Dual Plasma Focus- 160 kJ DuPF – Concept, Design & Installation

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Introduction 1/2

- Typically PF’s are operated for intense compression in time-matched fast focus mode FFM.
- However for materials deposition, it is advantageous to reduce intensity; using the focusing not for explosive radiation but for storage and transformation of energy into uniform streaming plasma, in slow focus mode SFM.
- Numerical experiments are carried out on plasma ion beams FIB and fast plasma streams FIB from the PF showing that a low-voltage, high-energy PF has big advantages as a source of FIB and FPS in the SFM. to produce a long uniform pulse for materials fabrication.

Introduction 2/2

- Using available capacitors, a 160 kJ device was designed to operate in FFM with one set and in SFM with another set of electrodes
- Detailed engineering designs were completed using SolidWorks software.
- Parts were manufactured in a cost-effective venture with Iranian-Turkish collaboration.
- These parts have now been received.
- Installation of the 160 kJ DuPF has begun.
- In SFM configuration, this device will be the biggest PF devoted to materials research.

Concept 1/2

- **PF Typical operation**: time-matched regime- radial phase starts near peak current- maximum energy pumped into radial shock waves and compression,- large inductive voltages, high temperatures and copious multi-radiations.- **Fast Focus Mode (FFM)**
- Targets in front of anode bombarded by bursts of fast ion beams (FIB) and post-pinch fast plasma streams (FPS) followed by materials exploded off the anode by relativistic electron beams (REB).
- As operational pressure P_0 is increased beyond time-matched regime, dynamics slows, the min pinch radius ratio k_{min} increases, peak inductive voltages V_{max} decreases, FIB reduces in energy per ion U, in beam power flow P_{FIB} and in damage factor D_{FIB}, as operation moves away from FFM into Slow Focus Mode (SFM).
- This is the same pattern for D_2, He, N_2 and Ne; but for the highest radiative gases Ar, Kr and Xe, radiative collapse becomes dominant past the time-matched point and the pressures of highest V_{max}, P_{FIB} and D_{FIB} shift to higher P_0.

Concept 2/2

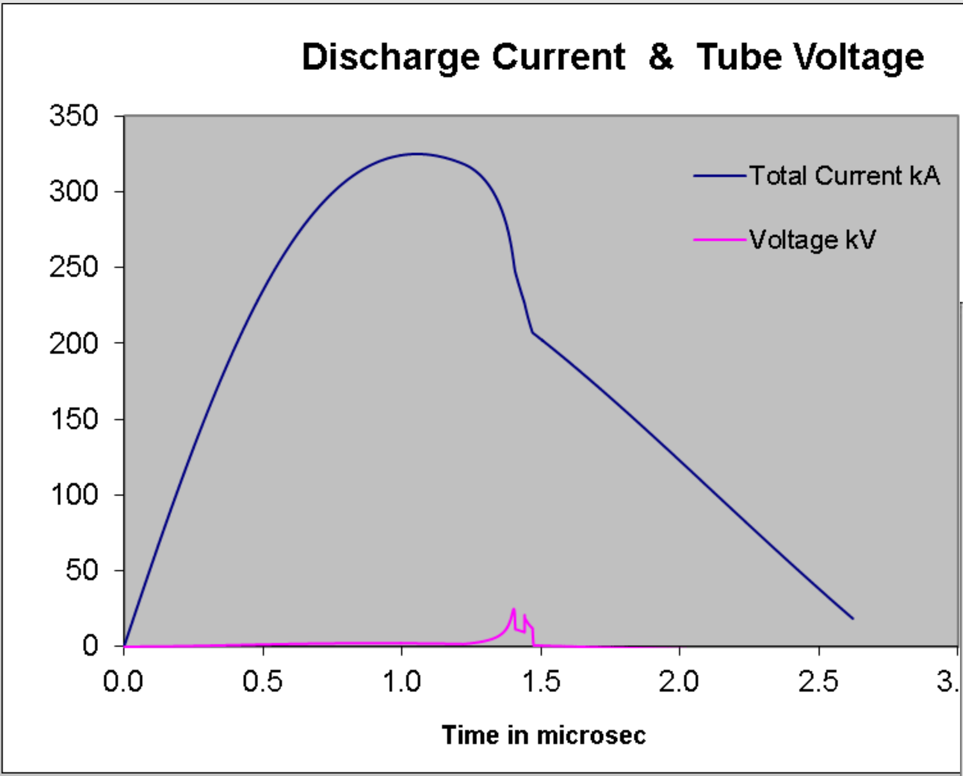
- In all gases and in all machines, as P_0 is increased further, comes a point (slowest SFM point) where compression is so weak that outgoing reflected shock barely reaches the incoming piston- the focus pinch barely forms.
- This SSFM point: **k_{min} is largest** (>twice that of FFM); **V_{max}, P_{FIB}** and **D_{FIB}** are **lowest** and **great reduction of anode boil-offs** due to **reduction of REB's**.
- However energy carried in fast plasma stream FPS is highest for case of H_2 in the INTI PF- also at or near highest levels in all gases and in all machines.
- Operation near this SSFM point reduces ion beam damage and anode materials/impurities on-target - Target interacts primarily with FPS.
- The above is surmised from results using our RADPF FIB code.
- Recent laboratory experiments with targets in INTI PF confirm that:

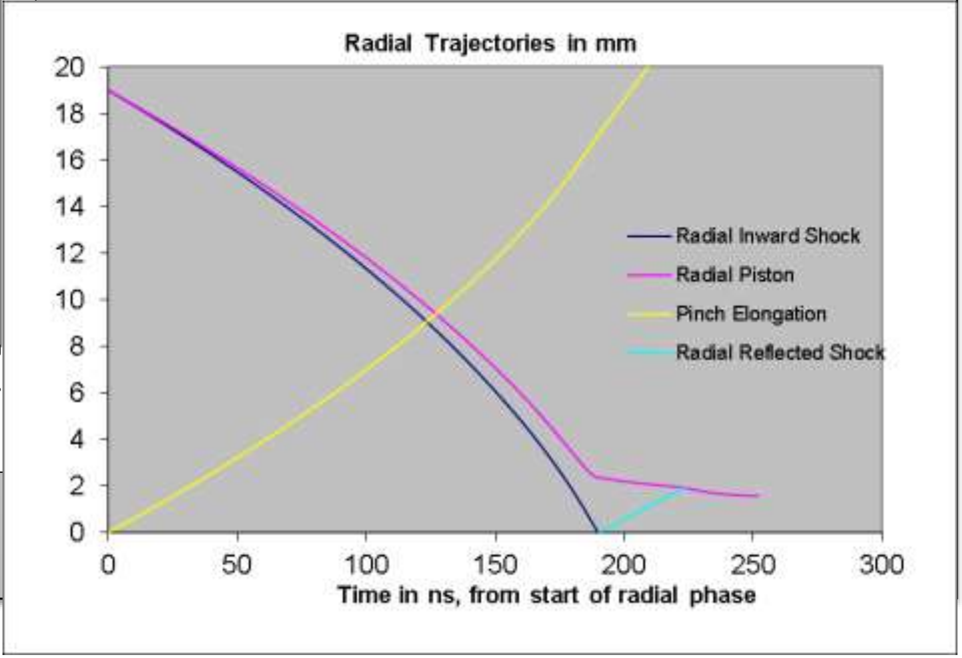
SFM regime- bigger area of more uniform target interaction.

- ➢ **SFM operation should produce better results in the production of nano-materials such as carbon nano-tubes on a graphite substrate.**

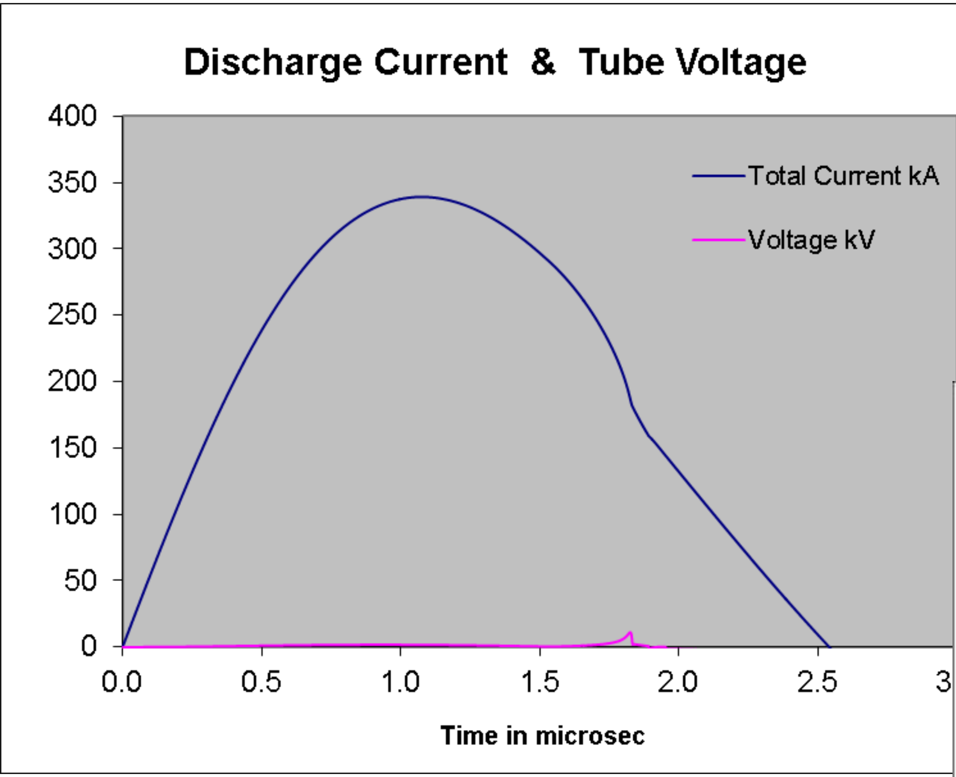
PF operated near time-matched-FFM

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

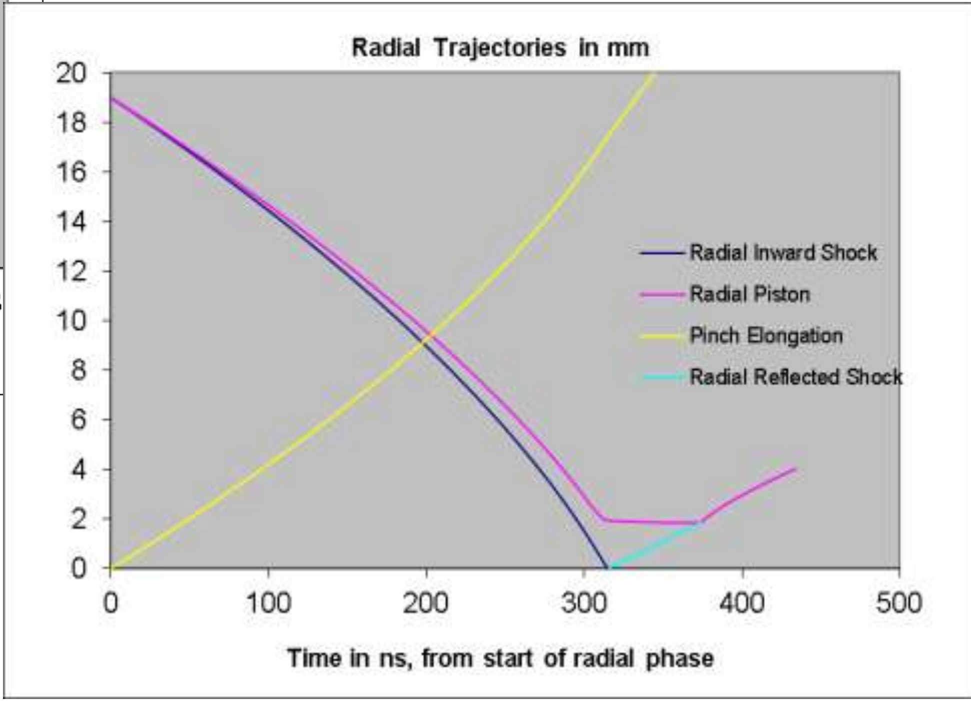




PF operated at higher pressure- SFM



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



Design of DuPF

- DuPF uses two interchangeable electrodes enabling it to be optimized for both Slow Pinch Mode (SFM) and Fast Pinch Mode (FFM); the latter using a speed factor (SF) of more than 70 kA cm^{-1} $\text{Torr}^{-0.5}$ for FFM in deuterium and the former with SF of less than half that value for SFM.
- Starting with available 6 ×450 μF capacitors rated at 11kV, numerical experiments indicate safe operation at 9 kV, 6 Torr deuterium with FFM anode of 5 cm radius; producing intense ion beam and streaming plasma pulses which would be useful for studies of potential fusion reactor wall materials.
- Operating at 5 kV, at 10 Torr deuterium with SFM anode of 10 cm radius leads to long- duration, large-area uniform flow which could be more suitable for synthesis of nano-materials. Also numerical experiments show that DuPF can be applied as a pulsed neutron source in FFM state even in more than 20 Torr deuterium gas.

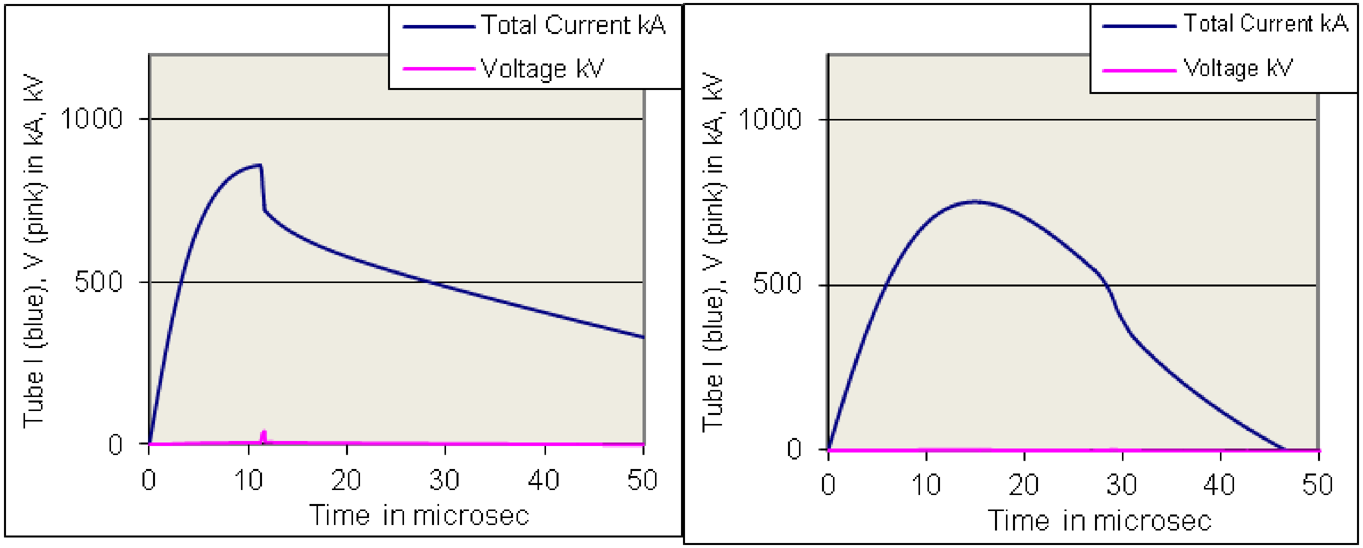
Table 1. Tube, Model and Operational parameters of DuPF in FFM

Tube Parameter	**Lo=50 nH**	**Co=2700 μF**	**b=8 cm**	**a=5 cm**	**Z_o=70 cm**	**r_0=1 mΩ**
Model Parameters	**Massf=0.1**	**Currf=0.7**	**Massfr=0.2**	**Currfr=0.7**		
Operational Parameters	**V_0=9 kV**	**P_0=6 Torr (Deuterium)**				

Table 2. Tube, Model and Operational parameters of DuPF in SFM

Tube Parameter	**Lo=50 nH**	**Co=2700 µF**	**b=15 cm**	**a=10 cm**	**Z_o=70 cm**	**r_0=1 mΩ**
Model Parameters	**Massf=0.1**	**Currf=0.7**	**Massfr=0.2**	**Currfr=0.7**		
Operational Parameters	**V_0=5 kV**	**P_0=10 Torr (Deuterium)**				

Computed discharge current for DuPF: FFM, 6 Torr D (Left). SFM, 10 Torr D (Right)



Computed radial trajectories for DuPF: FFM, 6 Torr D (Left). SFM, 10 Torr D (Right)

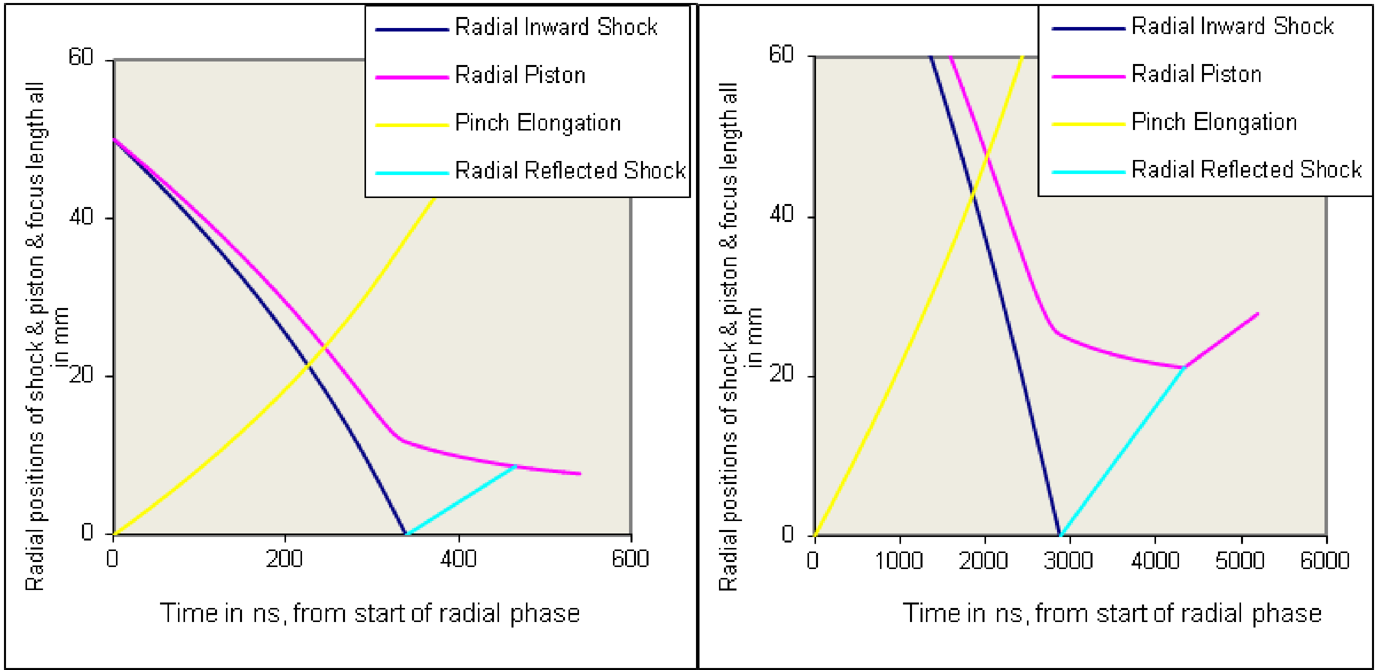


Table 3. Comparative table of FFM and SFM of DuPF

Parameter	FFM	SFM
b (cm)	8	15
a (cm)	5	10
c	1.6	1.5
z_0 (cm)	70	70
P (Torr)	6	10
V_0 (kV)	9	5
I_{peak} (kA)	858	753
I_{pinch} (kA)	523	243
v_a (cm/ms)	9.4	3.2
v_s (cm/ms)	21.3	4.5
v_p (cm/ms)	15.3	3.4
$(c^2-1)/\ln c$	3.32	3.08
Bank surge imp (mW)	4.3	4.3
Rdyn axial (mW)	4.4	1.3

I/a (kA/cm)	**172**	**75**
SF (kA/cm/Torr$^{0.5}$)	**70**	**24**
FIB ion energy (keV)	**104**	**7**
FIB beam energy (kJ)	**2.10**	**0.99**
FIB energy flux (W m^{-2})	**1.5E+14**	**4.7E+11**
FIB damage ftr (Wm^{-2}s$^{0.5}$)	**4.1E+10**	**4.4E+08**
PS energy (J)	**9965**	**6451**
PS speed exit (cm/μs)	**25**	**2**
Plasma Footprint radius (mm)	**7.85**	**27.1**
J_b flux ions (m^{2}s^{-1})	**8.9E+27**	**4.1E+26**
Fluence ions (m^{-2})	**6.7E+20**	**3.5E+20**
EINP	**13 %**	**25%**
EINP1 wrk on pnch (J)	**14170**	**8437**
Ion Current (kA)	**270.8**	**159.9**
Current Density (A m^{-2})	**1.4E+09**	**6.6E+07**
Numb ions per shot	**1.3E+17**	**8.6E+17**

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

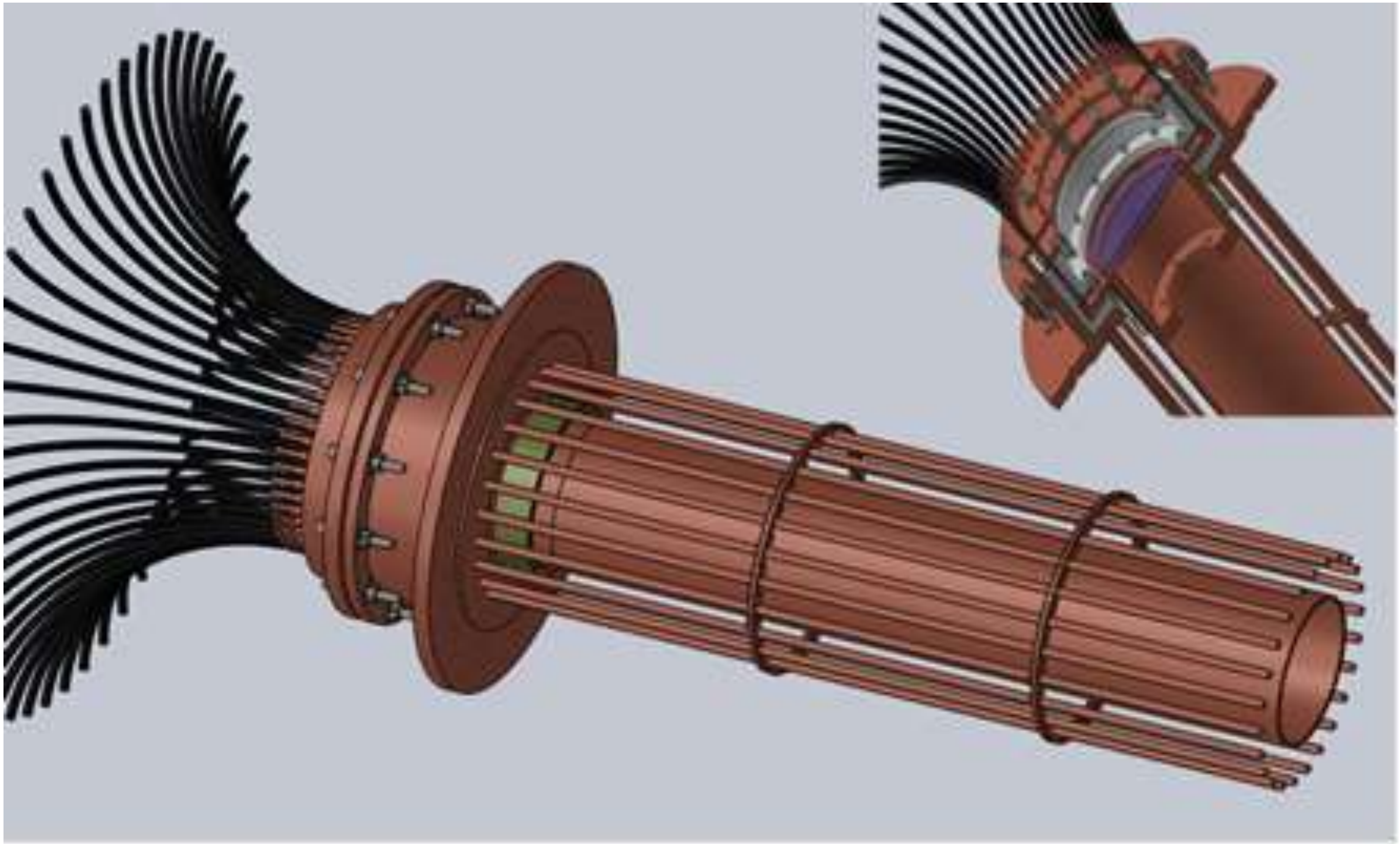


Figure 1. SFM electrodes and main collector Assembly of DuPF with 197 kg weight.

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

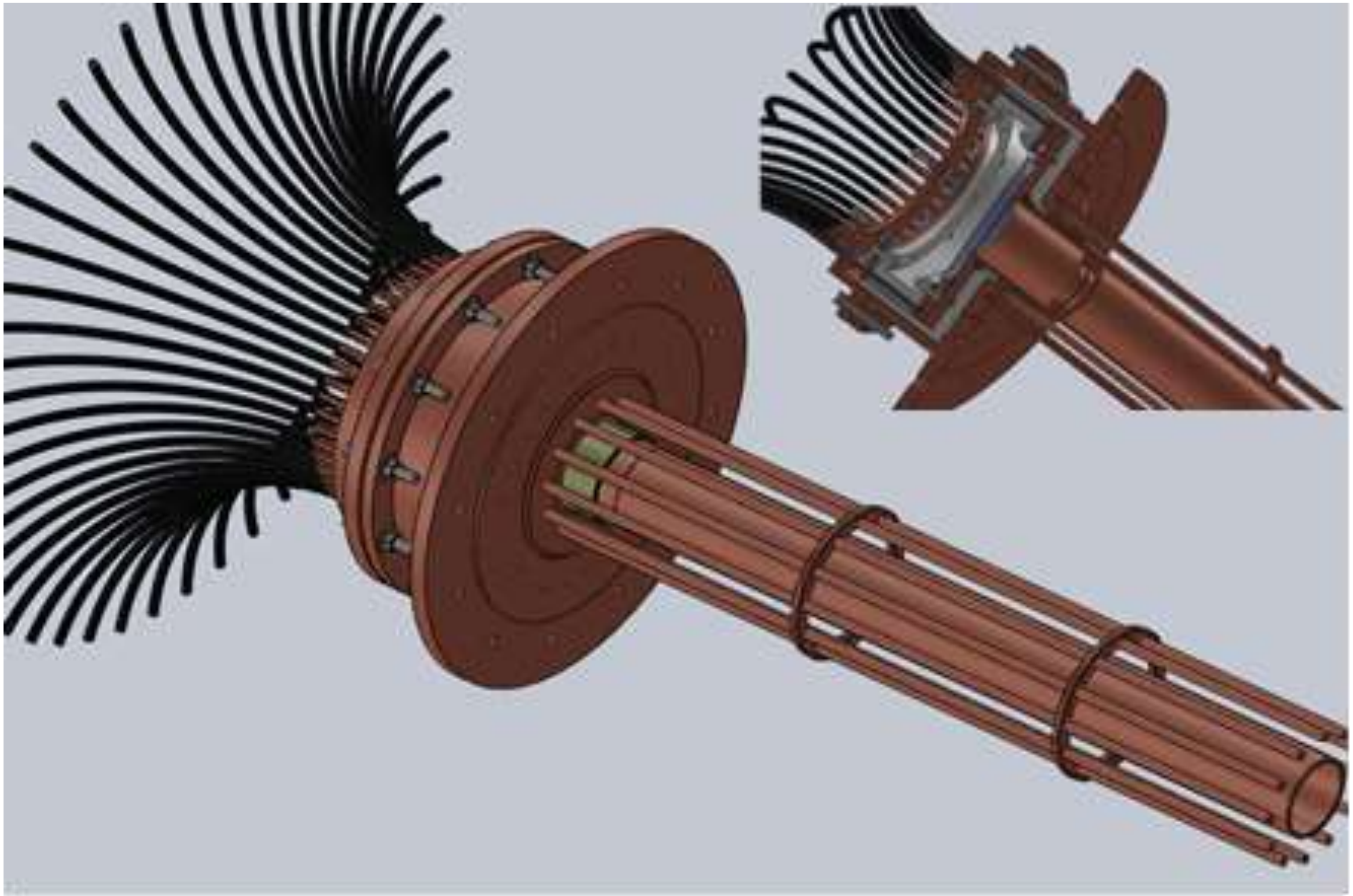


Figure 1. FFM electrodes and maincollector Assembly of DuPF with 170 kg weight

DuPF with SFM Configuration

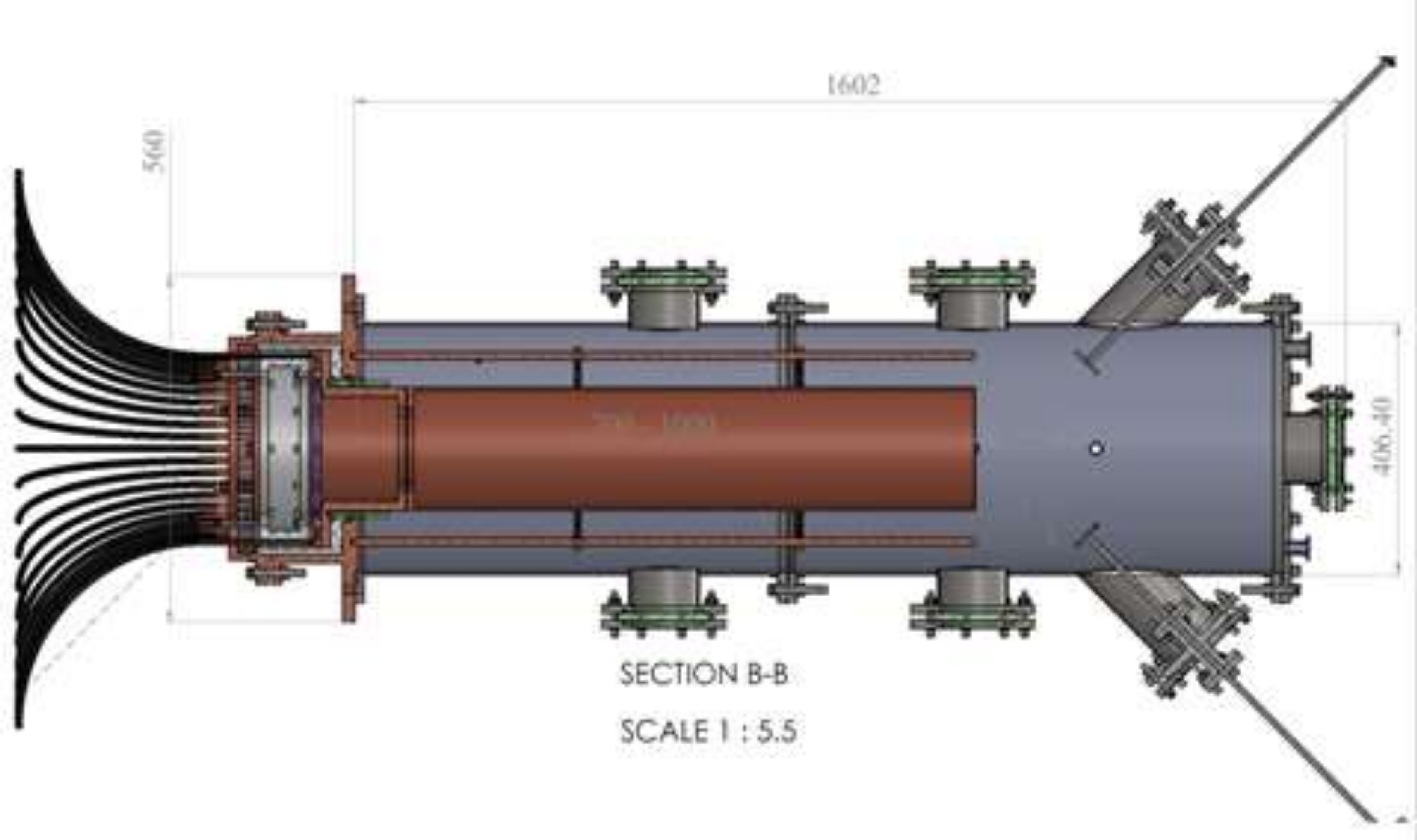


Figure 1. Electrodes and vacuum chember of DuPF, SFM (All dimention notifications are in mm).

Fabrication & Cost

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Installation

Testing

Proposed Projects