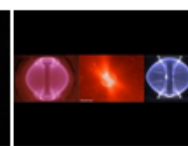




Energy Safety and Control Lab

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Advanced Plasma Engineering Lab



CNS 2019 – Fusion Panel, Ottawa, Canada

24-Jun-2019

Advances in Plasma Research at APEL - UOIT

Hossam Gaber (A.Gabbar), PhD, P.Eng, FS Eng (TÜV Rheinland), CEM,
Fellow RAMSP, ESCL, UOIT

APEL-UOIT

- Advanced Plasma Engineering Lab (APEL) at Ontario Tech University (UOIT)
- Research on plasma engineering and their applications on advanced fusion and clean energy
- Developed novel plasma generation technology based on virtual electrode and plasma array generation technique
- Apply our plasma generation on nuclear fusion, nuclear fuel recycling, and clean waste-to-energy
- Collaboration with number of industries and universities
- Collaboration with GPROSYS Corp. to develop and commercialize advanced plasma generation technology and their applications on nuclear and clean energy systems

APEL Team Members

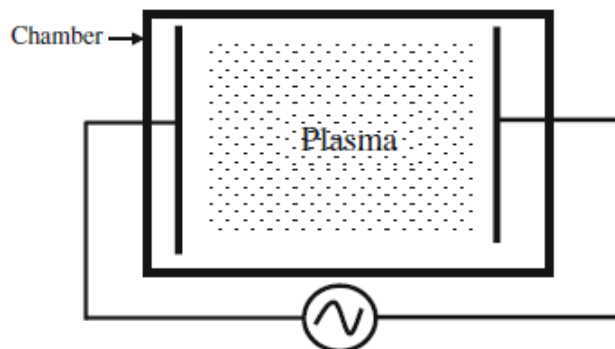
- PI: Dr. Hossam Gaber, Professor
- Postdoc: Dr. Ahmed Gad, Dr. Ahmed Abdelmaksoud
- PhD Student: Mohamed Aboughaly
- MASc Student: Md Rafiul Abdussami, Isaac Hensen
- Research Students: Manir Isham, Zachariah Zoepel
- Previous Members: Dr. Saif Elgriw, Dr. C. A. Barry Stoute, Daniel Bondarenko, Nicholas Tarsitano, Anas Abdel Rihem, Stefan Sirakov, Shraddhey Jani and Samskruthi Menashi, Anas Abdel Rihem, Nicholas Tarsitano

Plasma Generation

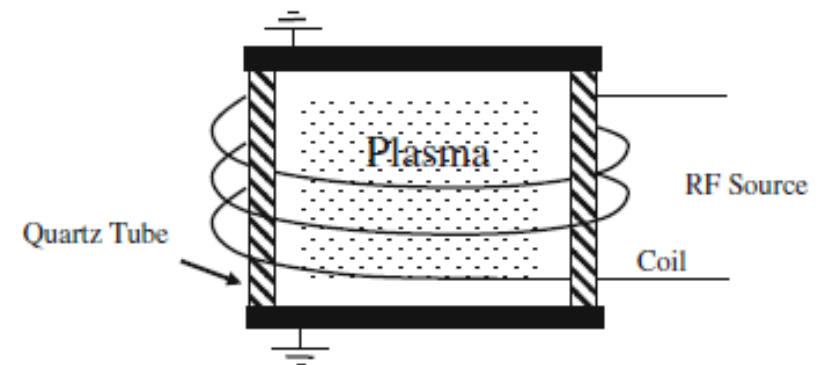
- Plasma is the fourth state of matter, it contains a significant number of electrically charged particles; hence, it has a relatively high electrical conductivity.
- Plasma state could be generated by:
 - Capacitive coupling (aka high voltage plasma).
 - Inductive coupling (aka radio frequency plasma).
- The gas pressure within the inductively-coupled plasma plays an important role in the plasma temperature:
 - Nuclear fusion applications
 - Waste to energy reactions

Thermal Plasma

- To use thermal plasma:
 - Capacitive coupling using a high voltage source as initially developed at the UOIT. First, the plasma adversely interact with the electrodes and reduce their lifetime. Second, metal vapor from the electrodes pollute the gaseous hydrocarbon products.
 - Inductive coupling using an RF source as currently developing at the UOIT. It has the advantages of plasma being generated with no direct contact with the electrodes.



Capacitive coupling

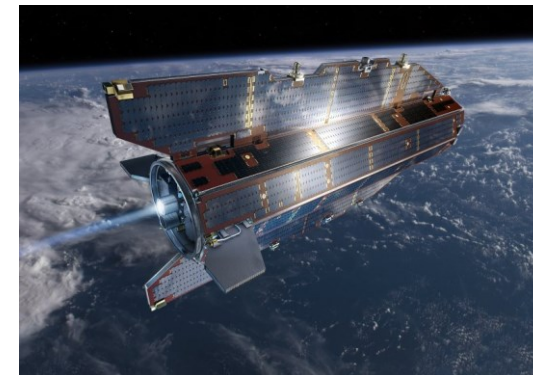
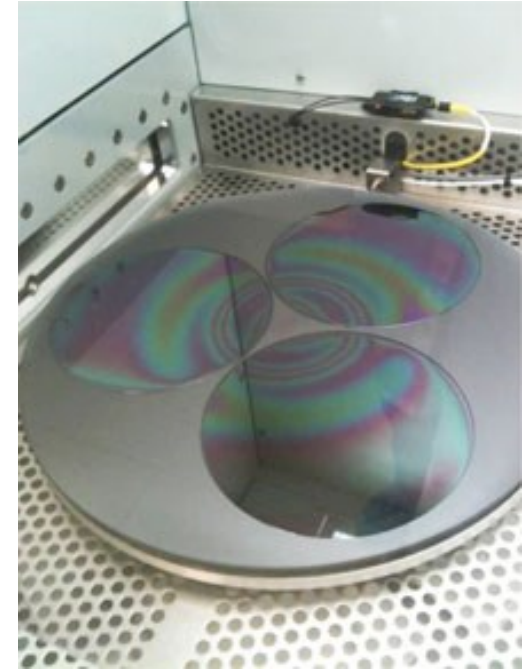
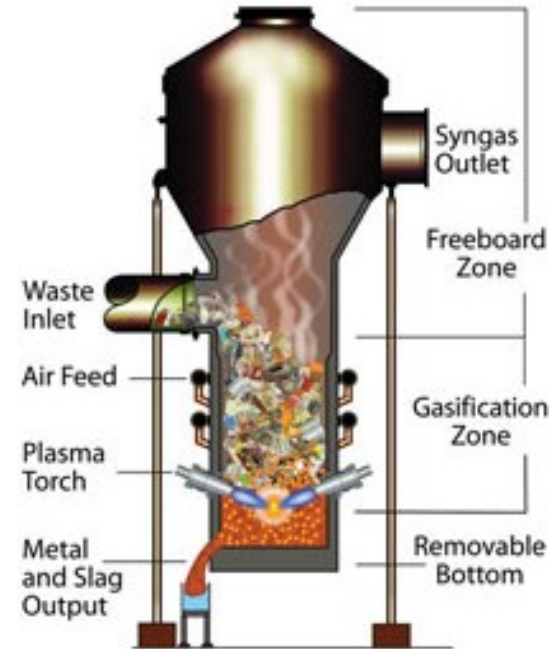


Inductive coupling

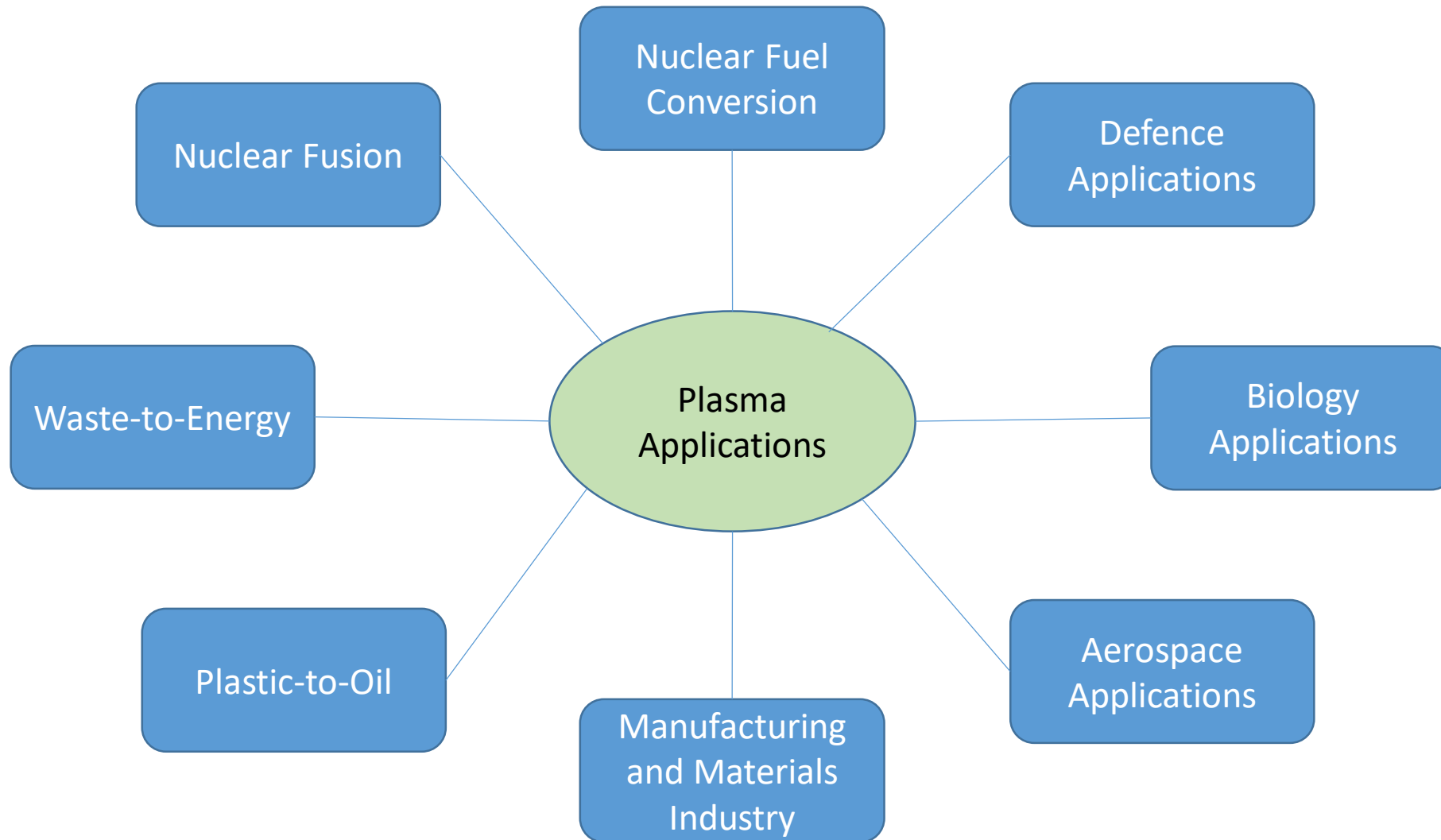
Plasma Applications

Potential Applications:

- Nuclear fusion
- Chemical and particle analysis
- Garbage/Waste gasification
- IC manufacture
- Long range Comm. and Radar
- Plasma welding and cutting
- Space propulsion systems



Plasma Generation Applications



APEL Research

Nuclear Fusion

- Experiment of one, two, and four intersecting plasma beams, with different fuels, with diagnostics and simulation
- Apply on neutron generation, nuclear waste/fuel recycle

Waste-to-Energy

- Test plasma-based waste to energy gasification
- Plasma gasification for Plastics-to-Oil conversion

Aerospace & Defence

- Use nitrogen rather than xenon for propellant
- Use ion and hall thrusters to manoeuvre satellites as commanded from the defense department
- Plasma actuators for military / space applications

Material Engineering

- Nanotechnology
- Spheroidization
- Deposition
- Microelectromechanical device Development
- Plasma lithography

Plasma
Generation

Plasma
Diagnostics

Thermal
Management

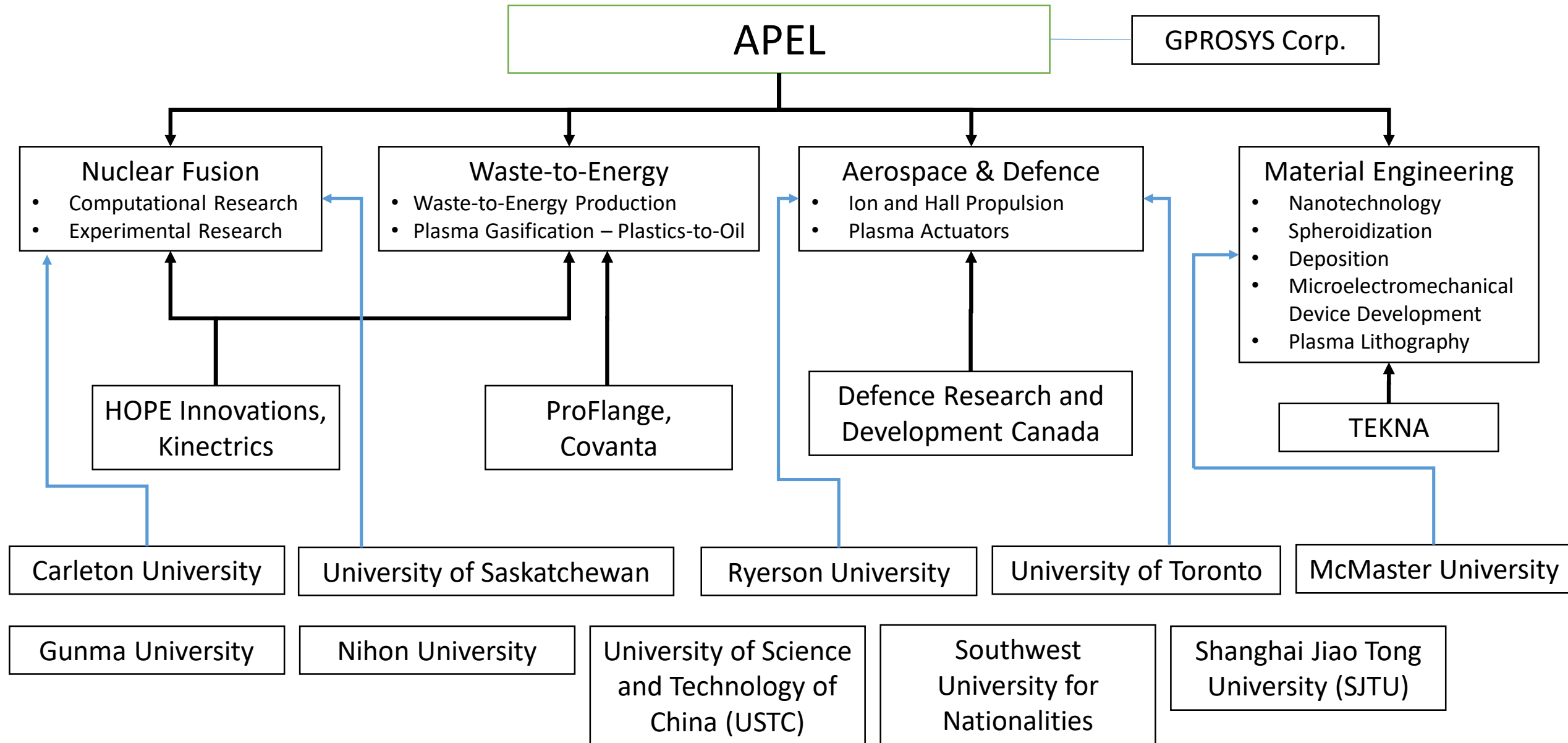
Plasma Physics

Plasma
Simulation

Neutron Physics
/ Detection

- Meet international strategic research plan on clean energy technologies - sustainability
- Investigate innovative DC and RF plasma generation technologies and apply on several applications for Canadian and international market, and in many disciplines
- Investigate new methods and technologies for plasma diagnostics and control
- Study thermal management of plasma generation systems
- Study low / high power space propulsion for nano / large satellites
- Produced 10 journal papers, 4 conference papers/presentations
- Research team include 18 undergraduate, graduate, and postdocs during last 3 years

Partner Institutions and Industries



R&D at APEL

- Dielectric Barrier Discharge Plasma Actuators
 - Purpose:
 - Control Flow Separation on an Airfoil
 - Control of Bluff Body Wakes
 - Control transition of a laminar boundary layer
 - Use of a dielectric barrier between two copper plates to create plasma using capacitive discharge
 - Function generator to control actuation
 - Experimental Set-Up from “Characterization of the time-dependent behaviour of dielectric barrier discharge plasma actuators”
 - Dielectric Plate - Polymethyl methacrylate
 - Separation – Kapton Tape
 - Electrodes – Copper
 - Function Generator
 - High Voltage Amplifier
 - Digital Oscilloscope
- Particle Image Velocimetry

R&D at APEL – UOIT for Fusion Energy

- Plasma generation, diagnostics, measurement
- Instrumentation and power supply systems (AC/DC, pulsed)
- Spatial control, real time and intelligent control with 3D simulation
- Safety design, risk and uncertainty analysis
- Energy Harvesting from Nuclear Fission/Fusion Hybrid Technology
(Thermoelectric Generation, Photovoltaics, Magnetohydrodynamic generator)
- Data analysis and verification, and 3D information visualization, for fusion experimentations and simulations

Research and Industrial Collaboration Projects

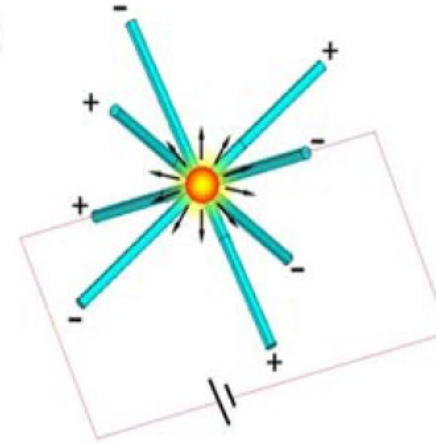
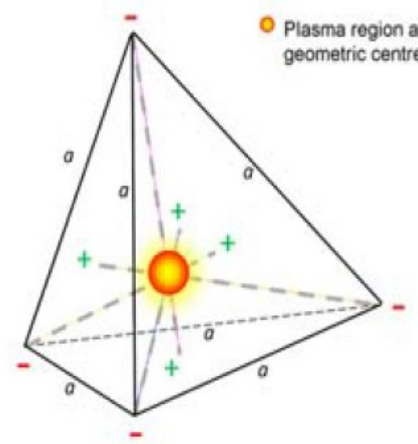
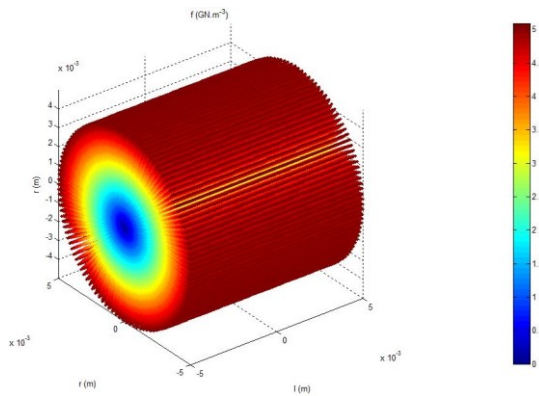
- **Plasma Simulations**
 - Computational Fluid Dynamics using Magnetohydrodynamics
 - Particle-in-Cell/Statistical Mechanics Modeling using Monte Carlo
 - Hybrid CFD/PiC modeling
- **Plasma Generation**
 - High Voltage – High Power DC Plasma
 - Low Power RF Plasmas
 - Capacitive Discharge
 - Inductive Discharge
- **Plasma Gasification**
- **Power Generation from Scramjets, Rockets, and Jet Engines**
- **Ion, Hall, and Magnetoplasma dynamic Thrusters**
- **Alternative Nuclear Fusion**
- **Laser Technology**
- **Plasma Etching for Micro- and Nanotechnology**
- **Ramjet and Scramjet Technology**

Impacts of Plasma-based Fuel Treatment

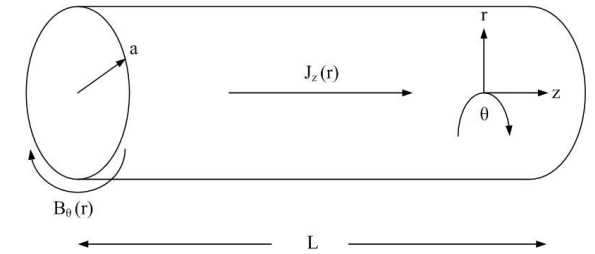
- UOIT will offer advanced test facility for industrial use/rent
- This research will support recycling of spent nuclear fuel/rods from Pickering and Darlington (\$12.2 Billion Dollars – OPG / IAEA reports)
 - Recycling spent nuclear fuel/rods to reduce cost of buying raw materials, decommissioning
 - Can sell certain nuclear materials for space-exploration and research (the use of radioisotope thermoelectric generator in satellites)
- The research brings Canada closer to nuclear fusion (\$6 Billion Dollars - IAEA)
 - Chamber enacts as a nuclear fusion reactor for power generation
- Society will benefit from clean and reduced energy generation, plastic recycling, waste-to-energy generation (\$400 Billion Dollars [in US alone] – SPI)
 - Recycling of plastic and processing of waste-to-energy provides sustainable clean energy
- New jobs will be created for handling fuel recycling and nuclear fusion
- Society will support the establishment of new generation engineers and Scientists with strong foundation of physics and mathematics to mobilize new technology development

Plasma Generation for Fusion Reactors

Force Density Distribution Inside the Beam

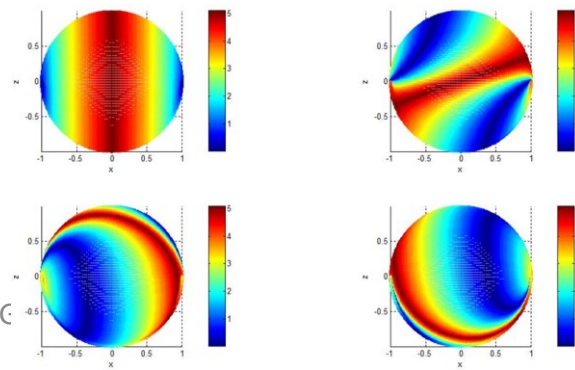


Analytical MHD Model for High Current Plasma Beam

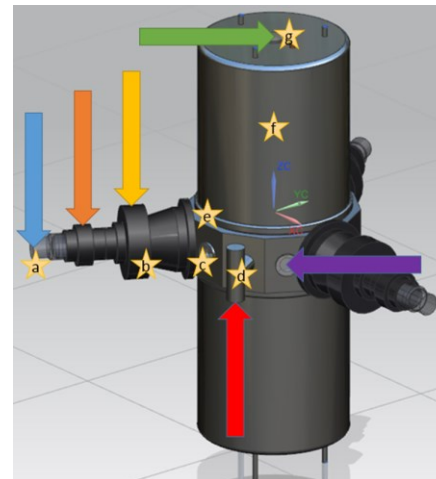


Lab Experimentation for Plasma Applications

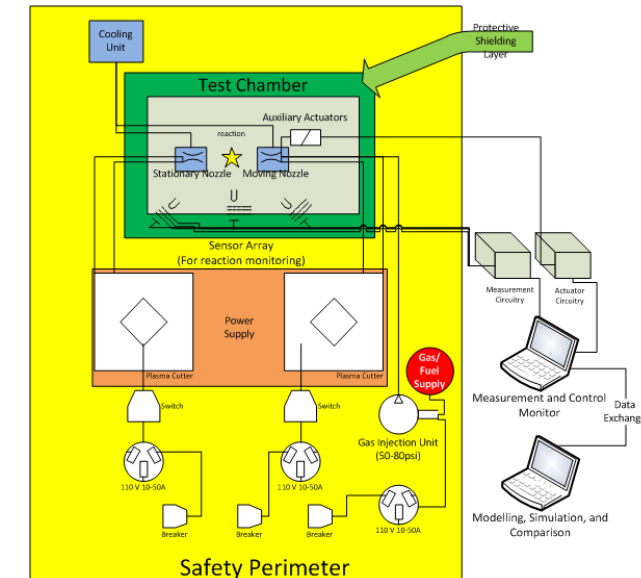
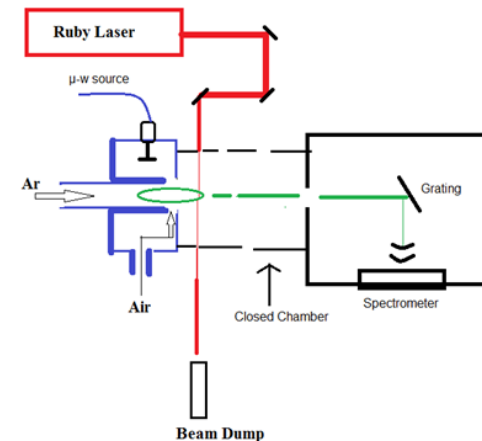
Self-Induced Lorentz Force of the 4 Plasma Beams



Simulation of Plasma Chamber using Elmer

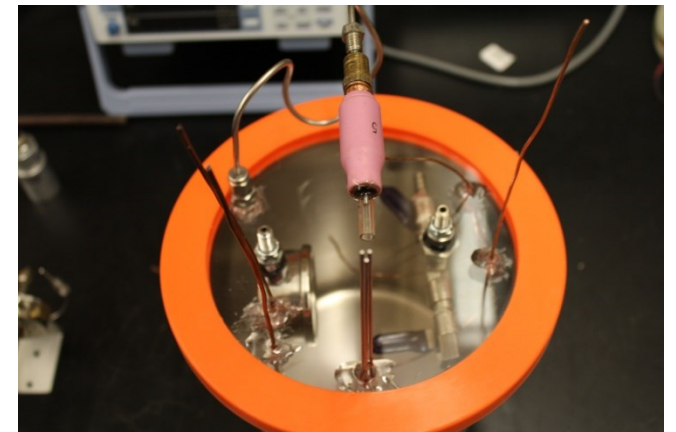
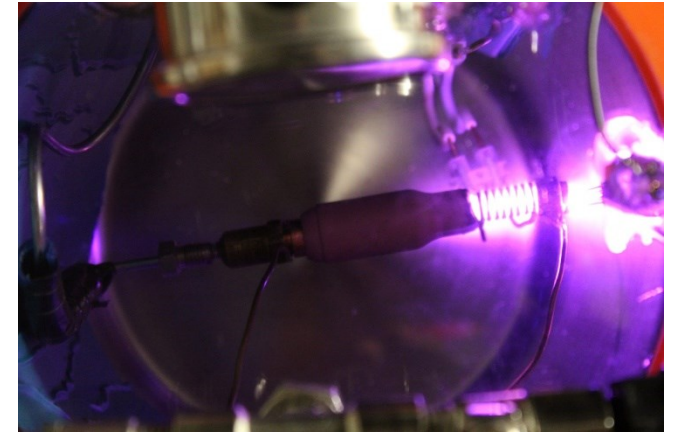


TSD Experimental Setup



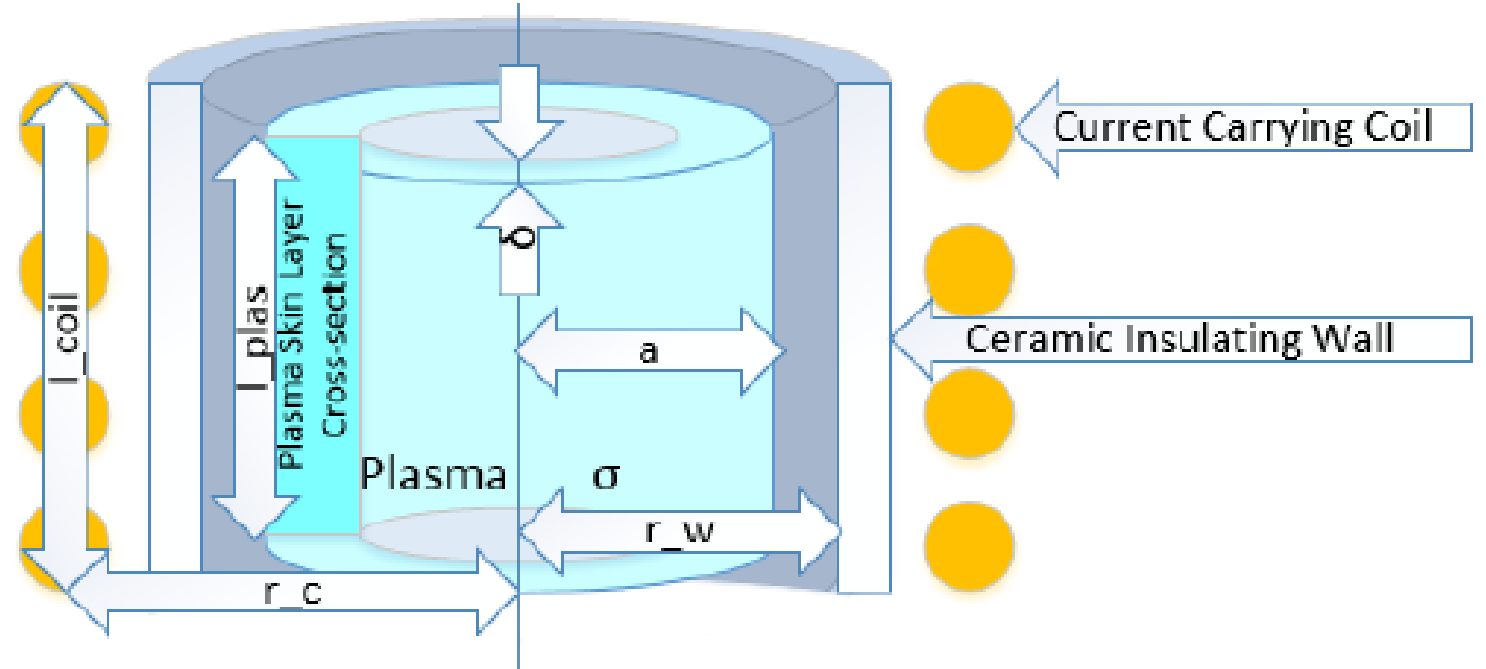
Plasma Generation Technology

- Plasma Generation
 - Miniature-Size Thermal Chamber
 - DC and RF Plasma Generation
 - 20 W to 1000 KW Power Input
 - **Fusion Applications**
- Advanced Hybrid Plasma Simulation
 - Elmer Modeling (Finite Element Method)
 - MATLAB (Finite Volume Method)
 - Monte Carlo Simulation, and MHD



RF Coupling and Confinement

- The goal for radio frequency (RF) heating of plasma is to stir the work gas in such a manner that it will maintain its ionized state
- It is possible to heat plasma by three modes of RF coupling: an oscillating magnetic field (inductive coupling), an oscillating electric field (capacitive coupling), or both (quasi-optical or microwave coupling)
- The effectiveness of plasma heating by RF depends on the strength of magnetic field, oscillation frequency, particle collision frequency and plasma conductivity

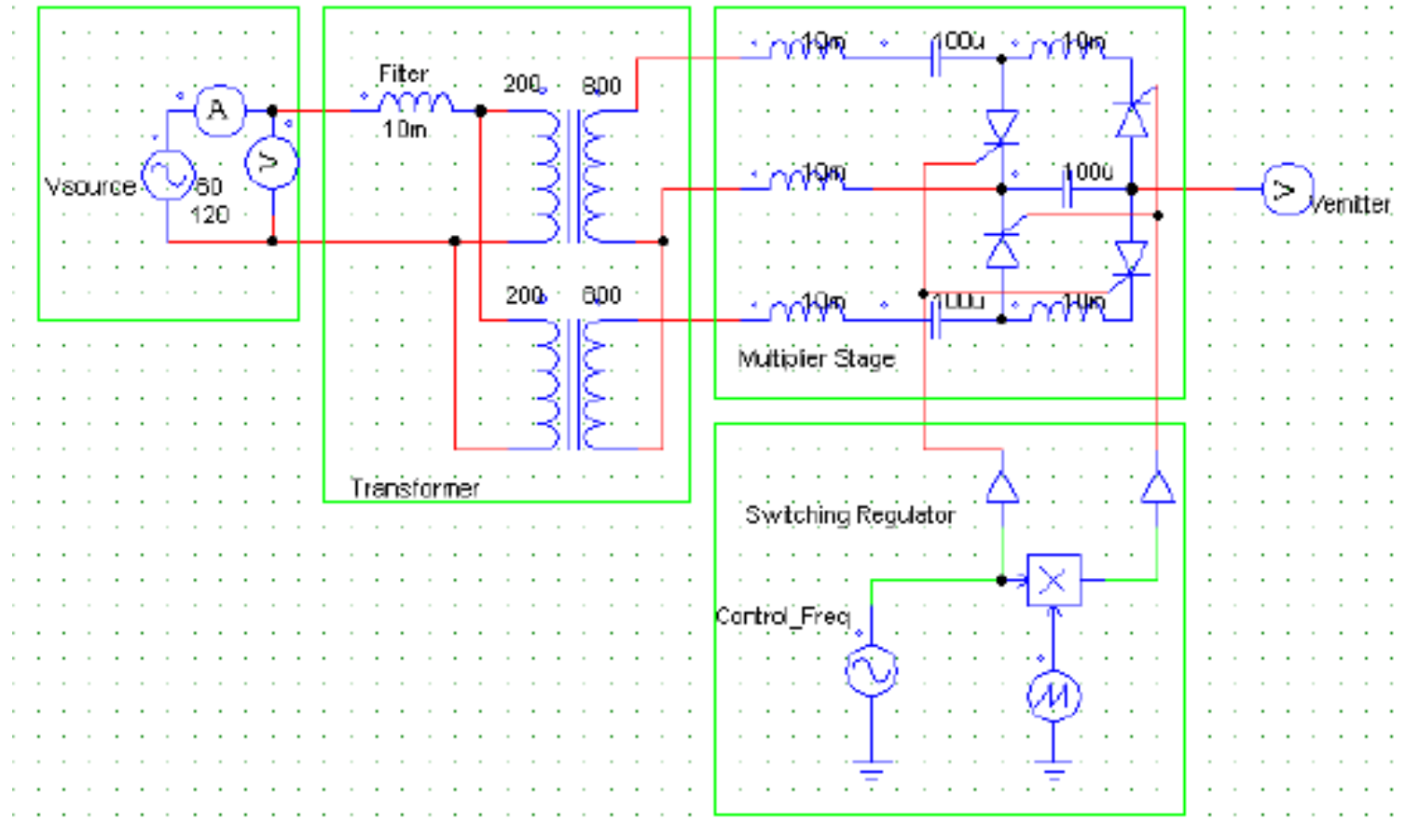


$$u_{B_{rms}} = \frac{B^2}{2 \cdot \mu_0} [J/m^3]$$

$$\delta_{skin} = \sqrt{\frac{2 \cdot m_e}{q^2 \cdot \mu_0}} \cdot \sqrt{\frac{\nu_0}{N_e \cdot \omega_{pe}}} = 7.516 \cdot 10^6 \cdot \sqrt{\frac{\nu_0}{N_e \cdot \omega_{pe}}} [m]$$

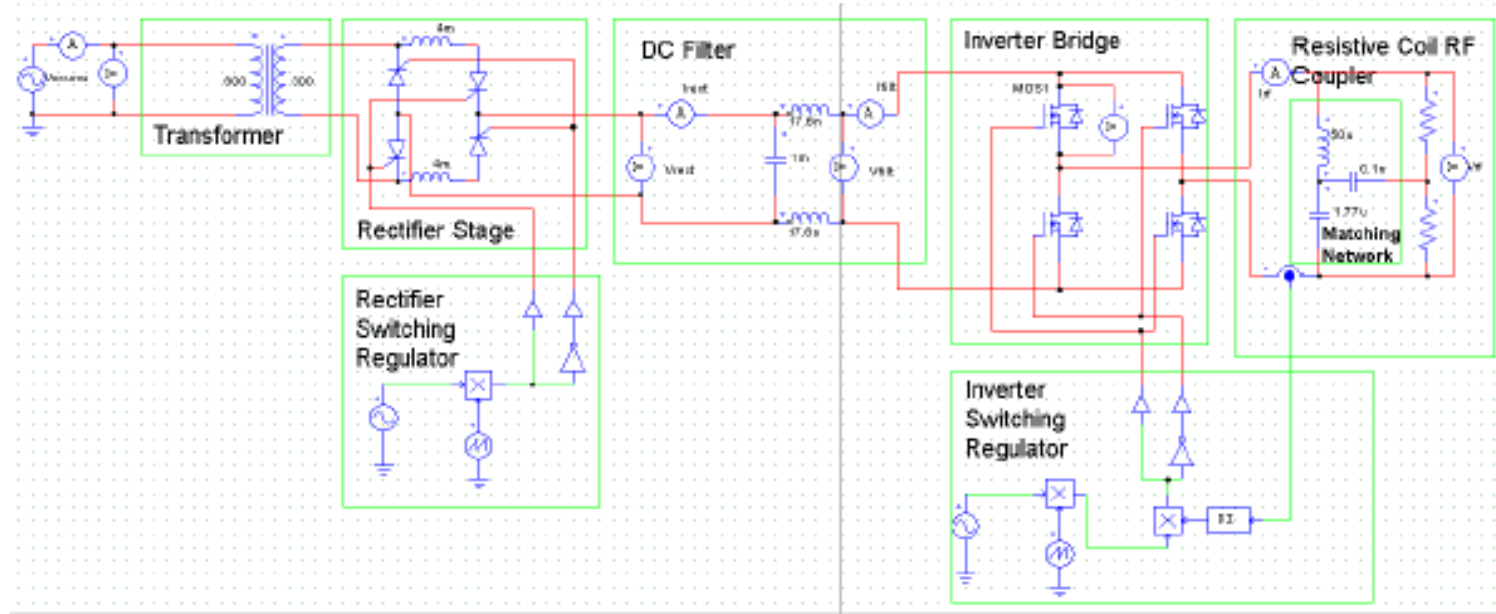
Proposed System Design: Circuit for plasma power and control

- The electric energy is supplied to ionize a gas via a high field emission and the resulting plasma is supported by the Ohmic heating process, sustained by the RF coupling circuit
- The three primary circuits in the virtual plasma generator include: (1) power control, (2) high field generator, and (3) RF coupling circuit



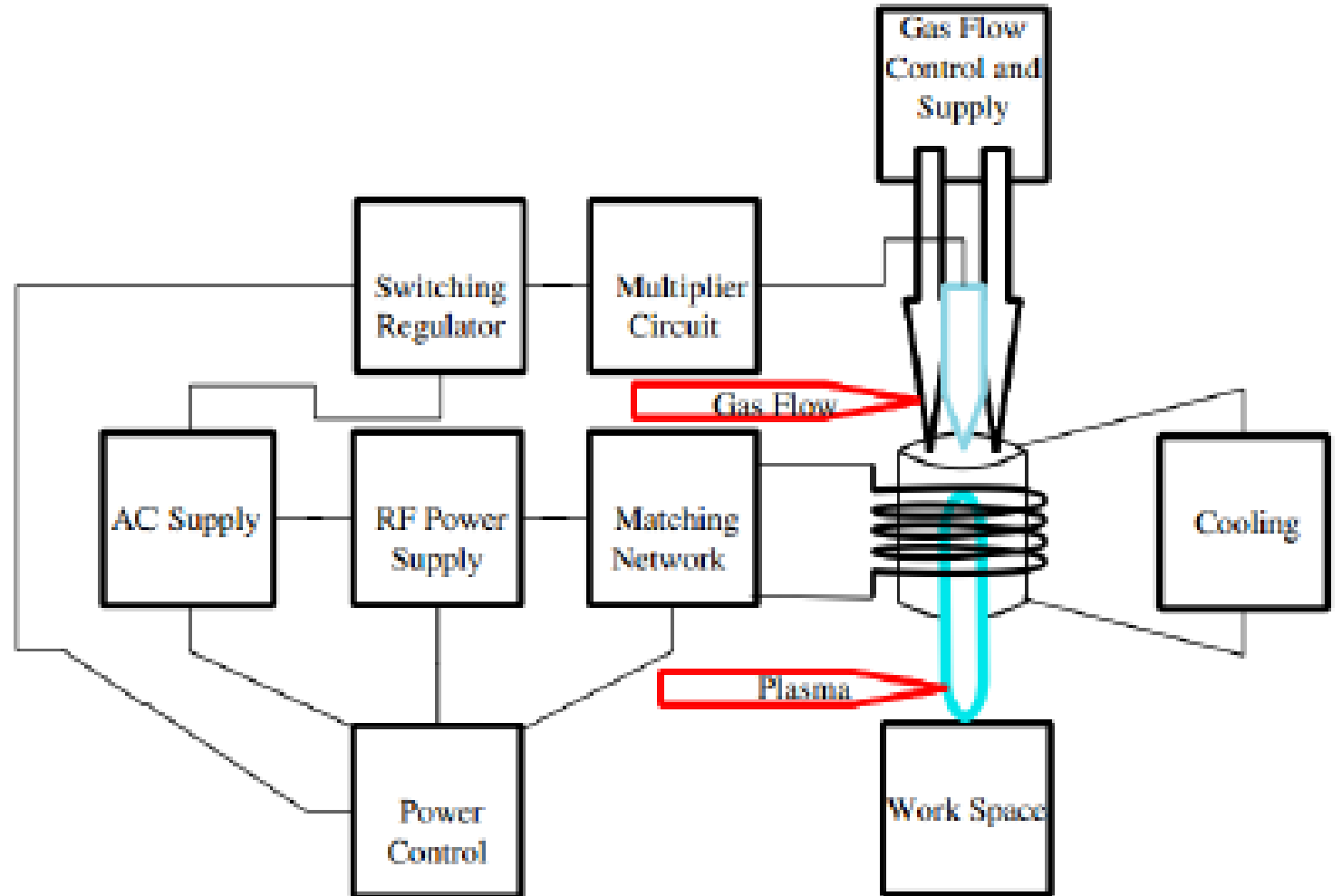
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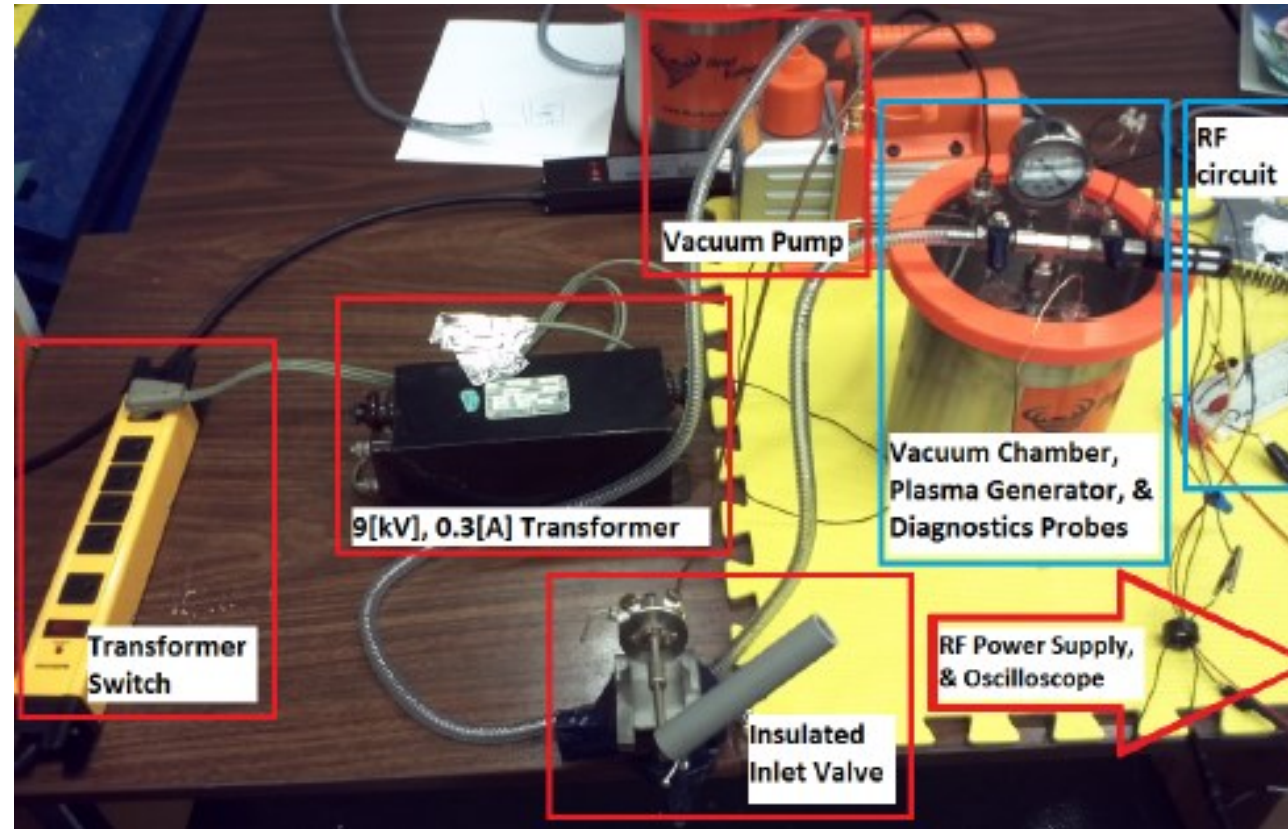


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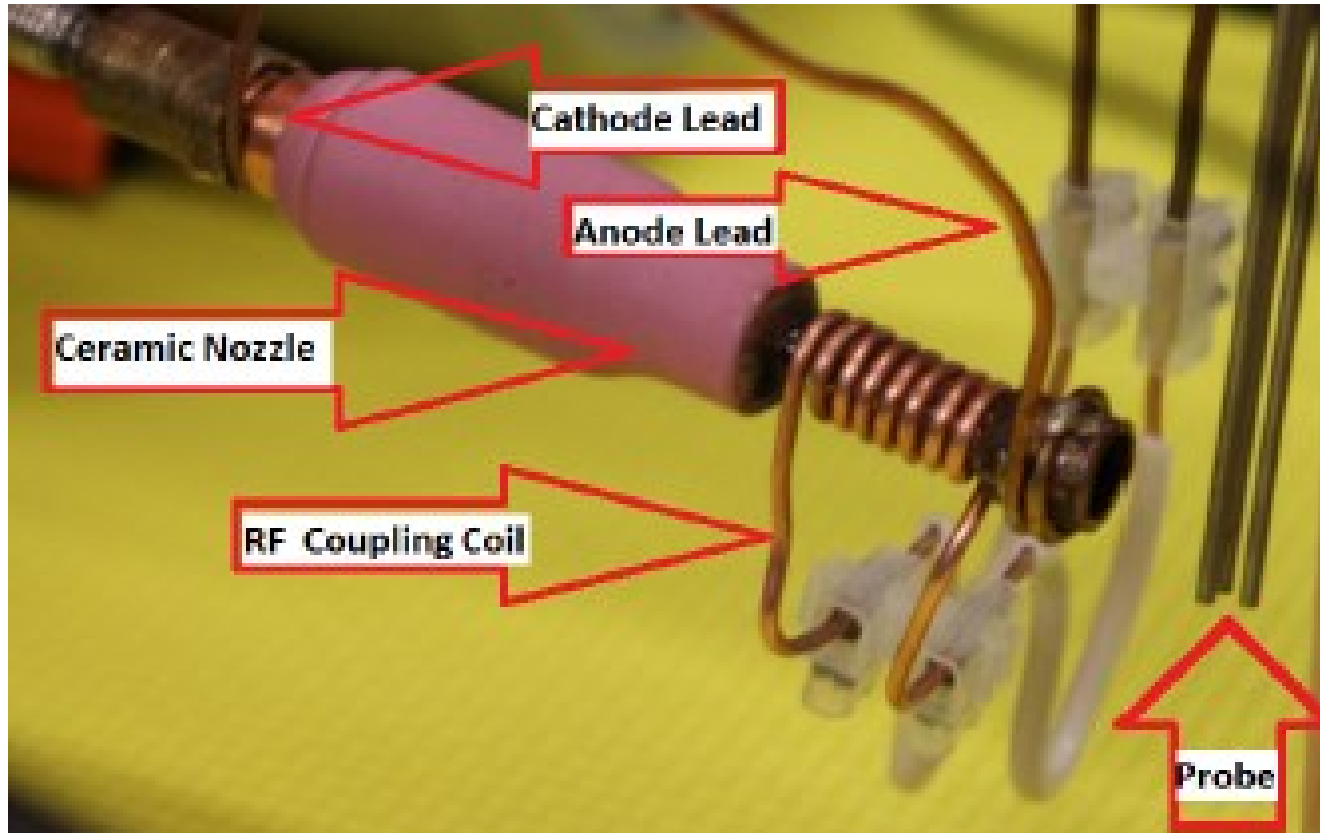


Plasma Generator Experiment



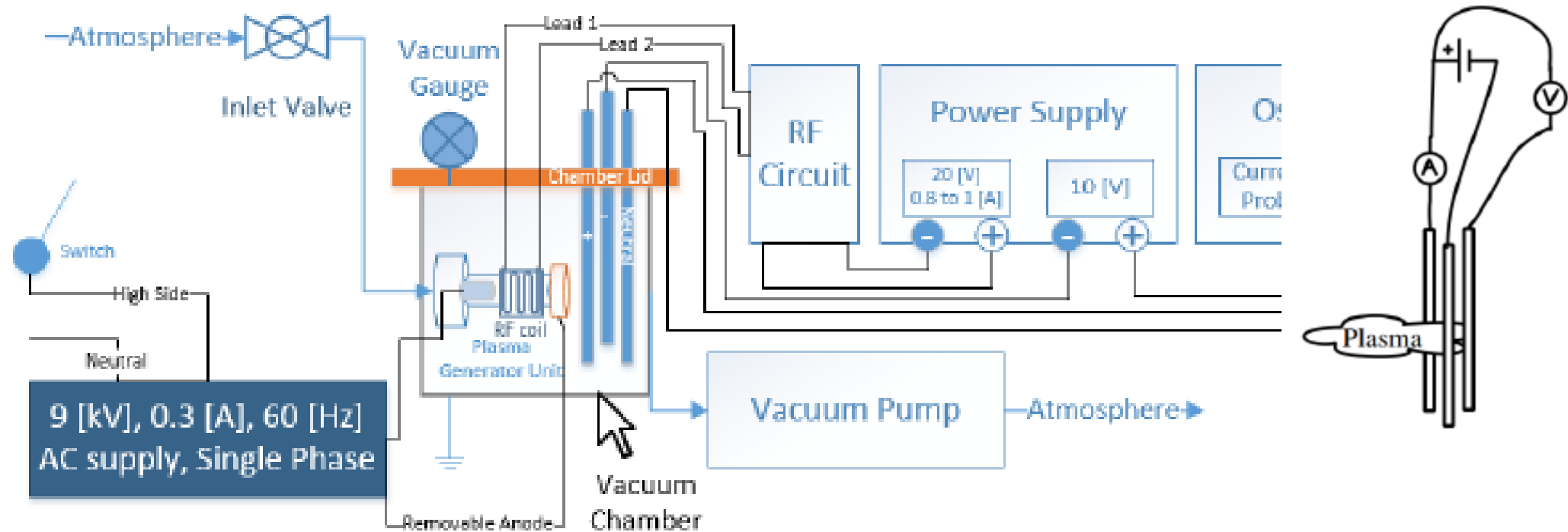
- The experiment is composed of three key subsections:
(1) Safety procedures, (2) Power supply, and (3) Data acquisition methodology

Plasma Generator Experiment



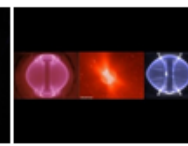
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Plasma Generator Experiment

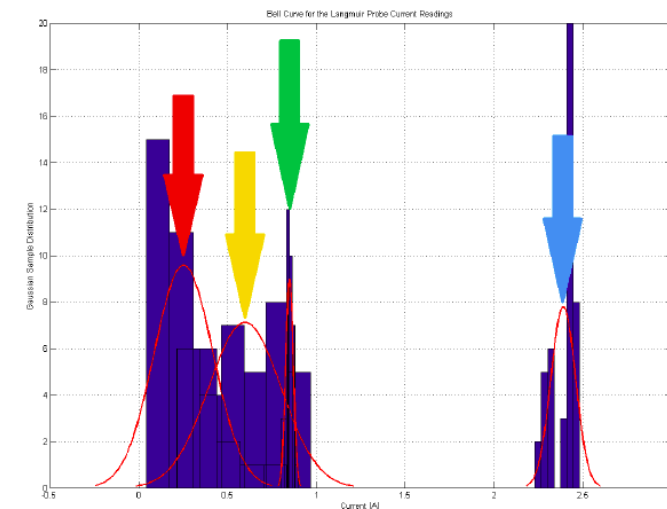
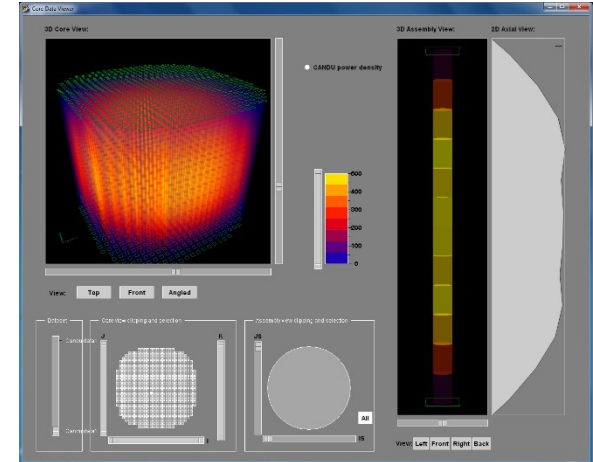


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(1) Safety procedures, (2) Power supply, and (3) Data acquisition methodology

3D Simulation Platform for Fusion Reactors, Safety Verification, and Information Visualization



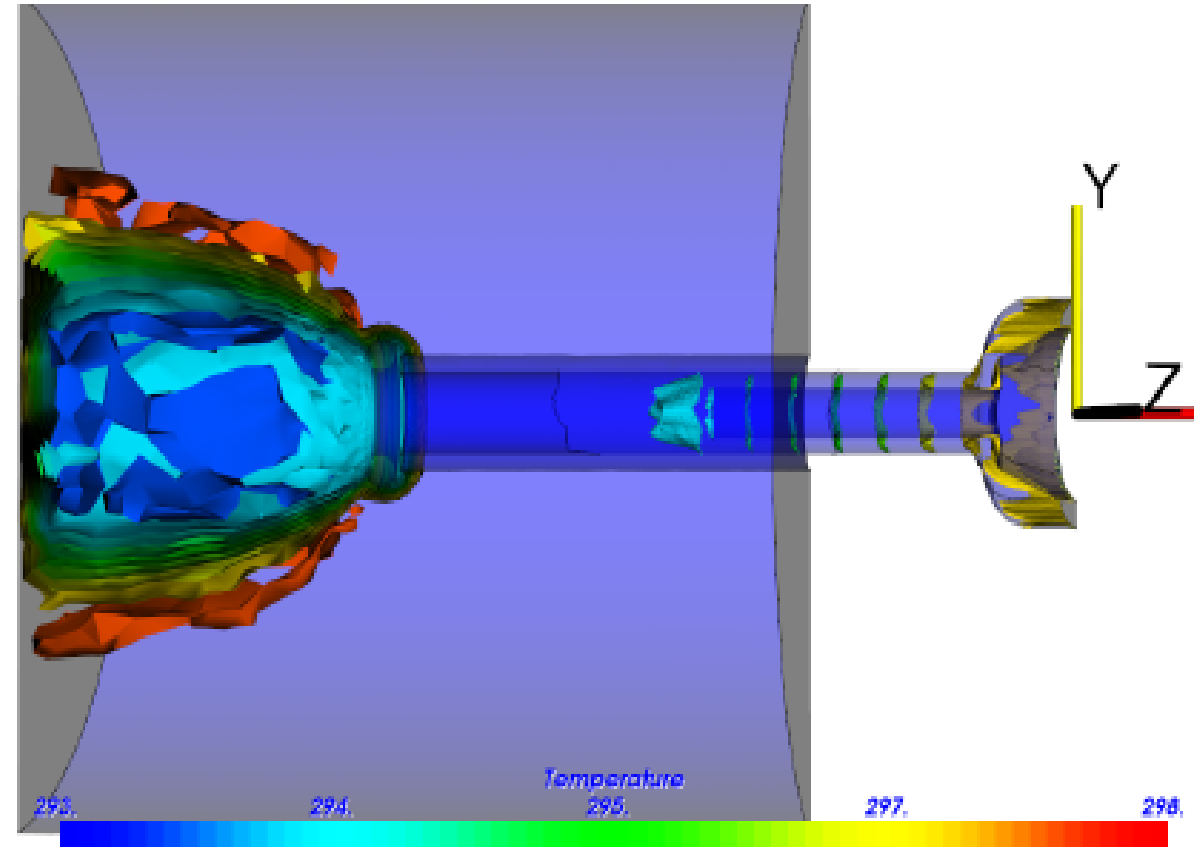
- Study and develop 3D simulation platform for fusion reactor core information
- Study real-time and online monitoring, diagnosis, and safety analysis
- Support spatial control and monitoring, 3D reactor core information includes 3D temperature profile, 3D flow profile, 3D pressure profile, 3D stress profile, etc.
- Currently, there is no powerful 3D visualization platform for fusion reactors to support the engineering design and experimentation activities, as well as R&D activities



Simulation and Modelling

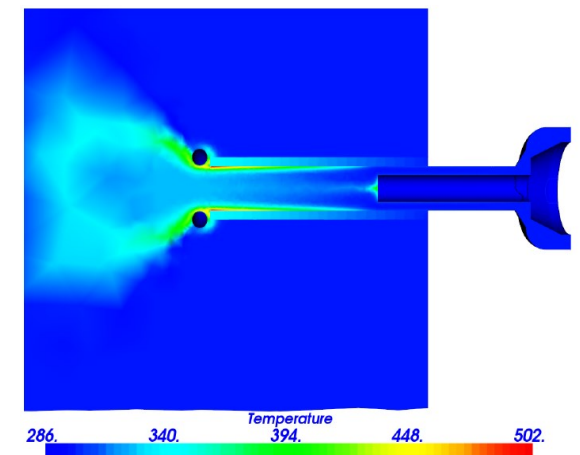
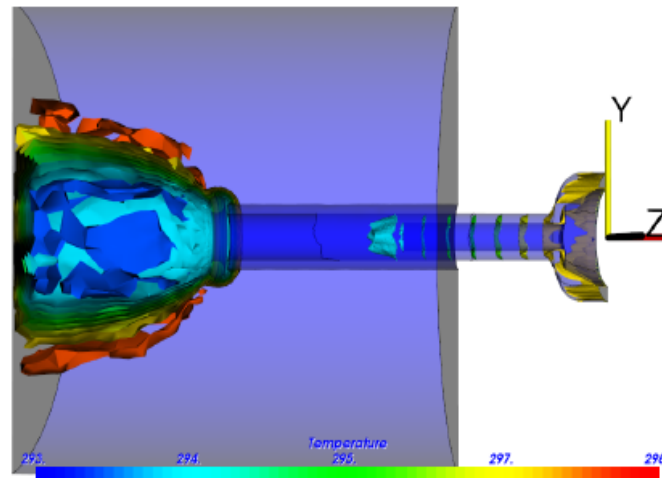
- Fluid and heat transfer simulations in mesh resolutions: 0.25[mm], 0.1[mm], and 0.05[mm]
- Direct discharge simulation based on the experimentally derived and simulation results
 - Plasma conductivity (Experiment and Computed)
 - Ion concentration
 - Current Density
 - Joule Heating

Parameters	Computed	Experiment
Conductivity	1.689e-5	2.404e-5
Current Density [A/m]	12.16	12.16
Max. Joule Heating [W/m]	8.755e6	6.151e6



Control Systems for Fusion Reactors

- Study spatial, real time and advanced control techniques for high performance plasma generation and fusion reactors
- Utilize 3D simulation to support fusion reactor control

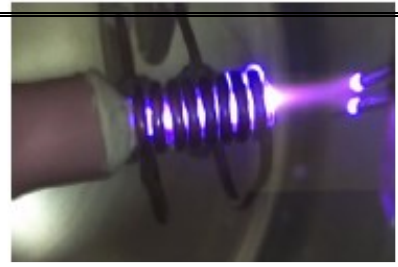
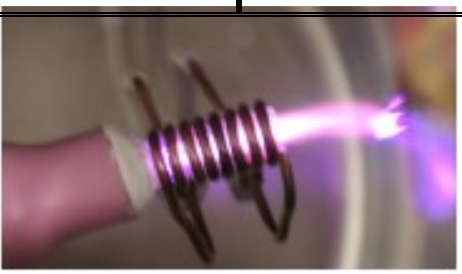
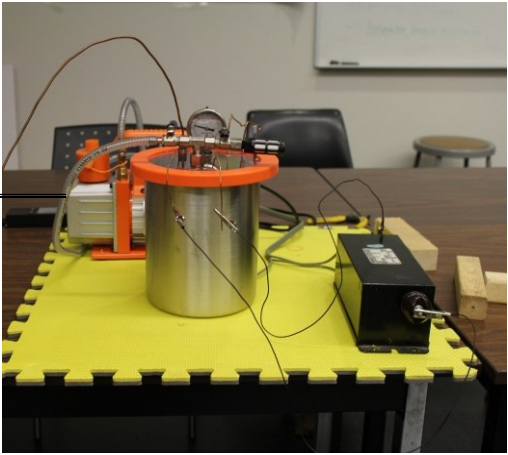
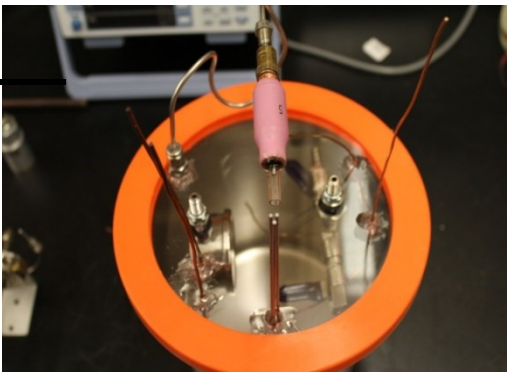
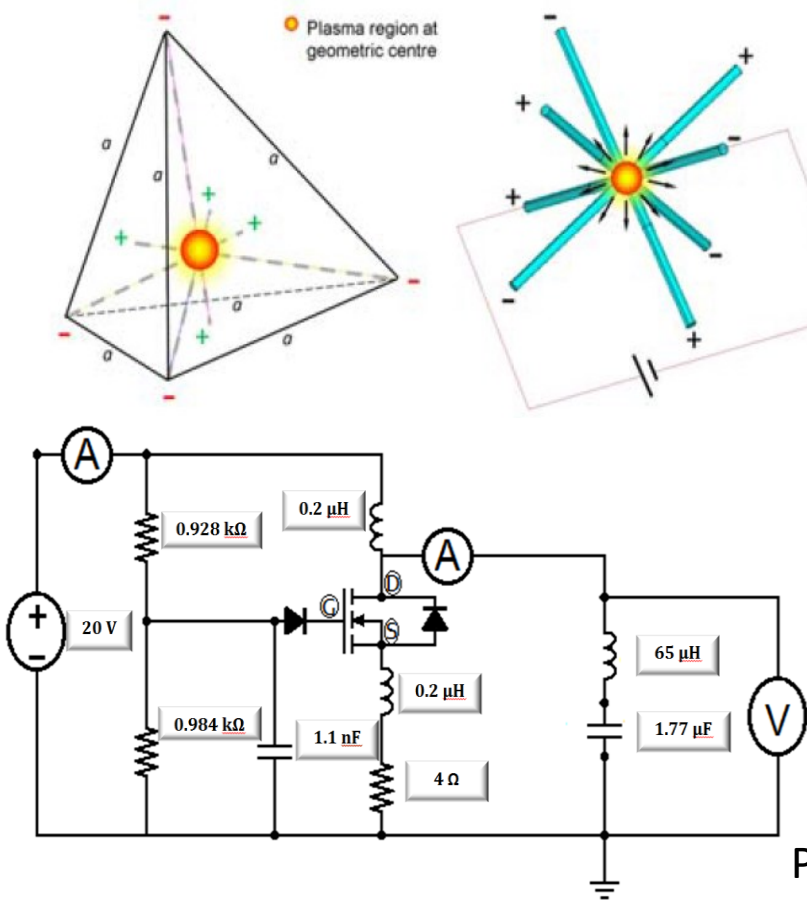


RF-Assisted DC Single Beam Plasma Generation for Multi-Beam Nuclear Fusion

- C. A. Barry Stoute¹, Daniel Bondarenko², Hossam A.Gabbar³, Anas Abdel Rihem⁴, Nicholas Tarsitano⁵

Table 2: Beam Current, Drift Velocity, and Force of the Plasma Generation Experiment

Solenoid Mode and Direction	Beam Current (mA)	Beam Drift Velocity (m·s ⁻¹)	Beam Force (mN)
None	424.2	121	24.9
DC Magnetic Field North	813.5	22.2	0.842
DC Magnetic Field South	439.6	38.5	25.4
78 MHz Radio Frequency	1069	222	84.4
125 MHz Radio Frequency	3017	321	176.9

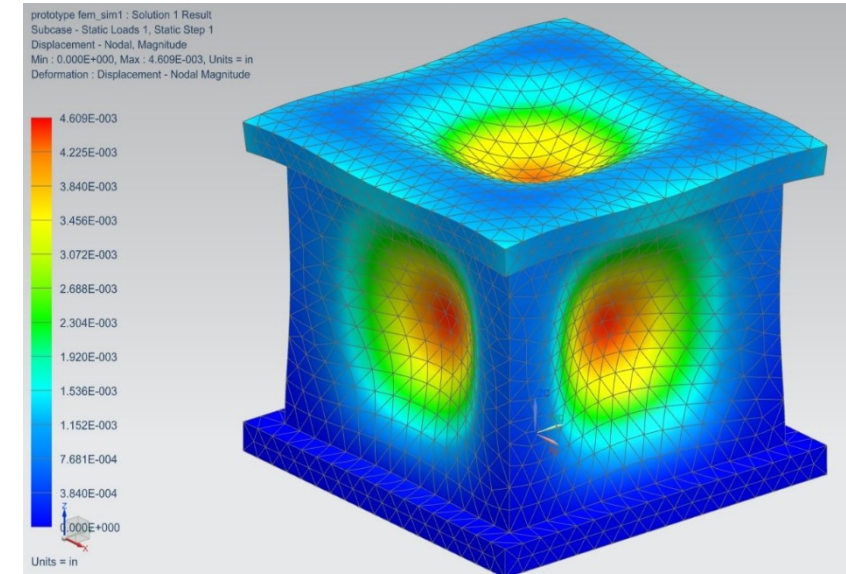
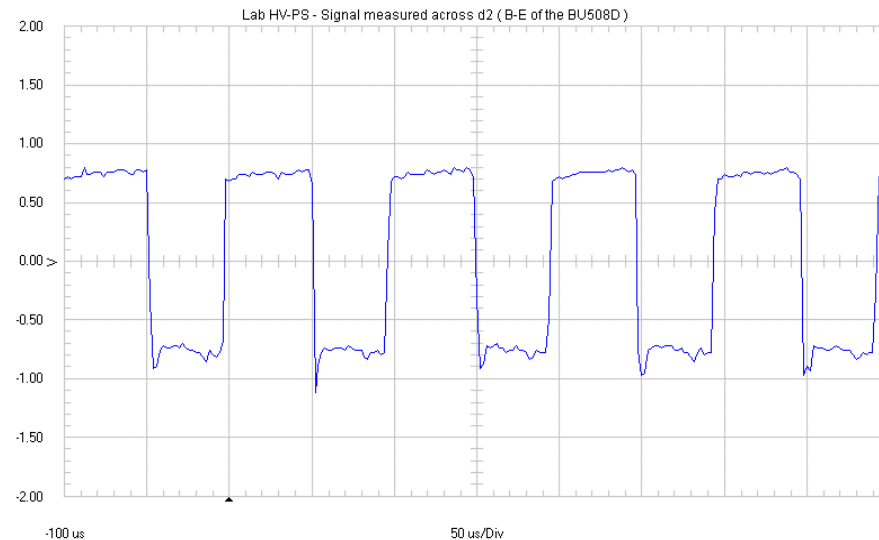
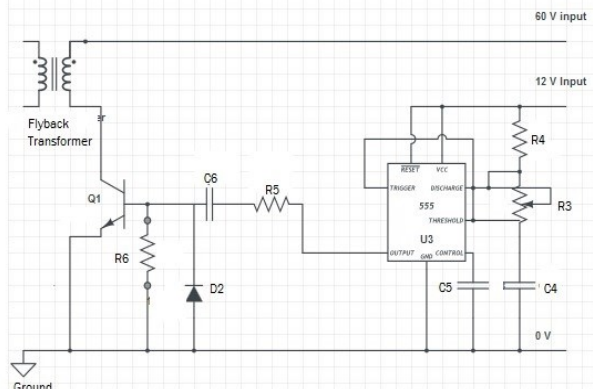
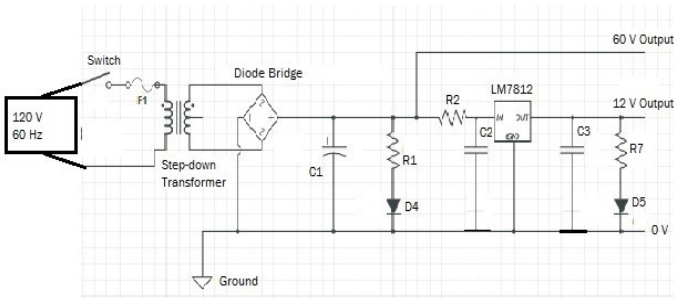


Plasma jet with DC Circuit

Plasma jet with RF Circuit

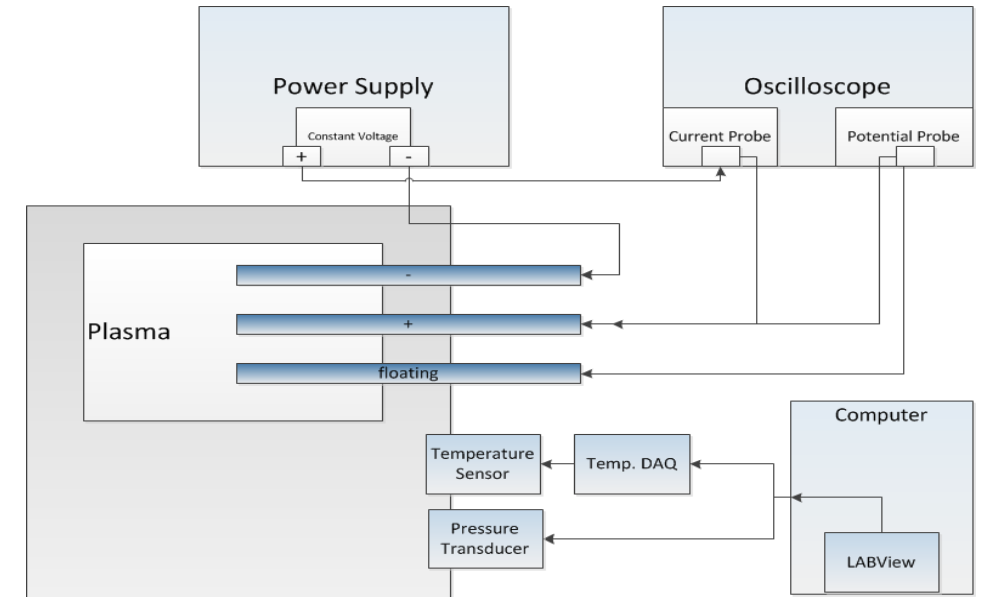
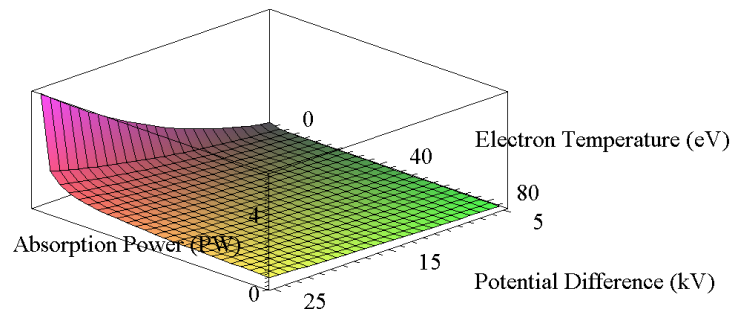
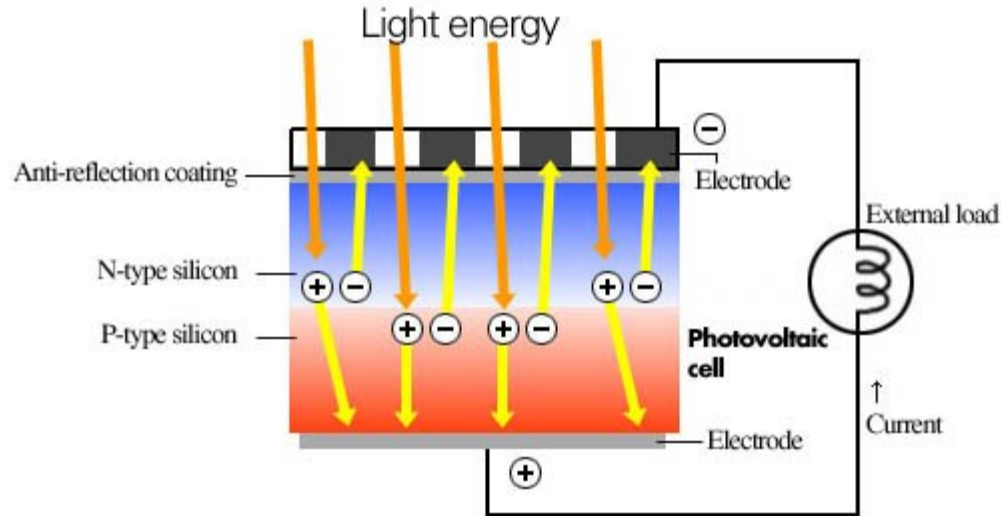
X-Pinch Plasma Generation Testing for Neutron Source Development and Nuclear Fusion

Hossam A.Gabbar *, C. A. Barry Stoute, Daniel Bondarenko, Nicholas Tarsitano, Anas Abdel Rihem, Stefan Sirakov, Shraddhey Jani and Samskruthi Menashi



Experimental results of power and efficiency from the single and double beams

A photovoltaic cell generates electricity when irradiated by sunlight.



Orientation-Position (inches)	Pinch Type	Voltage (mV)	Current (μ A)	Power (μ W)	Efficiency (%)
Horizontal-2.50	Z	53	6	0.318	1.17×10^{-7}
Horizontal-2.50	X	80	10	0.800	2.96×10^{-7}
Horizontal-1.25	Z	120	20	2.400	8.88×10^{-7}
Horizontal-1.25	X	131	30	3.930	1.45×10^{-7}
Vertical-2.50	Z	43	8	0.344	1.27×10^{-7}
Vertical-2.50	X	65	14	0.910	3.37×10^{-7}
Vertical-1.90	Z	80	11	0.880	3.25×10^{-7}
Vertical-1.90	X	100	16.5	1.650	6.11×10^{-7}

Evaluation Of Potential Designs For High Performance Fusion Energy Technologies

Hossam A.Gabbar^{1,2,*}, Daniel Bondarenko², Sayf Elgriw¹, Anas Abdel Rihem¹

Quality indicators

Device	Size Area [m ²]	Complexity # of parts	Confinement Geometry	Commercial Cohesiveness
Tokamak	0.8-1182	Designs vary, part count is anywhere between 100,000 and up to/or beyond the one million parts	Torus, possible employment of the D-shape, bundle, or ergodic diverters, or limiters	Scientific Value/ ITER oriented
Stellarator	1.2-572.5		Twisted Torus	Scientific Value WX oriented
Spherical Torus	2.5-~4		Spherical Torus	Scientific/Commercial
RFP	12.6 and up		Torus Variants	Scientific Value/ ITER oriented
Spheromak	0.8-1	1,000-100,000	Sphere propagating on a line	Scientific Value
Magnetic Mirrors	1-1160	~1,000-100,000	Cylinder	Historical/Scientific Value
Ø-Pinch	Needs to be long to be feasible	~1,000-10,000	Cylinder, Torus Variants	Historical/Scientific Value
Z-Pinch	0.04-0.2	~1,000-10,000	Cylinder	Neutron Generators
ØZ-Pinch	Unknown	~1,000-100,000	Cylinder	Scientific Value
Field Reversed Configuration	10-80	10,000-100,000	Sphere propagating on a line	Scientific Value Active Commercial Research
Inertial Confinement Devices	0.75km ²	100,000 to beyond 1 million	Sphere/miniature cylinder hollow	Weapons Research High Energy Science
Electrostatic Confinement Fusors	1-4	1,000-10,000	Sphere	Hobbyists, Neutron Generators, Historic/Scientific Value
Polywell	1-25	10,000-100,000	Sphere	Scientific Value

Economic Indicators

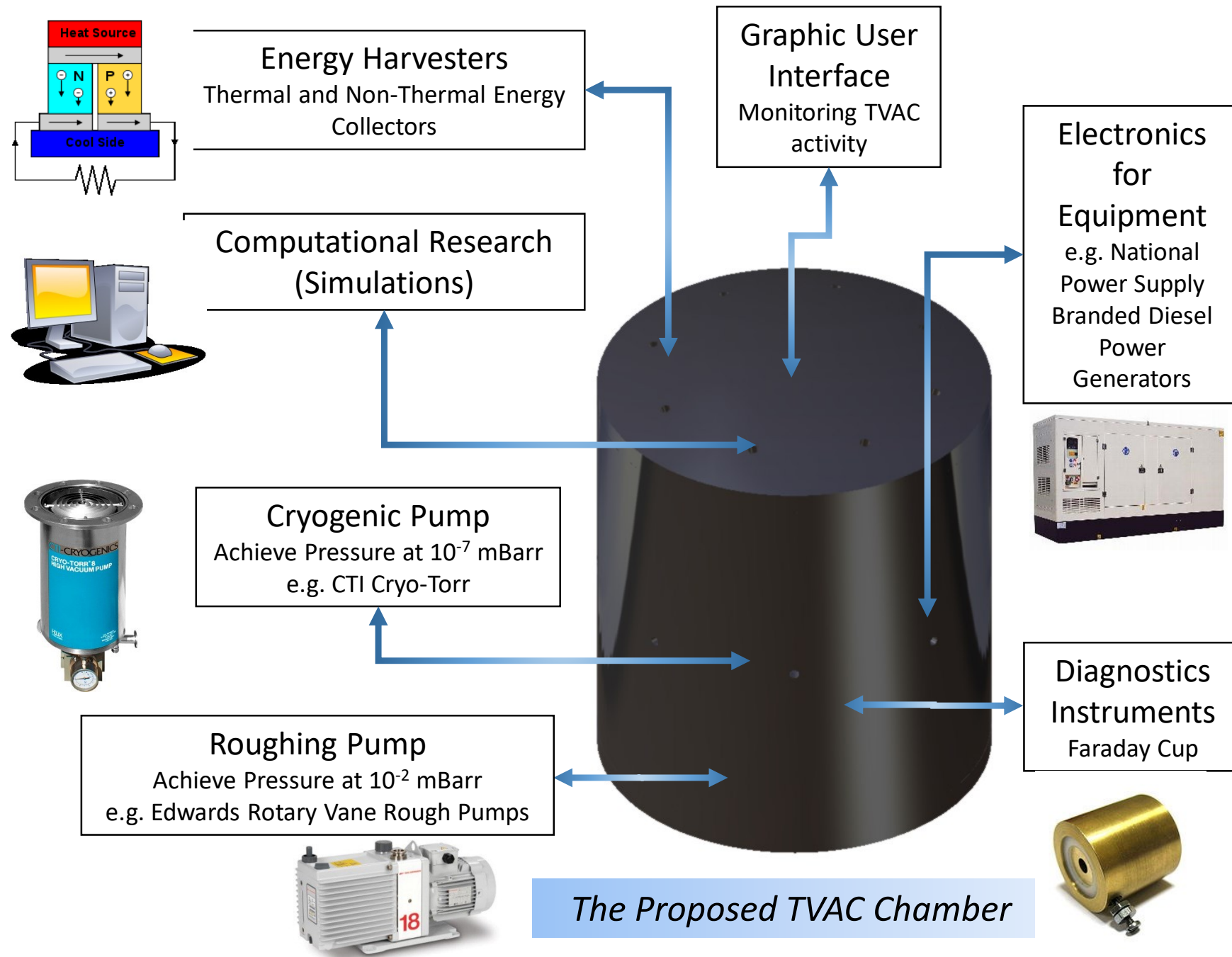
Device	Initial Costs (\$)	Annual Operational Costs (\$)	Annual Maintenance Costs (\$)	Design Flexibility	Adaptability	Manageability (min# of personnel)
Tokamak	100K to 16.6bn	8M to ~44M	6M to ~32M	1,~2,3,~4,5,~6	~1	20-200
Stellarator	3.4K to 1.28B	1K to ~3M	1K for small experiments and for large 200M to ~600M	1,~2,3,~4,~5	~1	1-200
Spheroidal Torus	10K to ~1M	3M to 40M	5.5M to 26M	1,2,~3,4,~5,~6,7	2	10-20
Reverse Field Pinch Device	~1M and up	~3M to ~40M	5M to 6M	1,~2,~3,~4,5,~6	~2	10-50
Spheromak	10K to ~1M	7.4M to 9.4M	5M to 6M	1,2,3,7,~8	~4	~10-~100
Magnetic Mirrors	10K to ~372M	~10K to ~100K	~10K to ~100K	1,2,~4,7,8	7	5-20
Ø-Pinch	10K to ~1M	~10K	~10K to ~100K	1,2,~4,7,8	8	1-10
Z-Pinch*	10K to ~1M	~10K to ~100K	~10K to ~100K	1,2,3,~4,~5,~6,7,8	3	1-10
ØZ-Pinch	~10K	~10K	~10K	1,2,3,~4,~5,~6,7,8	6	1-10
Field Reversed Configuration	100K to ~200M	~10K to ~100K	~10K to ~100K	1,~2,3,4,5,6	~2	10-100
Inertial Confinement Devices	1XK to ~1XM	~1XK to ~1XM	~1XK to ~1XM	~1,2,~4	4	100-600
Electrostatic Confinement Fusors*	1K to ~1M	1K to 100K	1K to 100K	1,2,~4,~6,7,8	~5	1-10
Polywell	100K to ~1XM	1XK to 100K	1XK to 100K	1,2,4,~5,7,8	~5	1-10

Conservation indicator

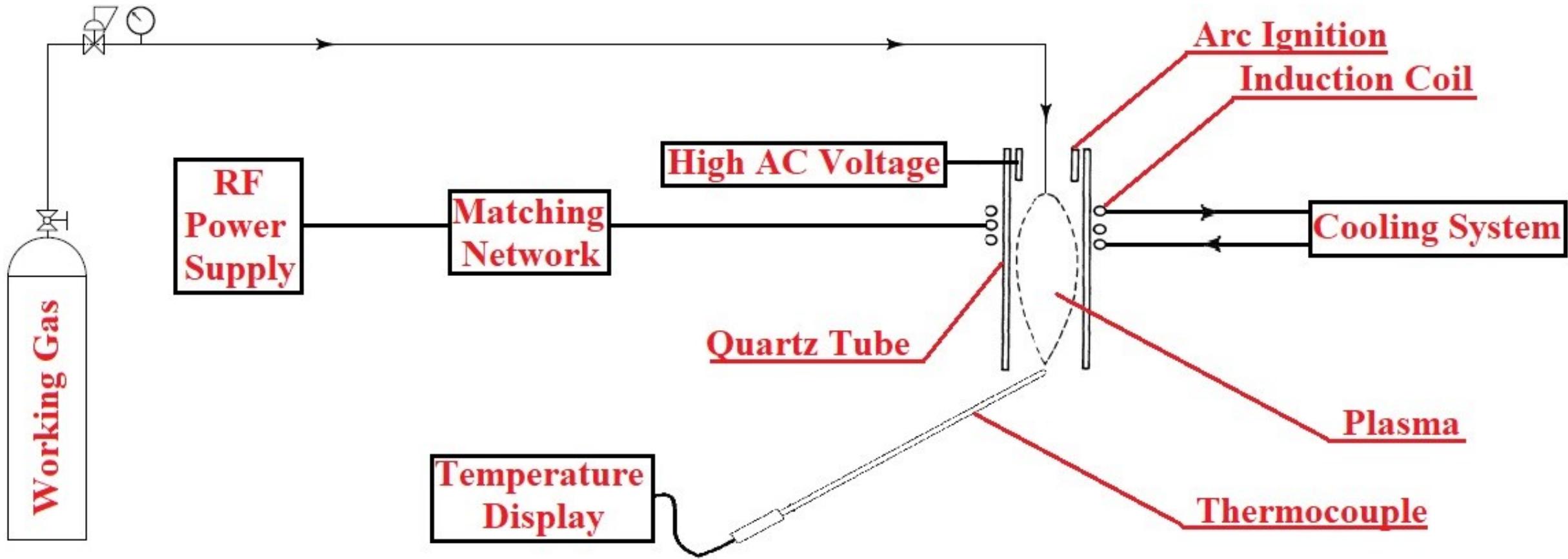
Device	Life Cycle (years)	Material Choice	Durability	Waste Generation	Safety Factors
Tokamak	4-20	Stainless Steel Copper Carbon Tungsten Titanium Niobium Liquid Nitrogen Superconducting Materials Hydrogen Deuterium Tritium Helium Isotopes Boron Rare Metals Semiconductors Synthetic Oils Coolants Typically, fractional amounts of hazardous, toxic, or exotic materials	In general, a high level of durability is chosen on the merits of thermal expansion and stress robustness. Clean and purification enabled. Maintenance of the internal components is only done in clean suits and as rare as deemed possible, diagnostics and injectors change /cleaning. Chamber external work requires meticulous electrical and mechanical maintenance.	Neutrons can cause radiation damage to the shielding, which may result in slightly radioactive materials for as long as 30 to 40 years, depending on the regulation policies. End of life components require either high return recycling or are simply dumped as waste, note the exotic/toxic materials. Maintenance and overhead waste.	Leaks. Plasma Instabilities. Toxic material containment breach. Rarefied/pure vacuum conditions. Power breach. Cooling breach. Neutrons. X-Rays. Audible Noise. EM interference. Vessel breach/implosion. Excess Heat Losses.
Stellarator	2-20				
Spherical Torus	2-20				
RFP	2-20				
Spheromak	2-20				
Magnetic Mirrors	2-20				
Ø-Pinch	2-20				
Z-Pinch	2-20				
ØZ-Pinch	Unknown				
FRC	2-20				
ICD	10-30				
ECF	2-10				
Polywell	2-10				

Research Facility

- Thermal Vacuum Chamber for Plasma-based Experiments
 - Dimensions: 1-meter diameter x 1.35-meter length
 - Depressurized: 10^{-5} - 10^{-7} mBarr with cryogenic pump
- Roughing Pump
- Cryogenic Pump
- Computers for Simulations
- Graphic User Interface for monitoring TVAC activity
- Electronics for Equipment powering the TVAC
- Instruments:
 - Optical Spectrometry
 - Thomson Scattering
 - Langmuir Probes
 - Faraday Cups
 - Neutron Detector
 - Gamma Ray Detector
- Energy Harvesters for testing effectiveness of nuclear fusion power and recycling wasted energy.

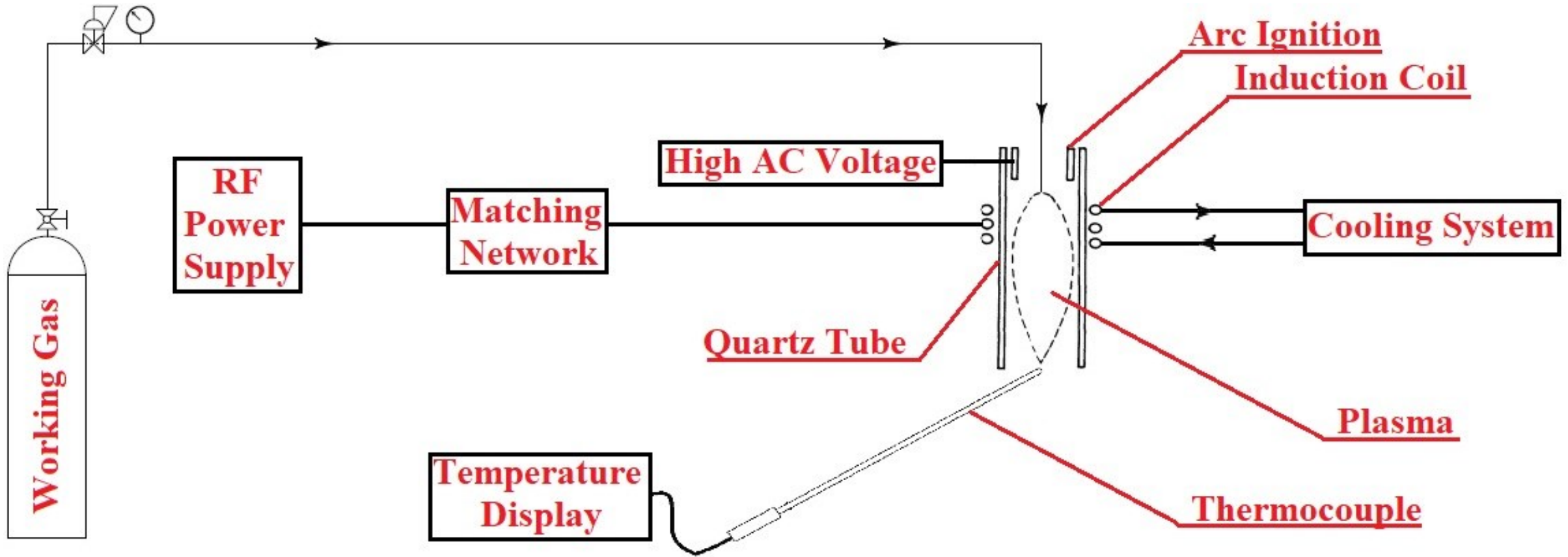


Experimental Setup



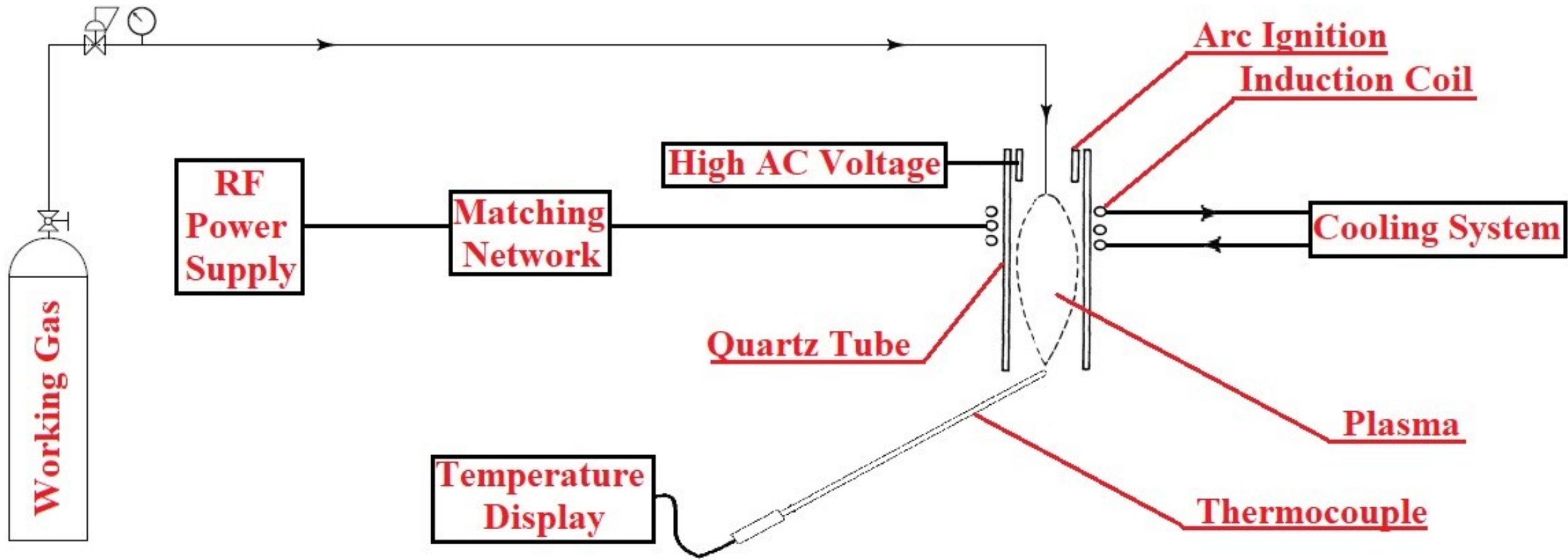
- The working gas is allowed to flow through the induction coil by the means of a quartz tube.

Experimental Setup



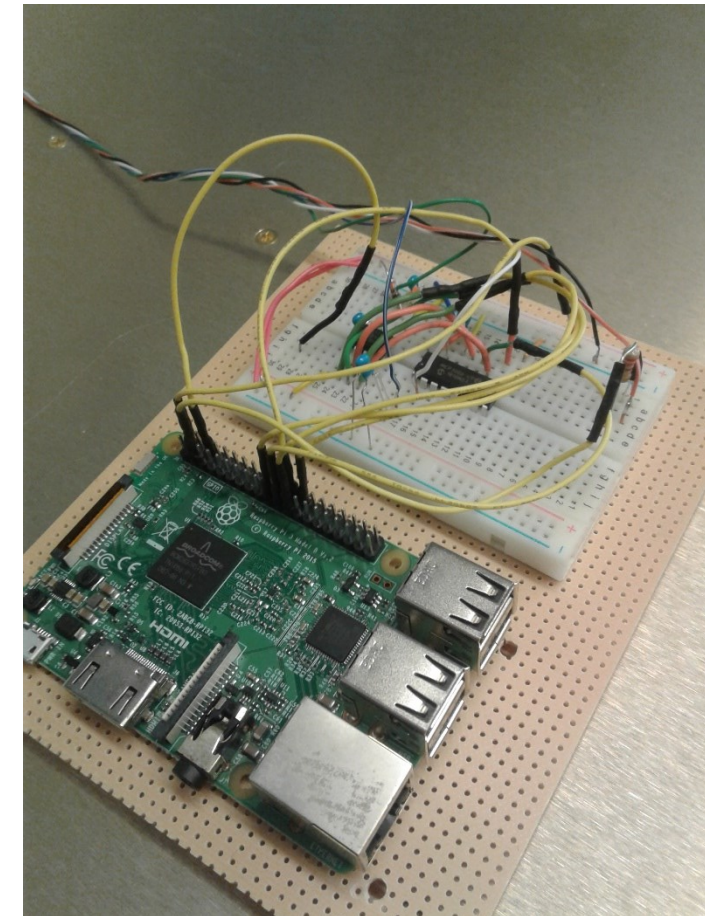
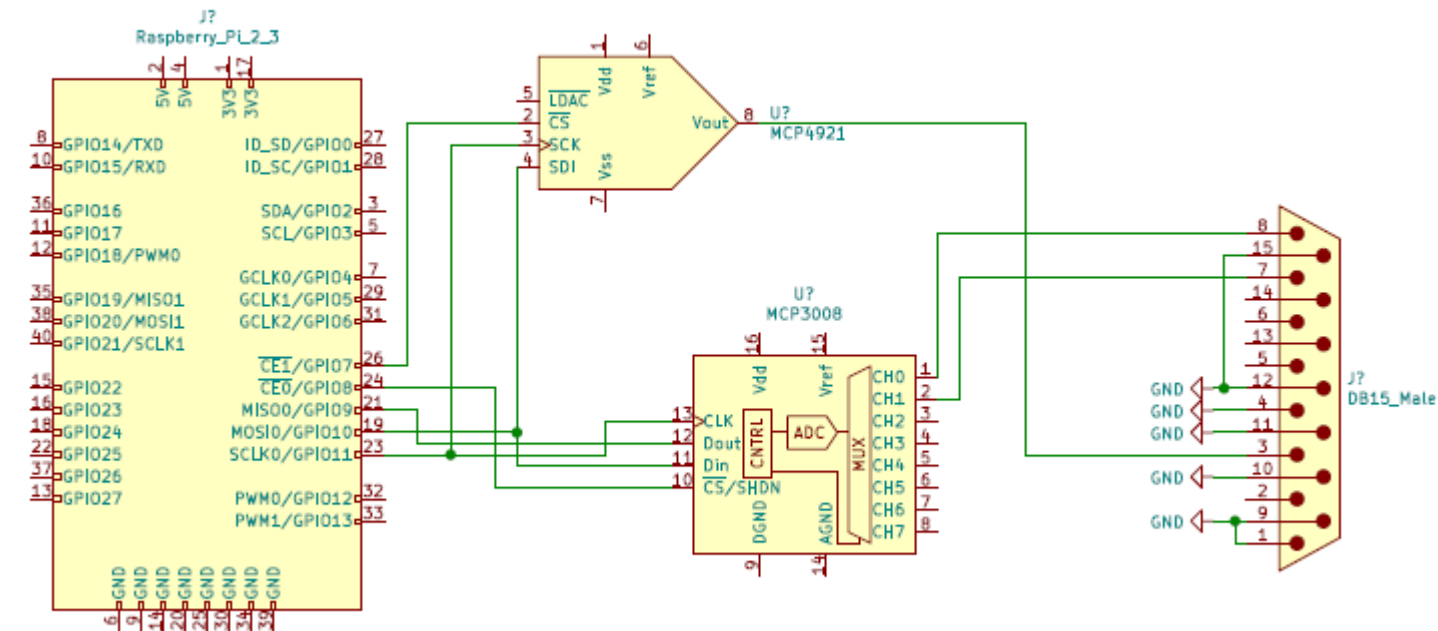
- The induction coil is fed from an RF power supply through a load-matching network. An ignition arc might be required to start the plasma; this arc is turned off after the RF plasma is sustained.

Experimental Setup



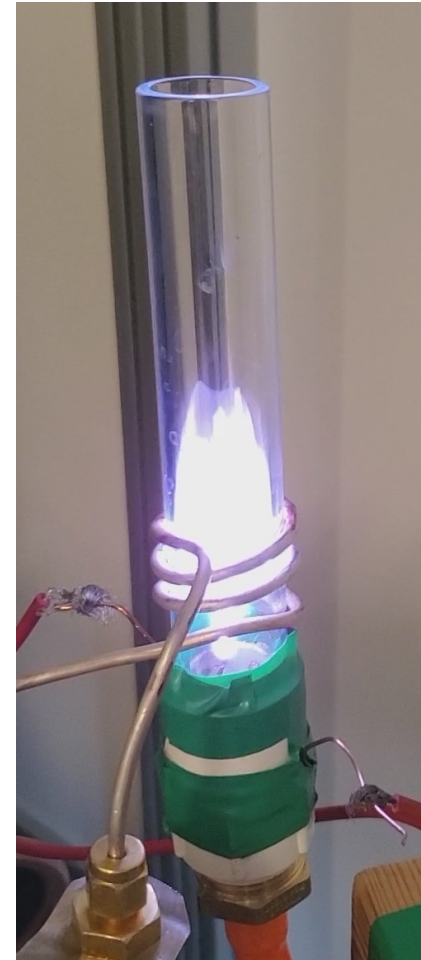
- The plasma temperature has to be measured in order to control the experiment variables.

Plasma Control System



Current Experiment RF Plasma

- The RF plasma is generated using the Argon gas with the torch directed either upwards or downward.
- The RF plasma was started using an AC 60-Hz ignition arc that was switched off after the plasma is sustained. Sometimes, the RF plasma was able to self-start without the arc if the matching network was at the appropriate setting.
- The injected RF power reached ~ 600 W with only ~ 30 W reflected. Preliminary temperature measurements recorded 300°C using a thermo-couple.



Proposed Opportunity for Aerospace

- Low-Power Magnetoplasmadynamic-Arc Thruster (experimental technology)
- Plasma Engineering for Aerospace Application
 - 20W Miniature Ion Thruster using affordable gases (Nitrogen, Helium, Argon, etc.)
 - Ion and Hall Propulsion for Nanosatellite to Full Scale Satellites (20 W to 2 kW)
- Energy Harvesting for Nuclear Fission/Fusion Technology
 - Thermionic Generation
 - Photovoltaics
 - Magnetohydrodynamic generator

Student Theses



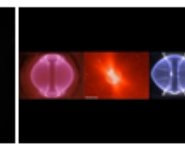
- Emmanuel Boafo: Uncertainty Analysis of Nuclear Power Plants
- Zhang, Luping: A Study of MHD and Monte Carlo Simulations of High-Current Plasma Beams in Industrial Applications
- Bondarenko, Daniel: Robust, Virtual-Electrode Dense Plasma Generator for Efficient Plasma Applications
- Stoute, C. A. Barry: Hybrid Electric Thruster using Gas Mixtures
- Completion of 4 Capstone Student Groups (2012~now)

Recent Papers



- Hossam A. Gabbar; Daniel Bondarenko; Sayf Elgriw; Anas Abdel Rihem, Evaluation of Potential Designs for High Performance Fusion Energy Technologies, International Journal of Latest Research in Science and Technology (IJLRST), Volume 4, Issue 5: Page No.140-147, September-October 2015.
- Hossam A. Gabbar; Luping Zhang; C. A. Barry Stoute; Emmanuel Boafo; Daniel Bondarenko, Simulations of High-Current Plasma Beam Model by Magnetohydrodynamics and Monte Carlo Methods, Accepted to World Journal of Nuclear Science and Technology, March 1 2016
- Daniel Bondarenko, Hossam A.Gabbar, Risk Assessment of High Density Plasma Experimentation, Volume 4, Issue 5: Page No.125-134, September-October 2015.
- C. A. Barry Stoute; Brendan M. Quine, Design and Testing of Low Cost Miniature Ion Thruster for Nanosatellites, Canadian Aeronautics and Space Journal, 30 September 2015, 61 (1), 1-8 10.5589/q15-009

Recent Papers



Advanced Plasma Engineering Lab



- Hossam A. Gabbar, C. A. Barry Stoute, Daniel Bondarenko, Nicholas Iarsitano, Anas Abdel Rihem, Stefan Sirakov, Samskruthi Menashi, Simulations and Experimentation of X-Pinch Plasma Beam Interaction
- C. A. Barry Stoute; Hossam A. Gabbar; Daniel Bondarenko; Anas Abdel Rihem, RF-Assisted DC Single Beam Plasma Generation for Multi-Beam Nuclear Fusion, Submitted to Fusion Engineering and Design
- Emmanuel Boafo, Elnara Nasimi, Luping Zhang, Hossam A. Gabbar, FSN-Based Co-Simulation for Real Time Safety Verification of Nuclear Power Plants, Mechanical Engineering Journal, JSME (Accepted).
- C. A. Barry Stoute, Hossam A. Gabbar, Daniel Bondarenko, Anas Abdel Rihem, *RF-Assisted DC Single Beam Plasma Generation for Multi-Beam Nuclear Fusion*, Submitted to Physics of Plasmas (submitted)
- Daniel Bondarenko, Hossam A. Gabbar, C. A. Barry Stoute, *Engineering Design of Plasma Generation Devices using Elmer Finite Element Simulation Methods*, Submitted

Related Conferences / Events

- Symposium on Plasma and Nuclear Systems (SPANS), IEEE NPSS, Toronto
- SPANS 2019: <http://sege-conference.com/SPANS.html>
- SPANS 2018 (<http://sege-conference.com/SPANS16CFP.pdf>)
- SPANS 2017 (<http://sege-conference.com/SPANS16CFP.pdf>)
- SPANS 2016 (<http://sege-conference.com/SPANS16CFP.pdf>)
- SPANS 2015 (<http://www.sege-conference.com/PAST/SPANS15.PDF>),
Gallery (<http://www.sege-conference.com/PAST/SPANS2015-gallery.pdf>)
- SPANS 2014 (<http://www.sege-conference.com/SPANS14.PDF>), Gallery
(<http://www.sege-conference.com/SPANS14-Gallery.pdf>)
- Contact: APEL Director, Dr. Hossam A.Gabbar, Email:
hossam.gabbar@uoit.ca

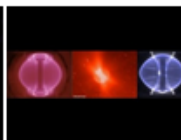


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