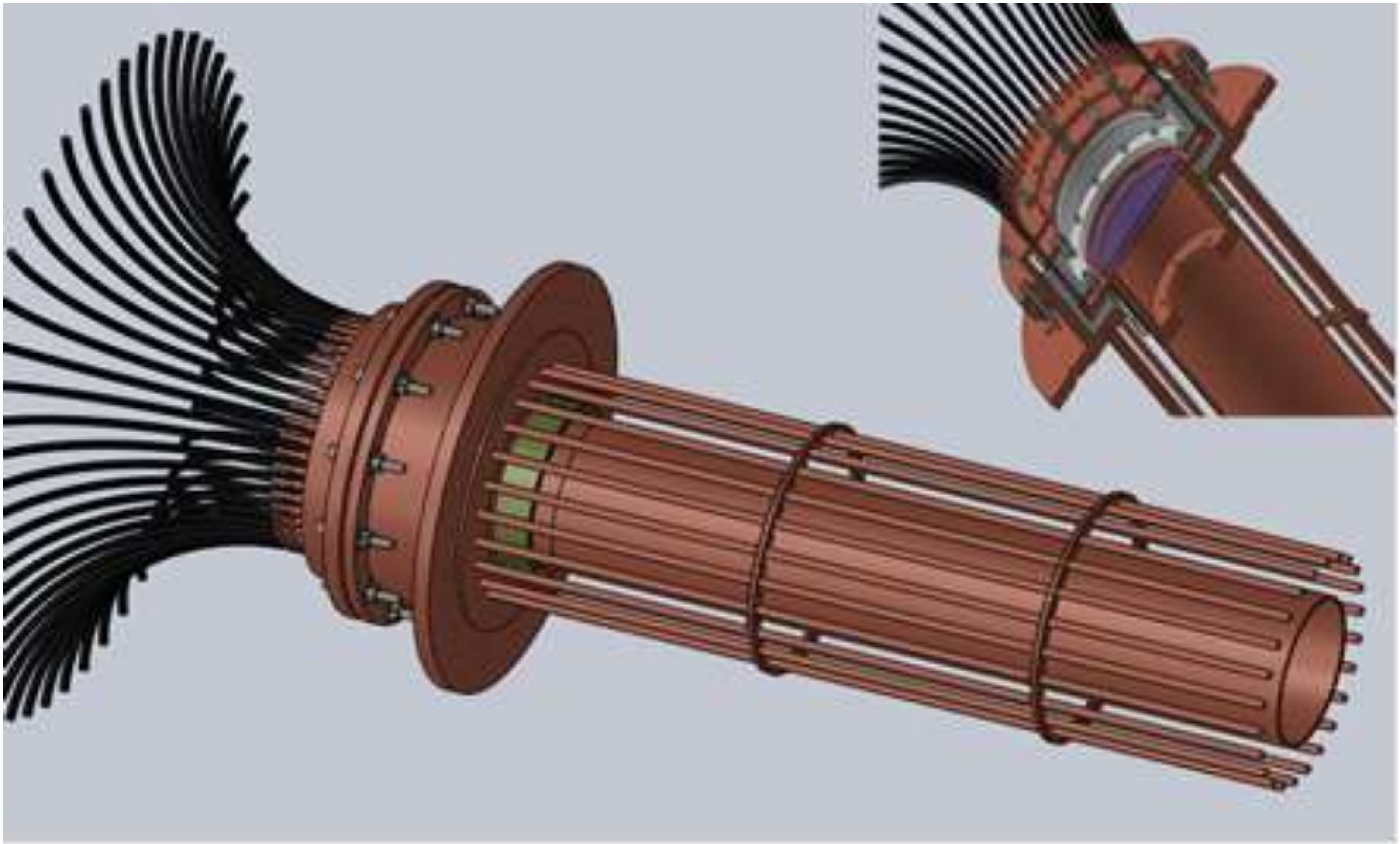


Figure 1. SFM electrodes and main collector Assembly of DuPF with 197 kg weight.

# International Collaboration

Australia Singapore Italy Syria Austria Kansas State

Iran Chile Bulgaria Nepal Turkey Serbia Saudi Arabia

# International Collaborating Partners

- Institute for Plasma Focus Studies (IPFS), Melbourne, Australia; KL, Malaysia and Singapore.
- Nanyang Technological University, National Institute of Education, Singapore
- Kansas State University, Department of Mechanical & Nuclear Engineering, USA
- International Centre for Theoretical Physics, Plasma Focus Laboratory, Trieste, Italy
- Syrian Atomic Energy Commission, Damascus, Syria
- Comision Chilena de Energie Nuclear, Santiago, Chile
- International Centre for Dense Magnetised Plasmas, Warsaw, Poland
- Asian African Association for Plasma Training
- Turkish Science and Research Foundation, Ankara, Turkey
- International Atomic Energy Agency (IAEA), Vienna, Austria
- Azad University, Plasma Physics Research Center (PPRC), Science & Research Campus, Tehran, Iran
- Sofia University, Faculty of Physics, Sofia, Bulgaria
- Department of Natural Sciences, Kathmandu University, Dhulikhel, Nepal
- Central Department of Physics, Tribhuvan University, Kathmandu, Nepal
- Institute of Experimental Physics V, Ruhr-University Bochum, Germany
- Czech Technical University, Prague, Czech Republic
- Plasma Physics Laboratory, University of Saskatchewan, Canada
- 
- at

# Founder:

## International Conference on Plasma Computation/Sciences & Applications

- 1st IWPCA2008(Malaysia)
- 2nd ICPSA2009(Singapore)
- 3rd ICPSA2010 (China)
- 4th ICPSA2011(Iran)
- 5th ICPSA2012(Bangkok)
- 6th ICPSA2013(Singapore)
- 7th ICPSA2014(Nepal)
- 8th ICPSA2015(Iran)
- **9th ICPSA2016 (Malaysia-UTM)**

# International Workshop on Plasma Computations & Applications (IWPDA 2008)

(INTI UC & UM)


## Initiate:
## Numerical Workshop on Plasma Focus Computation

- Internet Course 2008(Malaysia)
- NEW PF NURER 2010 (Turkey)
- NEWPF ICTP 2010, 2012 (Italy)
- NEWPF KSU 2011 (US)
- NEW PF ITAP 2012 (Turkey)
- NEWPF 2013, 2014(Kathmandu)

## Host:
## IAEA 2nd CRP Meeting2013 (Malaysia & Singapore)

# Regional Collaboration

NANYANG TECHNOLOGICAL UNIVERSITY

NIE NATIONAL INSTITUTE OF EDUCATION

MOSTI

NUKLEAR MALAYSIA


UTM UNIVERSITI TEKNOLOGI MALAYSIA

UNIVERSITI MALAYA KUALA LUMPUR

UNIVERSITI TENAGA NASIONAL

# Kansas State University (KSU) & University of Nebraska-Lincoln (UNL)





## IAEA-ICTP Workshop on Dense Magnetized Plasmas and Plasma Diagnostics Trieste Italy 15-26 November 2010.


# Seminar on Plasma Focus Experiments (SPFE 2010)
# 27 August

# Seminar on Plasma Focus Experiments (SPFE 2011) 1 July

# Seminar on Plasma Focus Experiments (SPFE 2012) 12 July

# UTM-Jazan University Summer Programme at INTI International University 8th – 12th July 2013


# Centre for Plasma Research Open Day
# 17th June 2014

# Conference on Plasma Focus Experiments (SPFE 2014) 20 June


icpsa
International Conference on Plasma Science and Applications 2014

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International Conference on Plasma Science and Applications

**22-24 September, 2014**
**Kathmandu, Nepal**

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**International Advisior Committee**

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| S. H. Saw | (Malaysia) |
| C. S. Wong | (Malaysia) |
| R. Rawat | (Singapore) |

**International Scientific Committee**

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| H. Ramos | (Philippines) |
| M. Zakaullah | (Pakistan) |
| K. Ostrikov | (Australia) |
| M. Mozetic | (Slovenia) |
| S. Hari lal | (USA) |
| A.E. Abdou | (Egypt) |
| S. R. Mohanty | (India) |
| E. Neyts | (Belgium) |
| M. Jacob | (Australia) |
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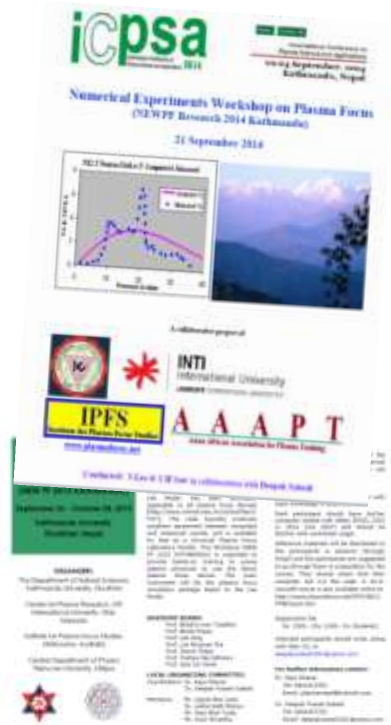



# 1st Research Presentation on Plasma Focus Experiments & New Applications with MNA & UTM 20th November 2014

# Key projects and collaboration

- IAEA CRP - Investigation of Fusion-Relevant Pulses from Plasma Focus Devices-Scaling and Properties - 15 countries
- MOE-FRGS - Development and construction of a Dual Mode 160 kJ Plasma Focus for Advanced Materials - NTU
- INTI IU MG -Optimisation of radiations yields from Plasma focus using Lee Model Code –NTU, UTM, SAEC, KU etc
- 4) Radiative Collapse – SAEC, Bochum U, Czech TU, ICDMP, UTM

# IAEA CRP - Investigation of Fusion-Relevant Pulses from Plasma Focus Devices-Scaling and Properties - 15 countries

AIP Physics of Plasmas

# Plasma focus ion beam fluence and flux—For various gases

S. Lee and S. H. Saw

Citation: Phys. Plasmas 20, 062702 (2013); doi: 10.1063/1.4811650
View online: http://dx.doi.org/10.1063/1.4811650
View Table of Contents: http://pop.aip.org/resource/1/PHPAEN/v20/i6
Published by the AIP Publishing LLC.

PHYSICS OF PLASMAS 20, 062702 (2013)

Plasma focus ion beam fluence and flux—For various gases

S. Lee[1,2,3] and S. H. Saw[1,2,a)]
[1]Centre for Plasma Research, INTI International University, 71800 Nilai, Malaysia
[2]Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone 3148, Australia
[3]Physics Department, University of Malaya, Malaysia

(Received 21 April 2013; accepted 13 May 2013; published online 19 June 2013)

A recent paper derived benchmarks for deuteron beam fluence and flux in a plasma focus (PF) [S. Lee and S. H. Saw, Phys. Plasmas **19**, 112703 (2012)]. In the present work we start from first principles, derive the flux equation of the ion beam of any gas; link to the Lee Model code and hence compute the ion beam properties of the PF. The results show that, for a given PF, the fluence, flux, ion number and ion current decrease from the lightest to the heaviest gas except for trend-breaking higher values for Ar fluence and flux. The energy fluence, energy flux, power flow, and damage factors are relatively constant from $H_2$ to $N_2$ but increase for Ne, Ar, Kr and Xe due to radiative cooling and collapse effects. This paper provides much needed benchmark reference values and scaling trends for ion beams of a PF operated in any gas. *© 2013 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4811650]

AIP | Physics of Plasmas

## Plasma focus ion beam fluence and flux—Scaling with stored energy

S. Lee and S. H. Saw

Citation: Phys. Plasmas **19**, 112703 (2012); doi: 10.1063/1.4766744



PHYSICS OF PLASMAS **19**, 112703 (2012)

## Plasma focus ion beam fluence and flux—Scaling with stored energy

S. Lee[1,2,3,a)] and S. H. Saw[1,2]
[1]*INTI International University, 71800 Nilai, Malaysia*
[2]*Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone 3148, Australia*
[3]*Physics Department, University of Malaya, Kuala Lumpur, Malaysia*

(Received 6 September 2012; accepted 24 October 2012; published online 12 November 2012)

Measurements on plasma focus ion beams include various advanced techniques producing a variety of data which has yet to produce benchmark numbers [A Bernard *et al.*, J. Mosc. Phys. Soc. **8**, 93-170 (1998)]. This present paper uses the Lee Model code [S Lee, http://www.plasmafocus.net (2012)], integrated with experimental measurements to provide the basis for reference numbers and the scaling of deuteron beams versus stored energy $E_0$. The ion number fluence (ions $m^{-2}$) and energy fluence ($J\ m^{-2}$) computed as $2.4-7.8 \times 10^{20}$ and $2.2-33 \times 10^6$, respectively, are found to be independent of $E_0$ from 0.4 to 486 kJ. Typical inductance machines (33–55 nH) produce $1.2-2 \times 10^{15}$ ions per kJ carrying 1.3%–4% $E_0$ at mean ion energy 50–205 keV, dropping to $0.6 \times 10^{15}$ ions per kJ carrying 0.7% $E_0$ for the high inductance INTI PF. © *2012 American Institute of Physics.* [http://dx.doi.org/10.1063/1.4766744]

**Newly formed collaboration on Radiative Collapse-** Malaysia, Australia, Singapore, Syria , Germany, Czech Republic, Poland: Paper accepted to be published in IEEE TPS 2016



# Conditions for Radiative Cooling and Collapse in the Plasma Focus Illustrated with Numerical Experiments on the PF1000

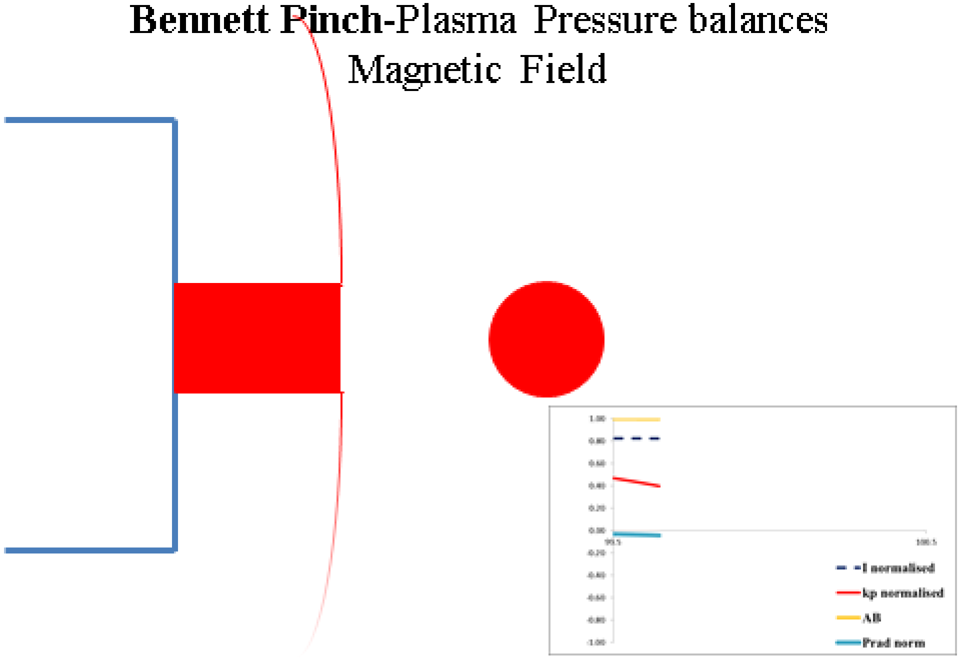
Sing Lee, Sor Heoh Saw, Mohamad Akel, Jalil Ali, Hans-Joachim Kunze, Pavel Kubes, Marion Paduch

*Abstract*—**Reduced Pease-Braginskii currents are estimated for a linear pinch in a range of gases namely D, He, Ne, Ar, Kr and Xe. A characteristic depletion time is defined as the time it takes for the plasma focus pinch energy to be radiated away. This quantity is used as an indicator for expectation of radiative collapse. The depletion times in various gases are estimated in units of pinch duration. The values indicate that in D and He,**

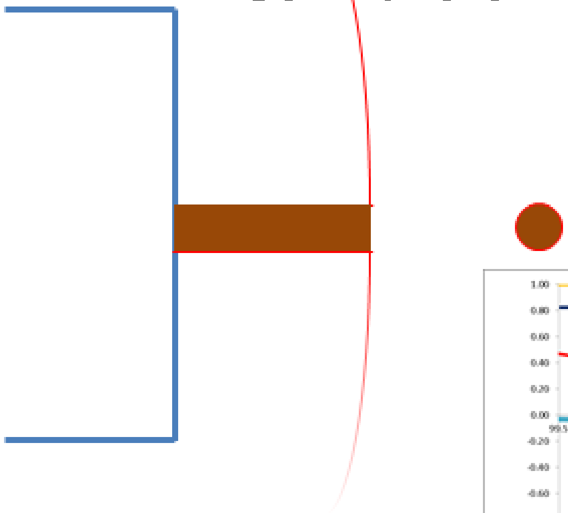
principle be computed [3]. This minimum pinch radius was computed to be 0.3 for a deuterium Z-pinch compared to Imperial College observation [4] of 1/3. For Ar the energy-balance and pressure balance method computed [5] the radius ratio as 0.18, compared to observations of 0.17 at temperatures of $2\times10^7$ K for the Imperial College low

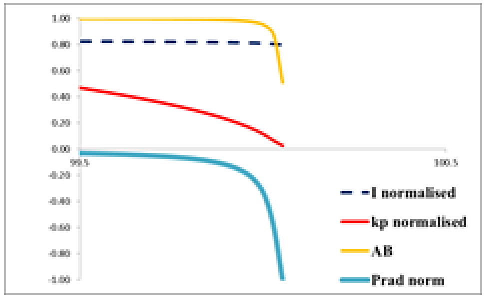
# Radiative Collapse in Plasma Focus

**Bennett Pinch-**Plasma Pressure balances Magnetic Field



**Radiative collapse continues**- plasma density increases, plasma begins to absorb its own radiation- becoming partially opaque to its own radiation





# Observed Radiative collapse in INTI PF

## Computed Radial Trajectory showing Radiative Collapse

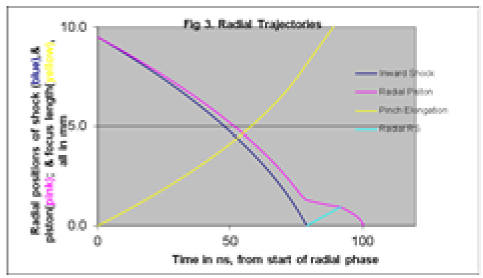



**Fig 2 shows the radial trajectory corresponding to the fitting of the current waveform of Fig 1 for INTI PF 12 kV, 0.5 Torr Kr.**

22nd IAEA Technical Meeting (TM) on Research Using Small Fusion Devices

51

# Radiative collapse in INTI PF

- **This intense compression, reaches $3.7 \times 10^{26}$ ions $m^{-3}$, 15 times atmospheric density (ambient: < 1/1000 atmosphere)**
- **30 J are radiated away in ps.**
- **Peak radiation power:- $4 \times 10^{12}$ W (4 TW).**
- **The energy density reaches $4 \times 10^{13}$ J $m^{-3}$ (40 kJ $mm^{-3}$).**
- **Even in this small PF intense HED is achieved with immense radiation power.**

# FFM electrodes and main collector Assembly of DuPF with 170 kg weight

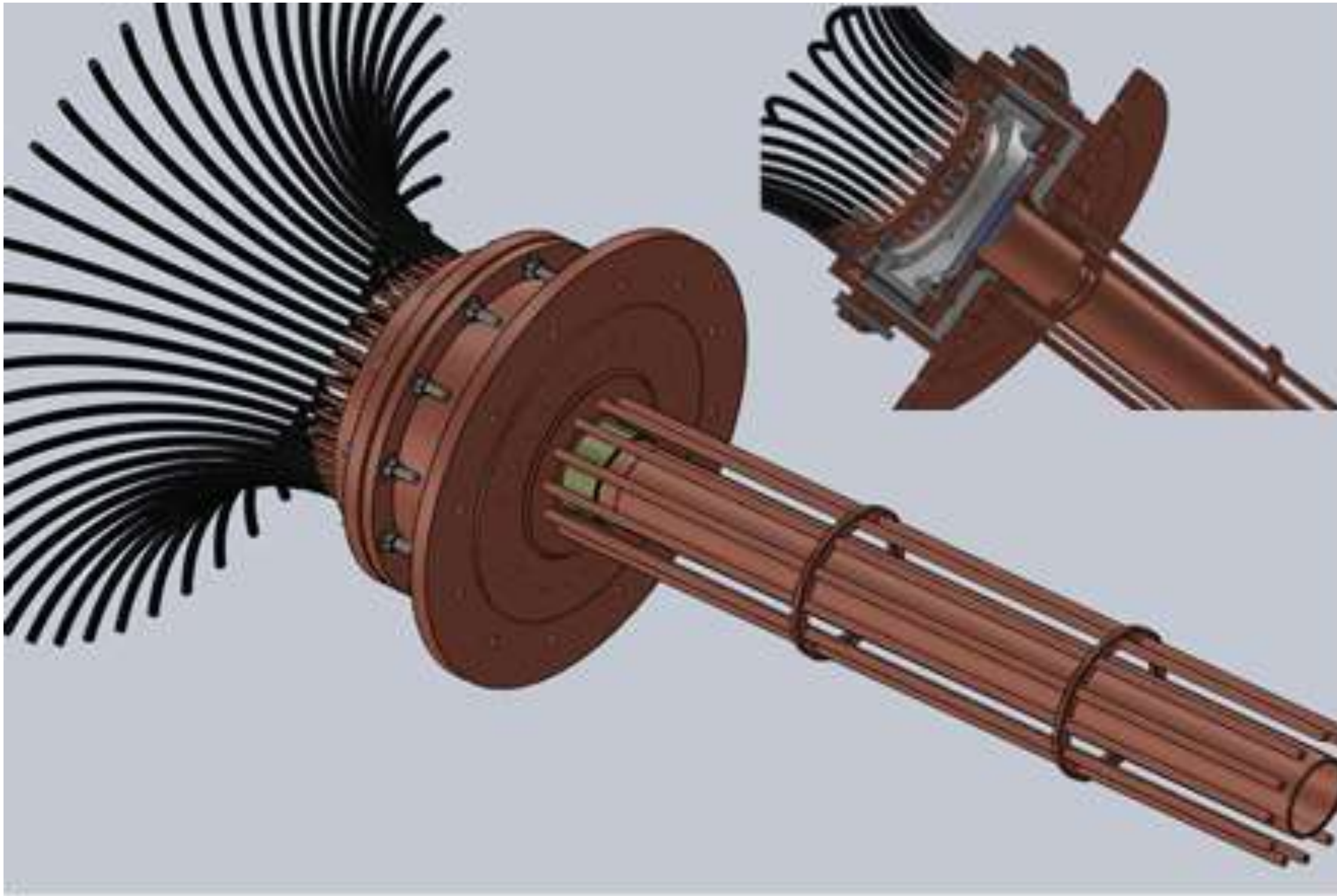


Figure 1. FFM electrodes and maincollector Assembly of DuPF with 170 kg weight

# Design Drawings- SFM electrodes and main collector Assembly of DuPF with 197 kg weight

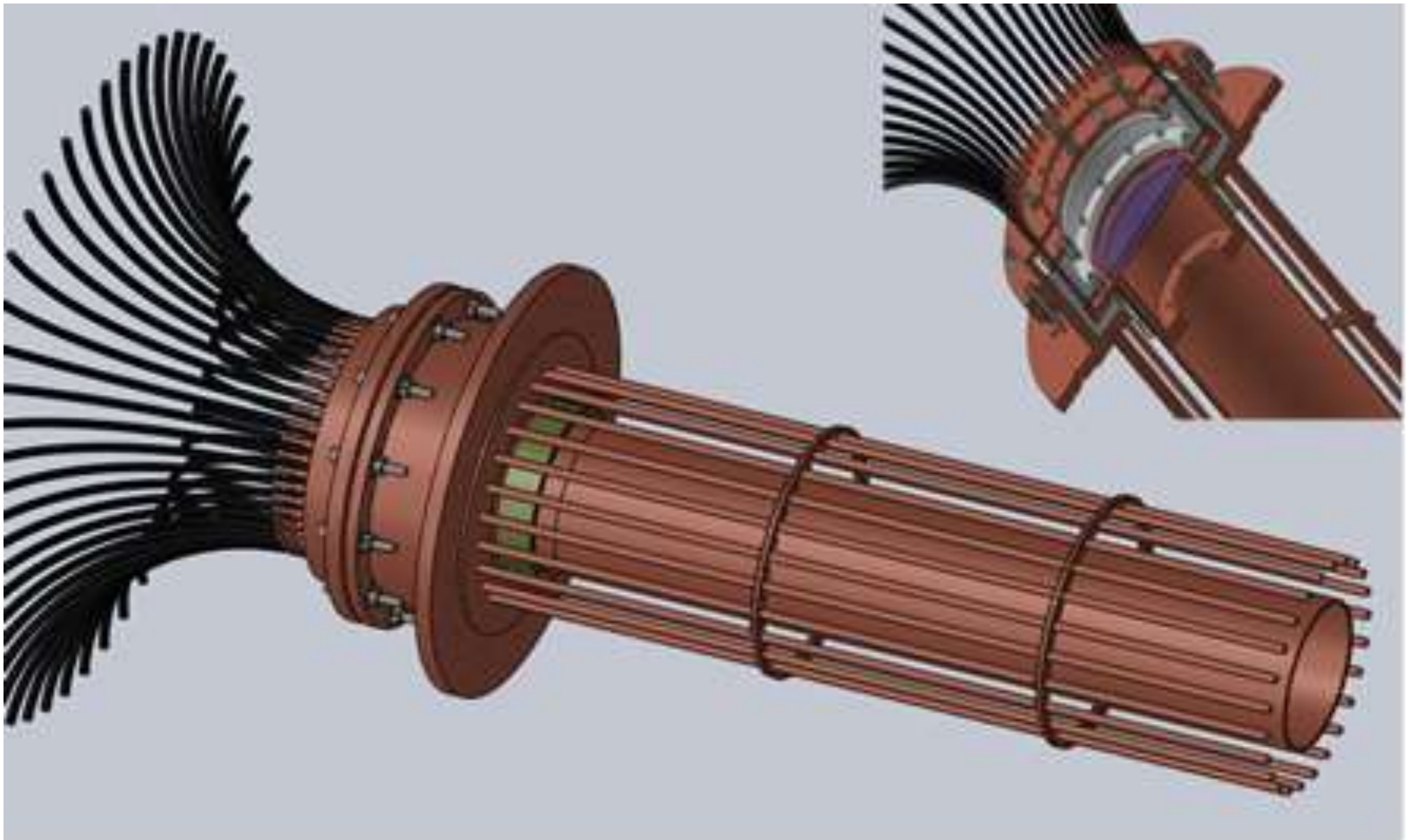
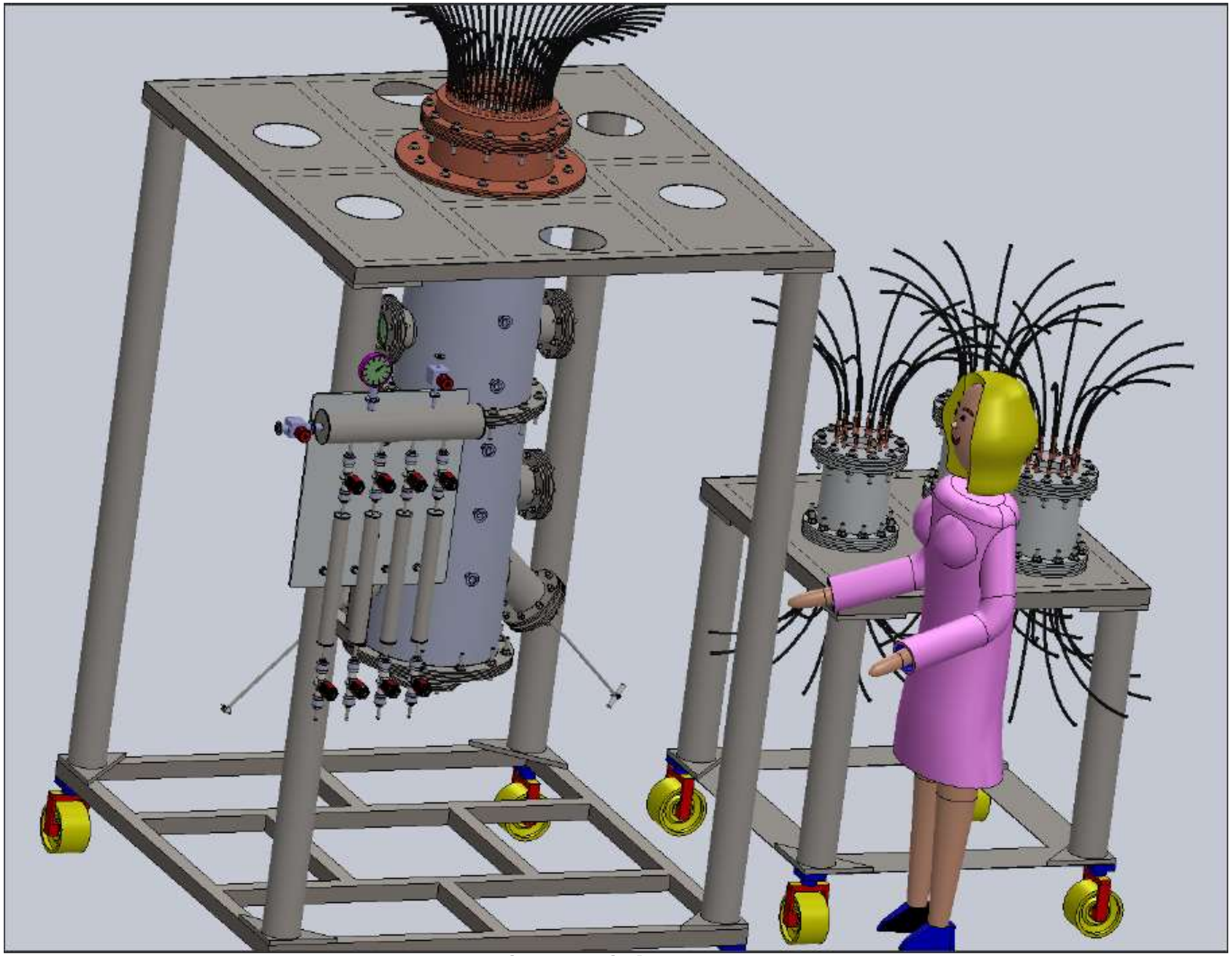


Figure 1. SFM electrodes and main collector Assembly of DuPF with 197 kg weight.

# Dual PF – 160 kJ



# Advanced Materials Unit

- High Temperature Superconductors
- Hardening of Materials
- Synthesis of Advanced Materials

# DuPF Paper

International Journal of Modern Physics: Conference Series
Vol. x, No. y (2014) pp-qq

DOI: 10.1142/insert DOI here

World Scientific
www.worldscientific.com

**A 160 KJ DUAL PLASMA FOCUS (DUPF) FOR FUSION-RELEVANT MATERIALS TESTING AND NANO-MATERIALS FABRICATION**

S H Saw

*INTI International University, 71800 Nilai, Malaysia*
*Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone, 3148 Australia*
*sorheoh.saw@newinti.edu.my*

V Damideh

*INTI International University, 71800 Nilai, Malaysia*
*v_damideh@yahoo.com*

P Lee

*National Institute of Education, Nanyang Technological University, Singapore*
*paul.lee@nie.edu.sg*

R S Rawat

*National Institute of Education, Nanyang Technological University, Singapore*
*rsrawat@nie.edu.sg*

S Lee

*INTI International University, 71800 Nilai, Malaysia*
*Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone, 3148 Australia*
*Physics Department, University of Malaya, Kuala Lumpur, Malaysia*
*leesing@optusnet.com.au*

This paper summarizes PF-160 Dual Plasma Focus (DuPF) numerical experiments using the Lee Model code and preliminary 3D design drawings using SolidWorks software. This DuPF consists of two interchangeable

# Scaling laws papers

15th Latin American Workshop on Plasma Physics (LAWPP2014) IOP Publishing
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## Multi-scaling of the dense plasma focus

S H Saw[1,2,4] and S Lee[1,2,3]
[1]INTI International University, 71800 Nilai, Negeri Sembilan, Malaysia
[2]Institute of Plasma Focus Studies, Melbourne, Australia
[3]University Malaya, Kuala Lumpur, Malaysia

E-mail: sorheoh.saw@newinti.edu.my

**Abstract.** The dense plasma focus is a copious source of multi-radiations with many potential new applications of special interest such as in advanced SXR lithography, materials synthesizing and testing, medical isotopes and imaging. This paper reviews the series of numerical experiments conducted using the Lee model code to obtain the scaling laws of the multi-radiations.

# Optimisation papers

1276 IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 37, NO. 7, JULY 2009

## Optimizing UNU/ICTP PFF Plasma Focus for Neon Soft X-ray Operation

Sor Heoh Saw, Paul Choon Keat Lee, Rajdeep Singh Rawat, and Sing Lee

***Abstract*—The United Nations University/International Centre for Theoretical Physics Plasma Focus Facility (UNU/ICTP PFF), a 3.3-kJ plasma focus, was designed for operation in deuterium with a speed factor $S$ such that the axial run-down time matches the current rise time at an end axial speed of nearly 10 cm/$\mu$s. For operation in neon, we first consider that a focus pinch temperature between 200 and 500 eV may be suitable for a good yield of neon soft X-rays, which corresponds to an end axial speed of 6–7 cm/$\mu$s. On this basis, for operation in neon, the standard UNU/ICTP PFF needs to have its anode length $z_0$ reduced by some 30%–40% to maintain the time matching. Numerical experiments using the Lee model code are carried out to determine the optimum configuration of the electrodes for the UNU/ICTP PFF capacitor system. The results show that an even more drastic shortening of anode length $z_0$ is required, from the original 16 to 7 cm, at the same time, increasing the anode radius "$a$" from 0.95 to 1.2 cm, to obtain an optimum yield of $Y_{sxr} = 9.5$ J. This represents a two- to threefold increase in the $Y_{sxr}$ from that computed for the standard UNU/ICTP PFF.**

***Index Terms*—Dense plasma focus, neon plasma, numerical experiments, soft X-ray (SXR) source.**

### I. Introduction

The UNU/ICTP PFF is a 3.3-kJ Mather-type plasma focus system powered by a single 15-kV 30-$\mu$F Maxwell capacitor switched on by a simple parallel-plate swinging cascade air gap [3]. The system produces remarkably consistent focusing actions and neutron yields of $0.5–1.0 \times 10^8$ neutrons per discharge at 3.0 torr of deuterium operating at 15 kV and 180 kA [3], [4]. This was not unexpected as the UNU/ICTP PFF was designed for optimum neutron yield in deuterium. It has a speed factor $S = (I/a)/P_0^{0.5}$ of 97 kA/cm per [torr of deuterium]$^{1/2}$ that is consistent with the range of other neutron-optimized plasma focus devices operating in deuterium [5]. The speed factor determines the speed in both the axial and radial phases. For operation in deuterium, this corresponds to just under 10 cm/$\mu$s for the end axial phase (just before the start of the radial phase) and a radial speed of 25 cm/$\mu$s when the imploding shock nears the axis. The ratio of average to end axial speed for a typical focus device is around 0.6. Thus, the UNU/ICTP PFF is designed for an average axial speed of 6 cm/$\mu$s running over an anode length of 16 cm. This ensures that the axial run-down time matches the effective current rise time of 2.6 $\mu$s at an end

# Radiative Collapse Papers- Warsaw, Prague

**Experiments and Simulations on the Possibility of Radiative Collapse in the Plasma Focus PF-1000**

M. Akel,[1] J. Cikhardt,[2] P. Kubes,[2] H.-J. Kunze,[3] S. Lee,[4] M. Paduch,[5] and S. H. Saw[4]

*[1] Department of Physics, AEC, Damascus, P.O. 6091, Syria*
*[2] Czech Technical University, Prague, Czech Republic*
*[3] Institute for Experimental Physics V, Ruhr-University Bochum, Germany*
*[4] INTI International University, Nilai, Malaysia*
*[5] Institute for Plasma Physics and Laser Microfusion, Warsaw, Poland*

PLASMA 2015, Warsaw, September 7-11, 2015

**Radiative Cooling and Collapse in the Plasma Focus**

**S H Saw[1,2] & S Lee[1,2,3]**

*[1] INTI International University, 71800 Nilai, Malaysia* sorheoh.saw@newinti.edi.my
*[2] Institute for Plasma Focus Studies, 32 Oakpark Drive, Chadstone, VIC 3148, Australia*
*[3] University of Malaya, Kuala Lumpur, Malaysia*

22nd IAEA Technical Meeting (TM) on Research Using Small Fusion Devices
12-14 October 2015
Prague, Czech Republic

# Way forward

- DuPF: SFM research on materials, FIB & FPS
- High Energy Density using Radiative Collapse
- High Temperature Superconductor & Other Advanced Materials
- Advanced materials research in PF HED environment linked to our advanced materials laboratory

# DuPF with SFM Configuration

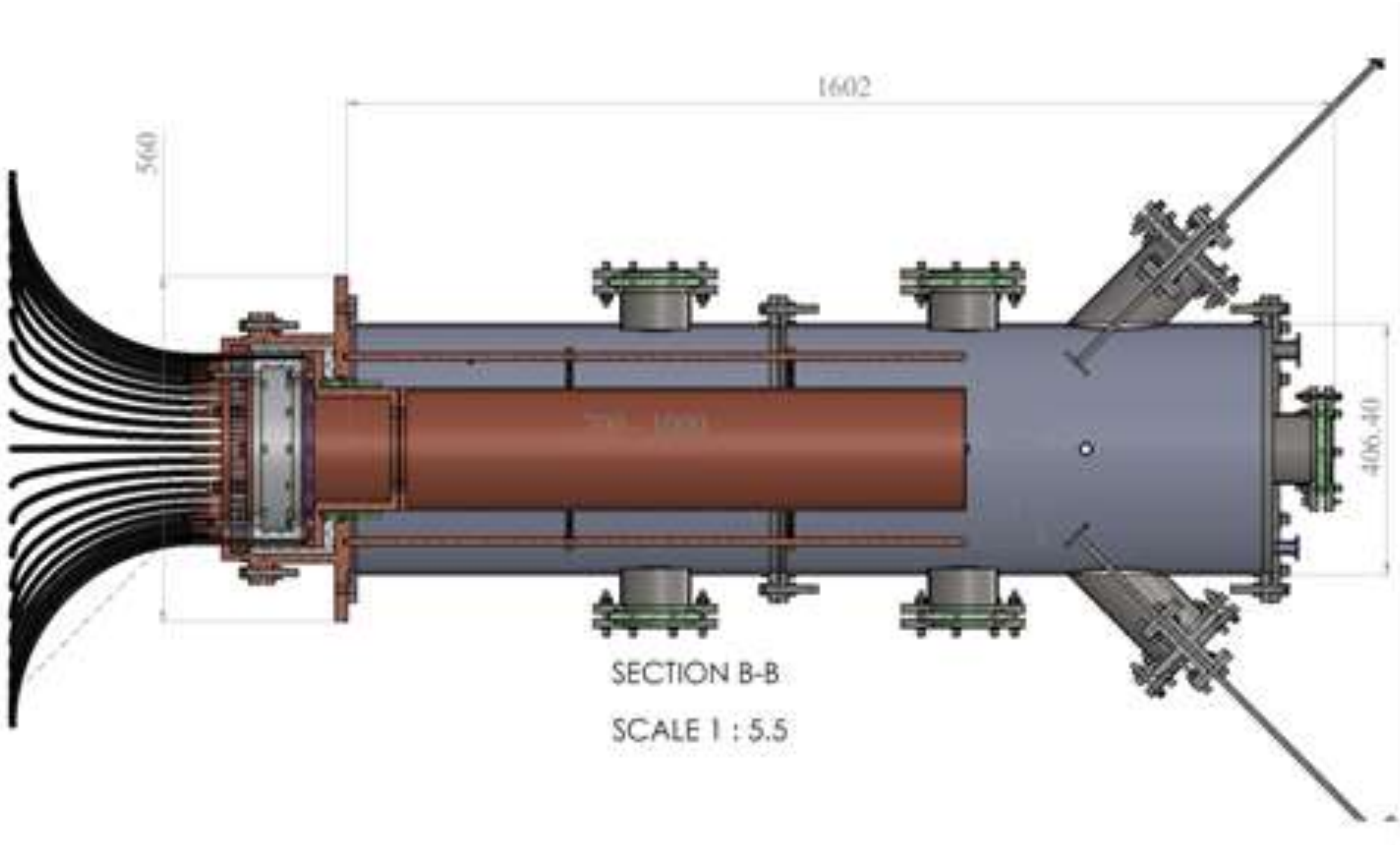
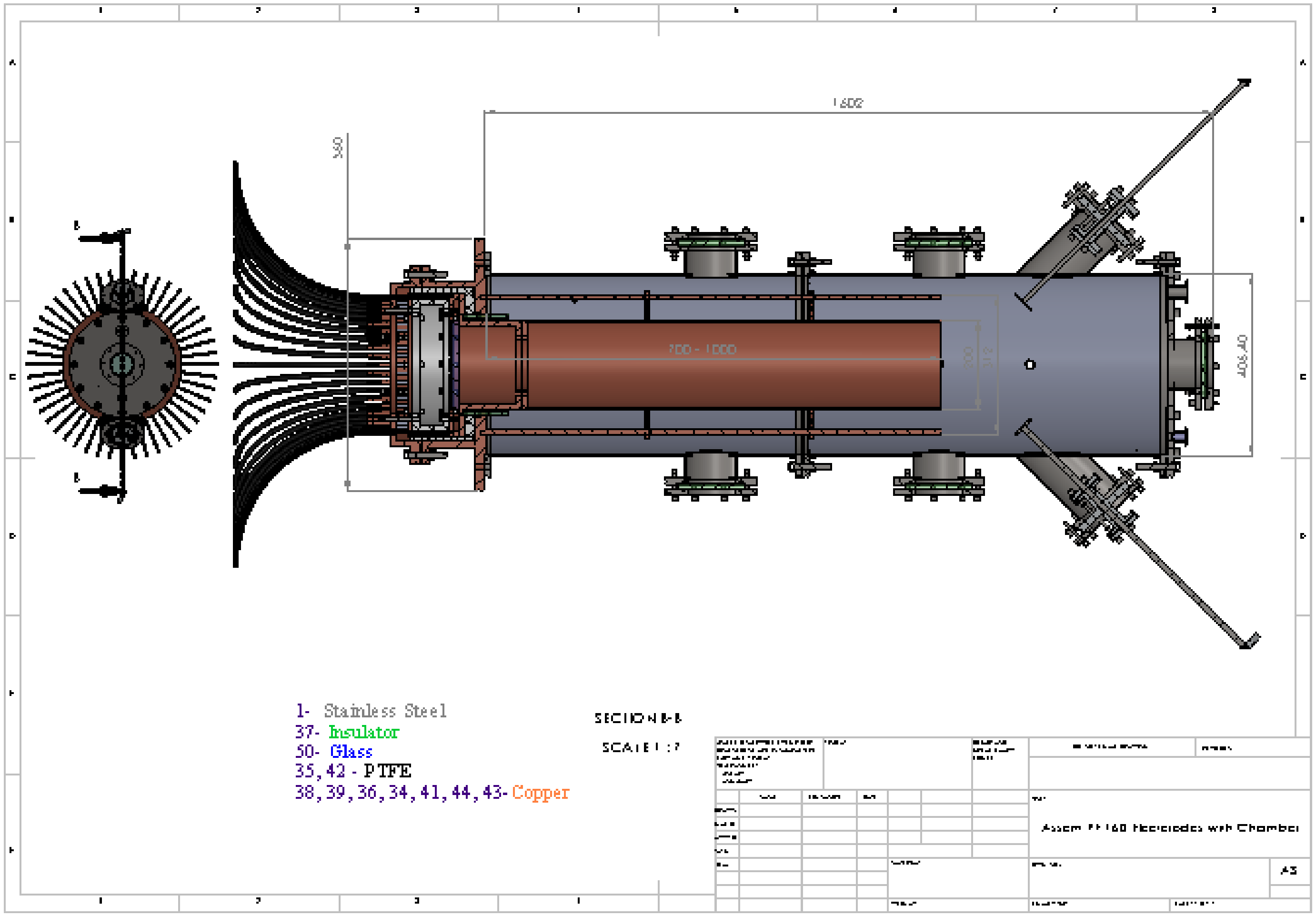



Figure 1. Electrodes and vacuum chamber of DuPF, SFM (All dimention notifications are in mm).


1602
360
700 - 1000
406.40
1- Stainless Steel
37- Insulator
50- Glass
35, 42 - PTFE
38, 39, 36, 34, 41, 44, 43- Copper
SECTION B-B
A3