Government of India
BHABHA ATOMIC RESEARCH CENTRE
Beam Technology Development Group
Accelerator & Pulse Power Division
Mumbai-400085- INDIA

High Power Pulsed Electron Accelerators Development for Industrial Applications

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परमाण ऊर्जा विभाग

Topics Covered

परमाणु ऊर्जा विभाग – स्वर्ण जयंती वर्ष
अगस्त २००३ – अगस्त २००४
Department of Atomic Energy
Golden Jubilee Year
August 2003 - August 2004

- **Expertise of BARC in Pulsed Accelerators**

- **PRESENT STATUS OF KALI-5000 SYSTEM (0.8-1 MV, 80 kA, 60 ns)**
  - **1.5 MV, 25kJ MARX GENERATOR**
  - **1MV, 5kJ, 100ns CASTOR OIL BLUMLEIN**
  - **1 MV SF_6 SPARKGAP SWITCH**

- **GENERATION OF INTENSE RELATIVISTIC ELECTRON BEAMS (REB)**

- **UTILIZATION OF REB for Flash X-Rays, HPM & Neutrons.**

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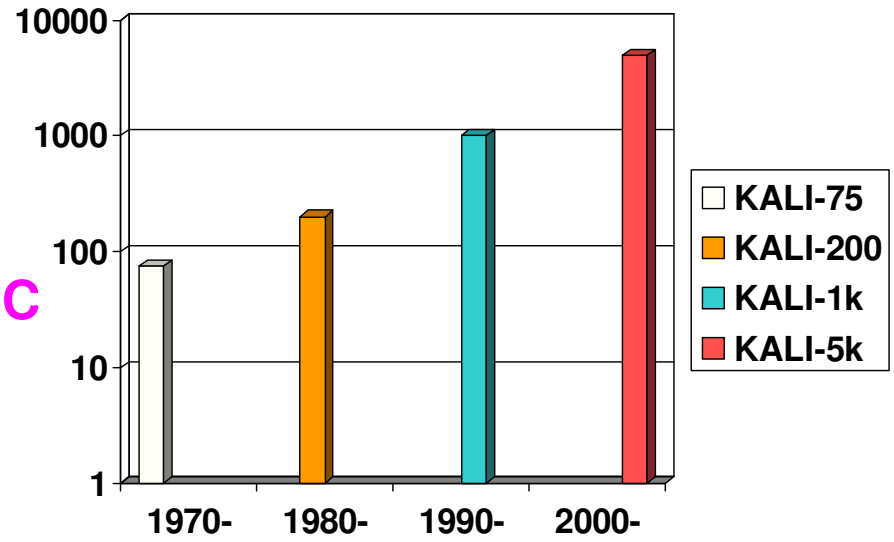
BARC's EXPERTISE



Since 1970s,

Pulse Power Systems have been Indigenously Developed by APPD, BARC

*KALI-75, 375kV, 2kA, 180ns;
*KALI-85, 780kV, 4kA, 60ns;
*KALI-200, 300kV, 15kA, 60ns;
*KALI-1000, 300kV, 20kA, 100ns,
***KALI-5000, tested up to 600kV, 40 GW, 100ns,**

LIA-200, 200kV, 5kA, 100ns, 10-100Hz under commissioning

To make the system compact and repetitive, Consistent efforts are being made.

*** KALI: Kilo- Ampere Linear Injector**

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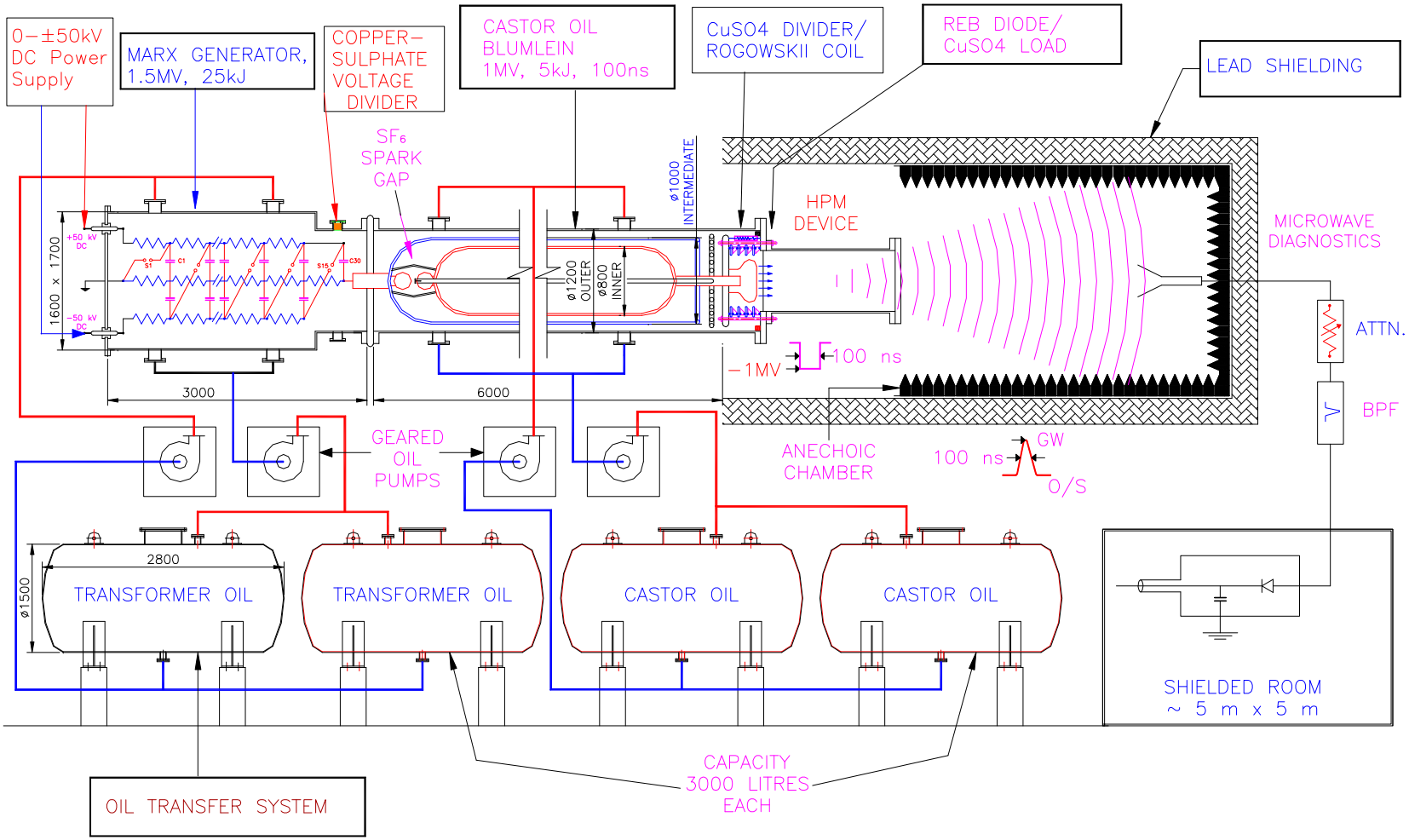
Schematic of KALI-5000

Pulsed Accelerator

1MeV electron beam pulse



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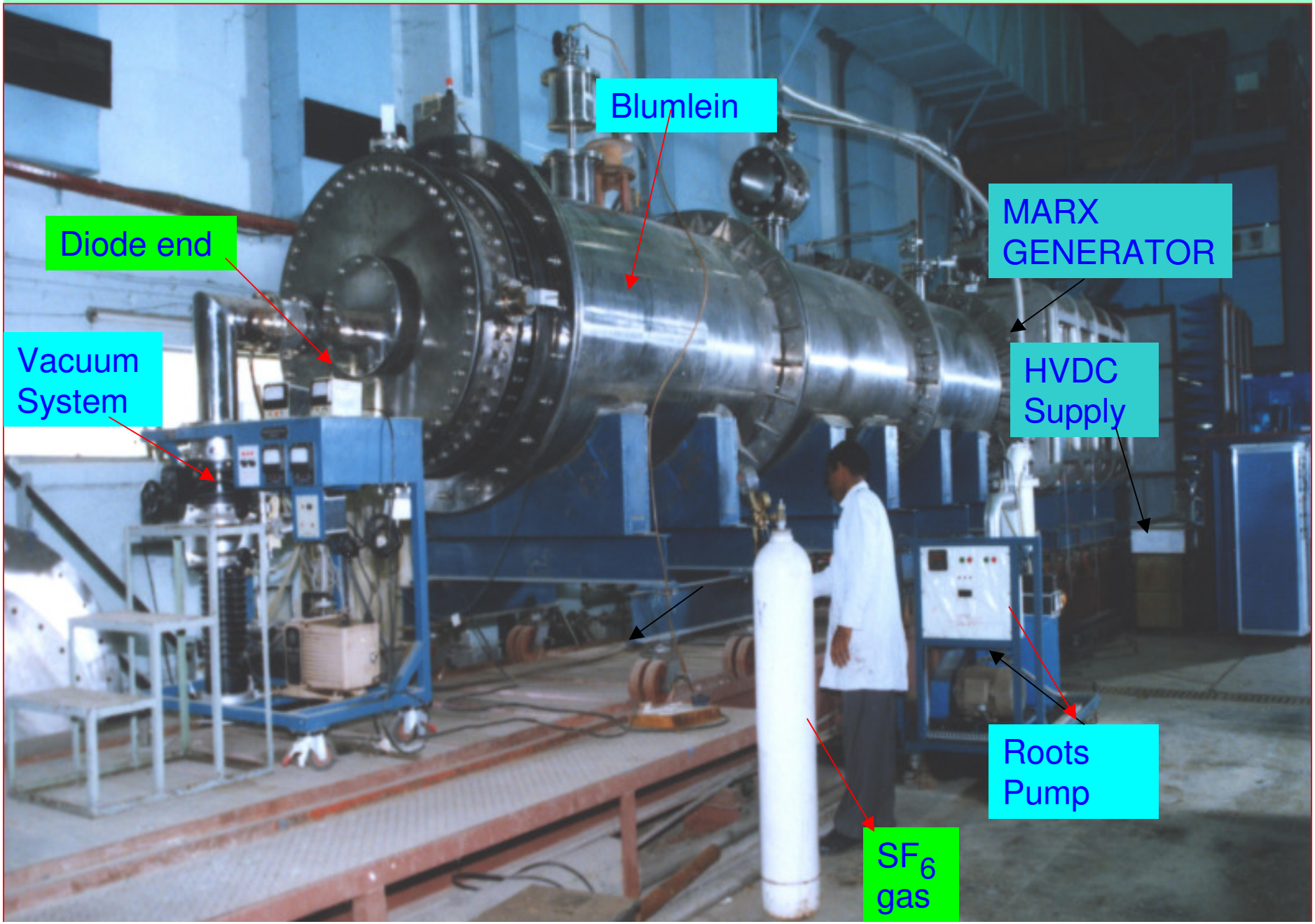
Photograph of the KALI-5000 PULSED Accelerator (0.8-1MV, 80kA, 100ns, 5kJ)

KALI-5000 SYSTEM (0.8-1MV, 40kA, 100ns, 40GW)



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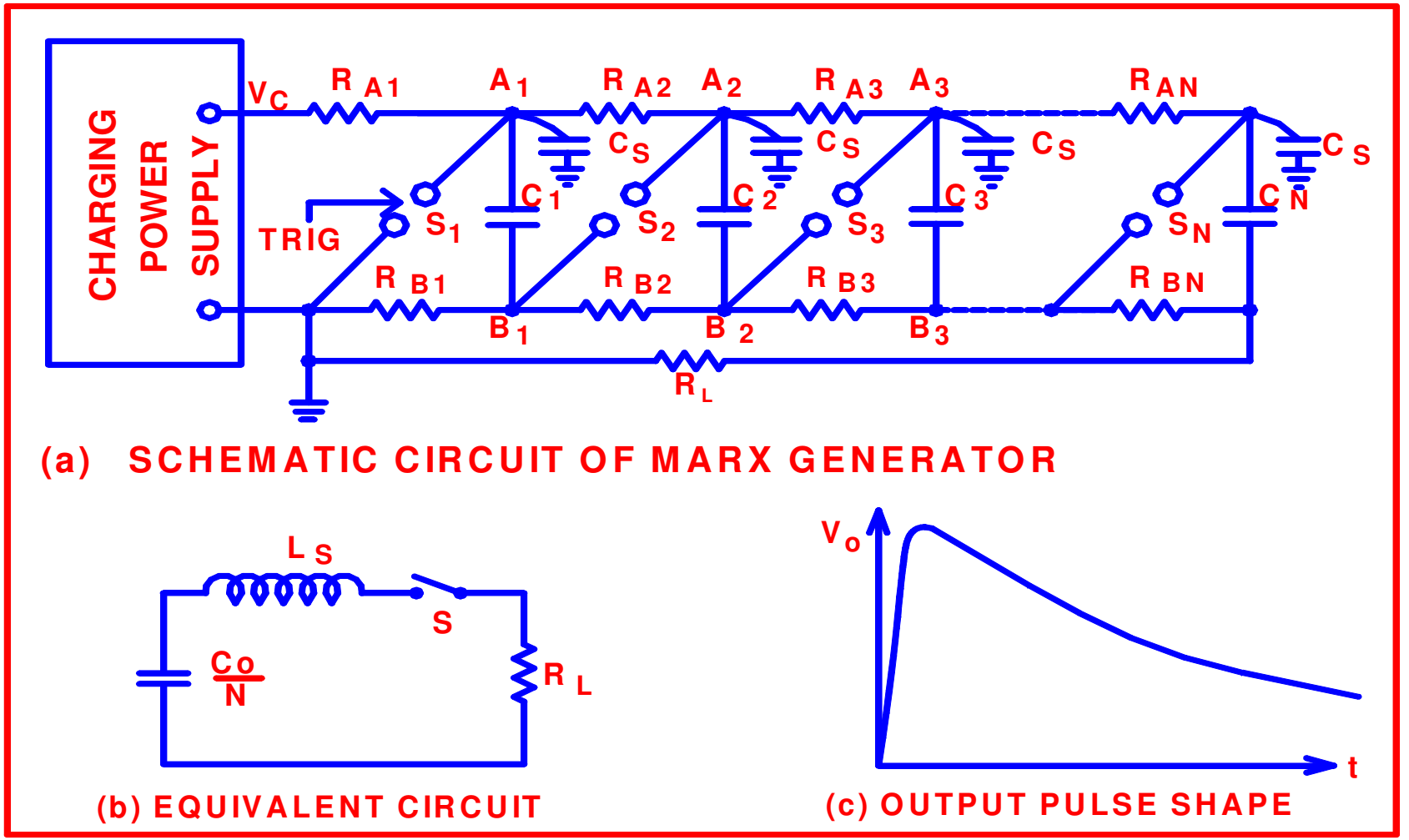
Principle of Marx Generator



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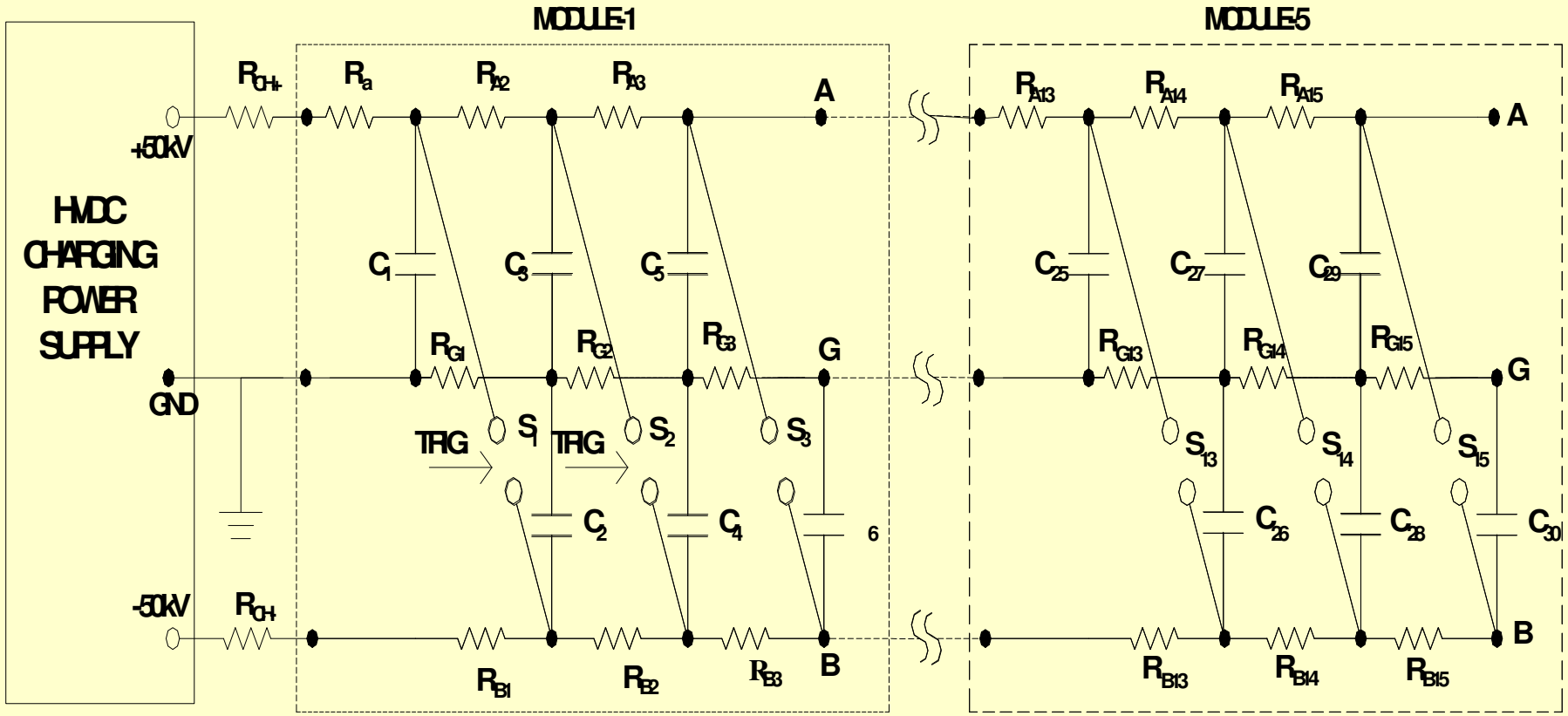
Operation of ± Marx Generator

A) WHILE CHARGING:



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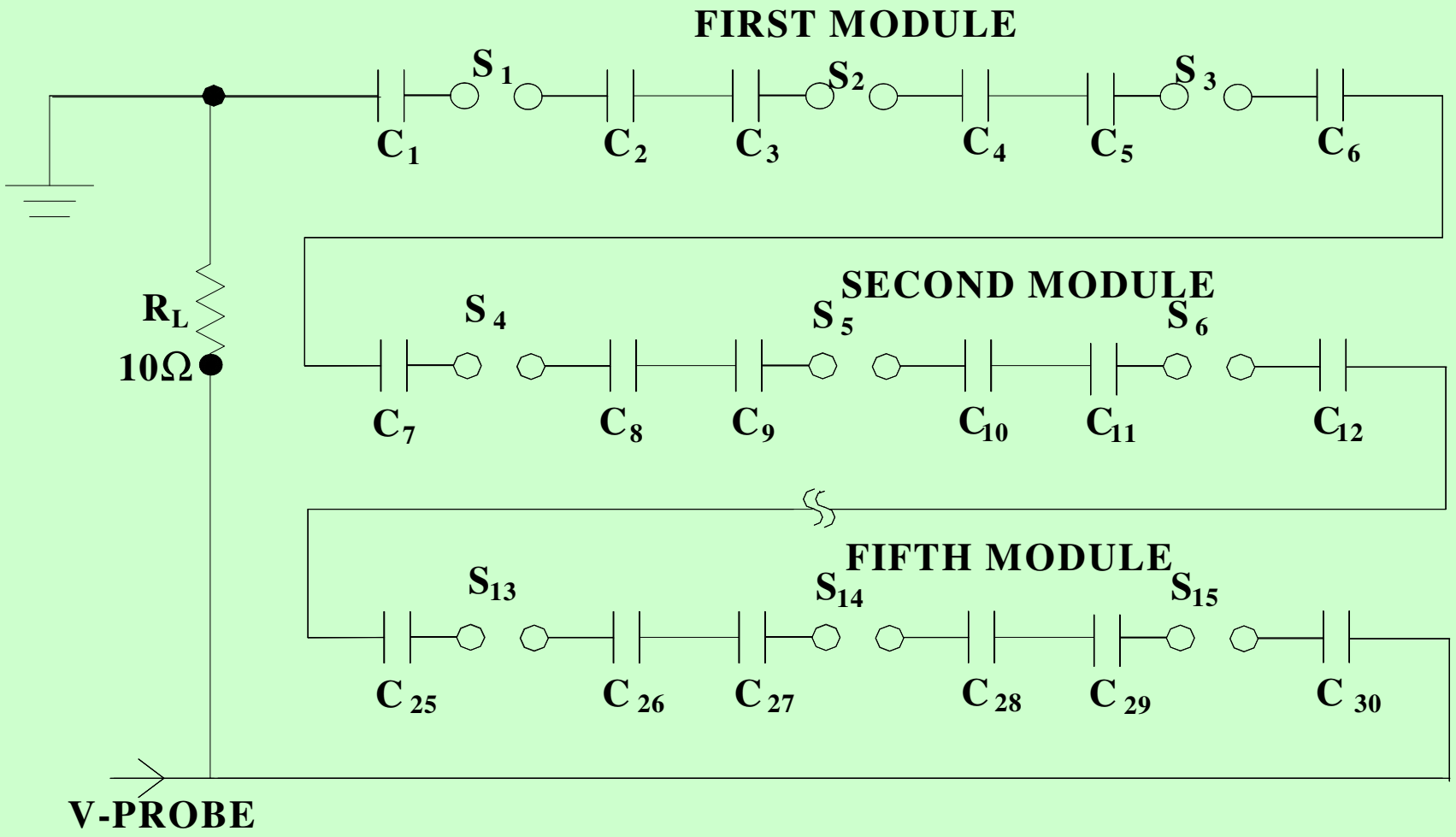
Operation of ± Marx Generator

B) WHILE DISCHARGING :



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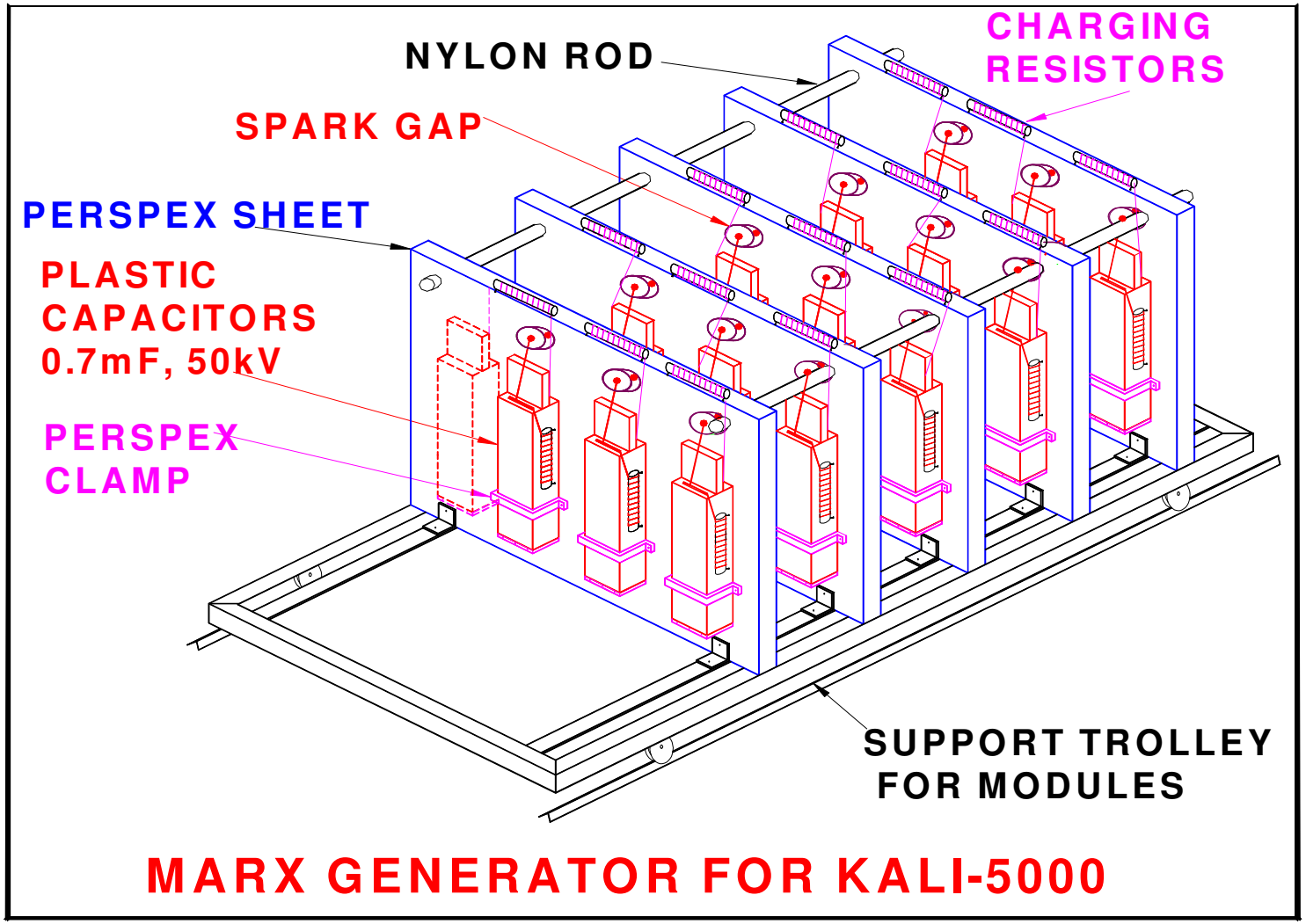
Assembly of Marx Modules



MARX GENERATOR FOR KALI-5000

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PHOTOGRAPH OF THE FIRST MARX MODULE

(END VIEW)

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Photograph of the

Assembled Marx Modules

1.5MV, 25kJ

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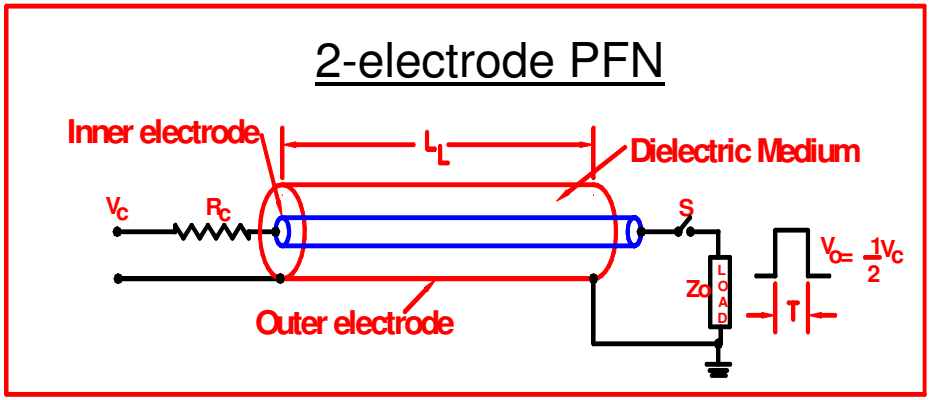
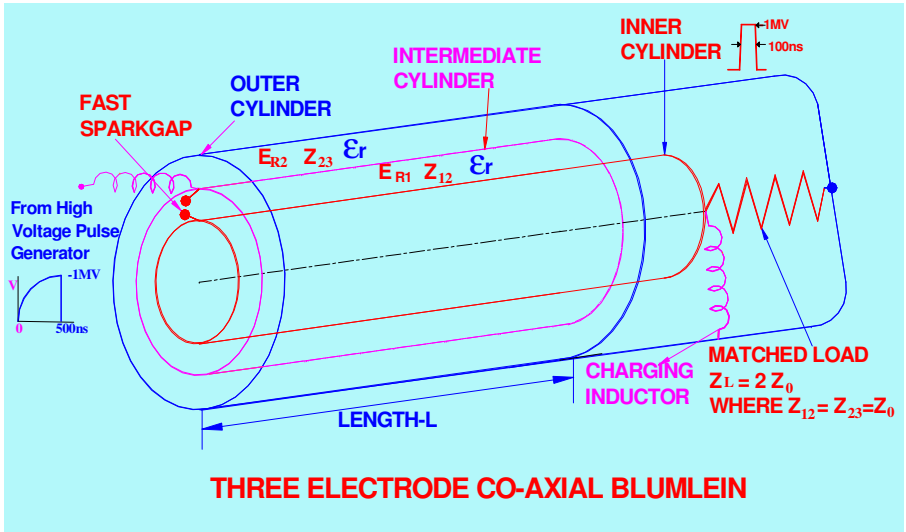
PULSE FORMING LINE

(PFL)



DESIGN EQUATIONS OF PFN MODULE

- **Characteristics Impedance, $Z_{OM} = (L/C)^{1/2}$**
- **Pulse, $T_{OM} = 2n (LC)^{1/2}$**
- **Rise Time, $t_r = 0.3 (LC)^{1/2}$**
- **Energy, $E_M = \frac{1}{2} nC (V_C)^2$**
- **Output Voltage, $V_{OM} = \frac{1}{2} V_C$**



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End View of The Blumlein Sparkgap and Prepulse Inductor

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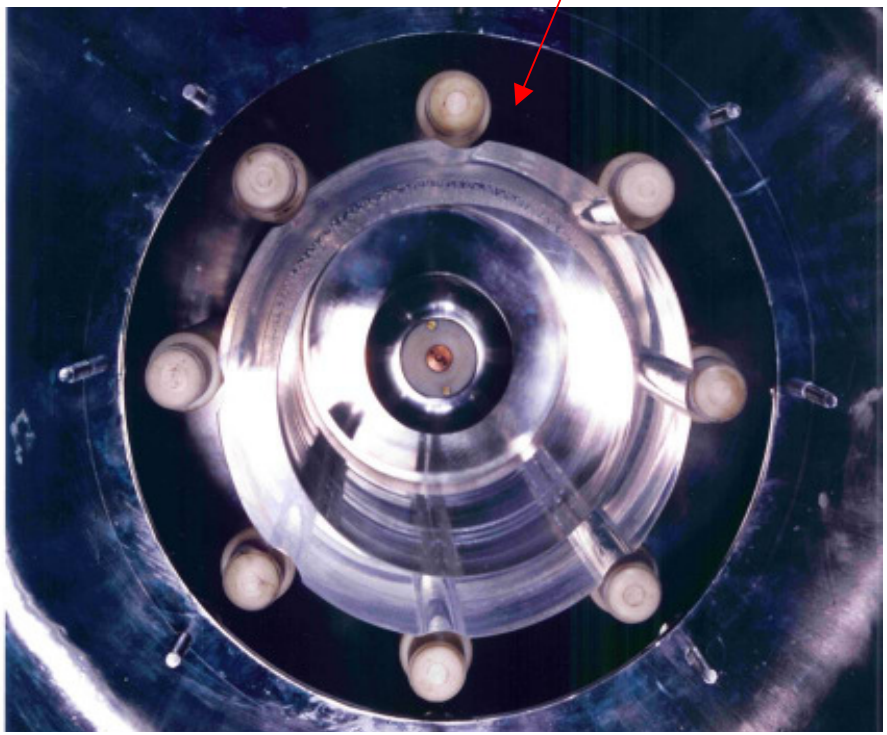

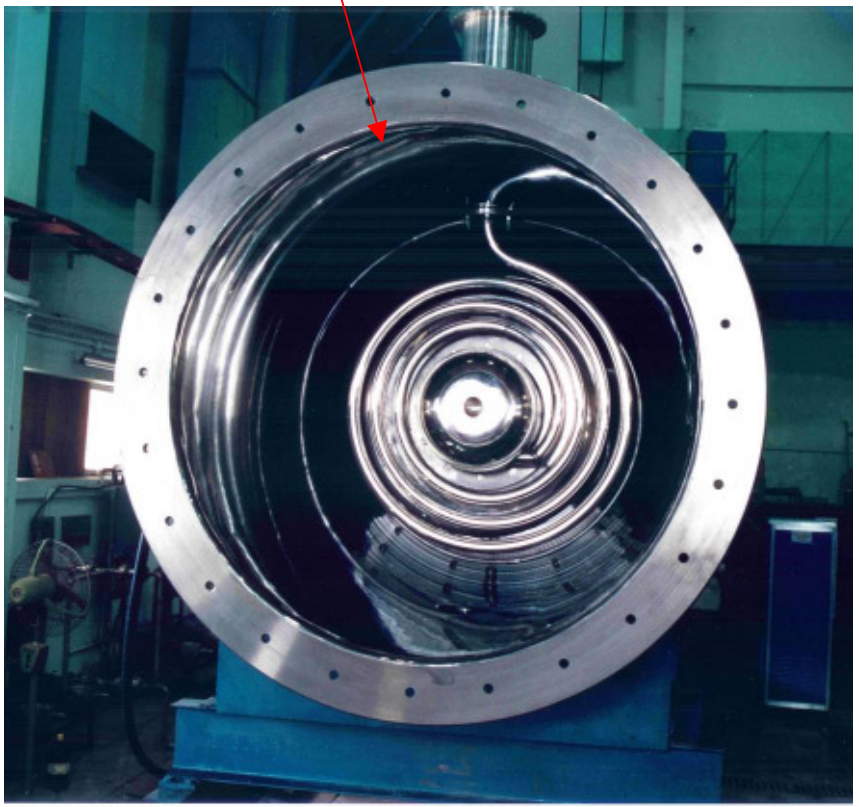

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Results of KALI-5000

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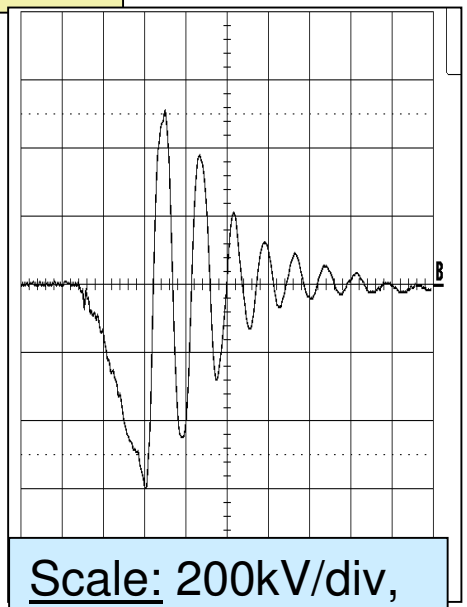
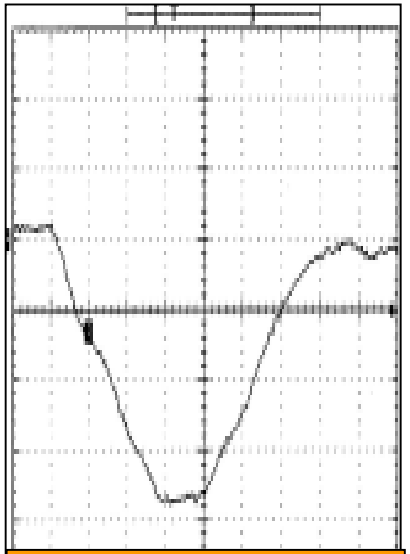
High Voltage PULSE Generator (Marx/Tesla Transformer) → Pulse Forming Line Water/oil filled → H.V.Switch (spark gaps- N_2/SF_6 filled) → REB diode/ e-GUN

Marx Output
Peak Voltage = 600kV.
Charging time = 500ns.



Scale: 200kV/div, 500ns/division

E- Beam current
Imax = 71kA at 600kV.
FWHM = 100ns.



Scale: 20kA/div., 20ns/division

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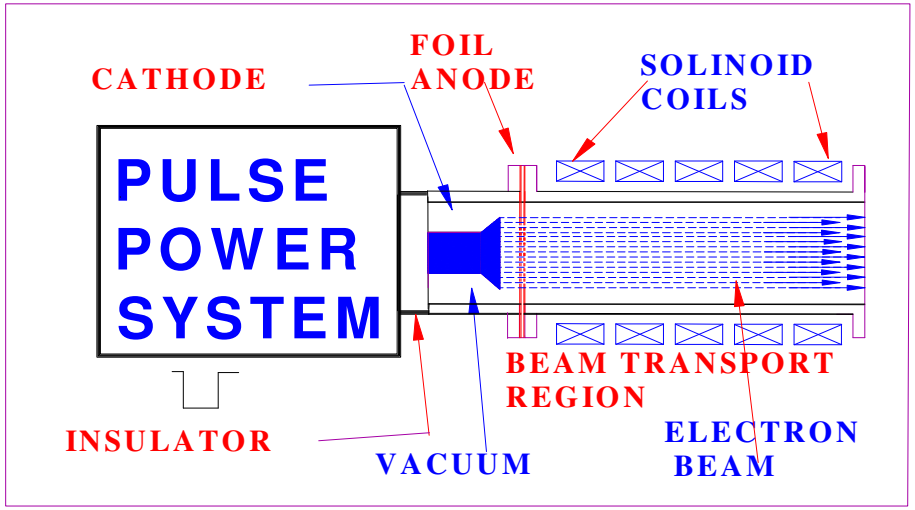
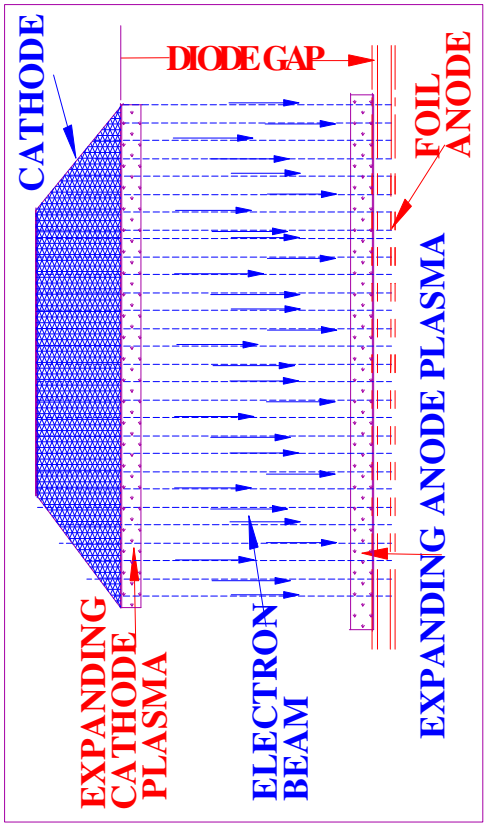
Relativistic Electron Beam

REB Generation





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Virtual Cathode Oscillator

(VIRCATOR)

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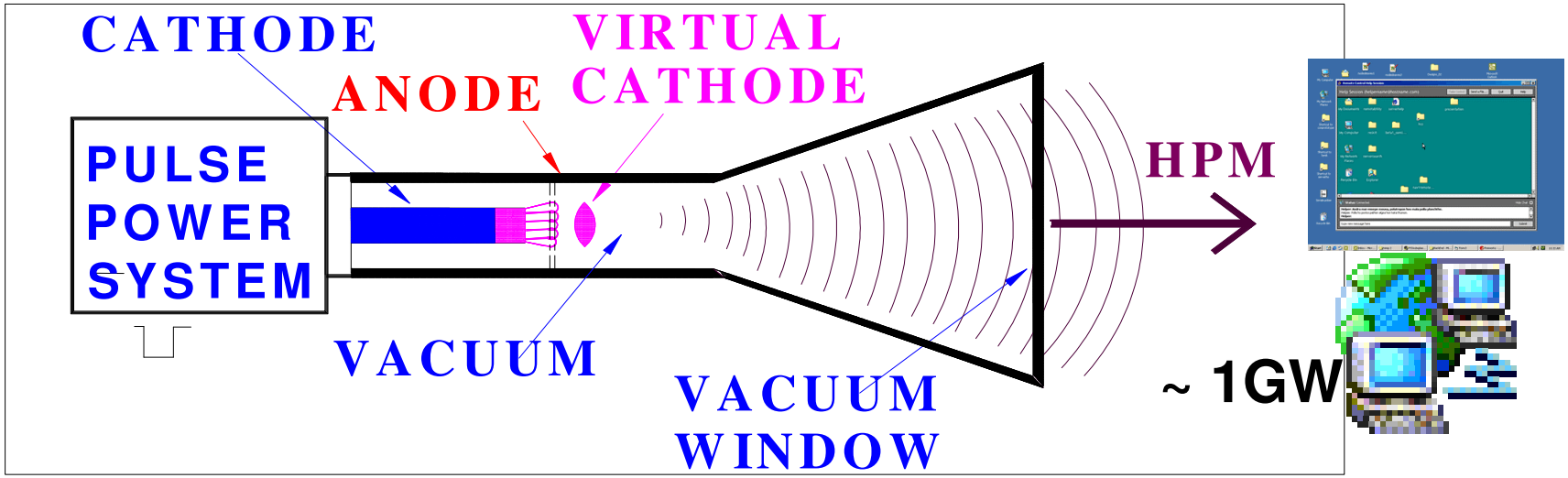

HPM weapons offer military commanders the option of:

(i) Speed-of-light, all-weather attack of enemy electronic systems

(ii) Area coverage of multiple targets with minimal prior information on threat characteristics

(iii) Surgical strike (damage, disrupt, degrade) at selected levels of combat

(iv) Minimum collateral damage in politically sensitive environments

(v) Simplified pointing and tracking

(vi) Low operating costs

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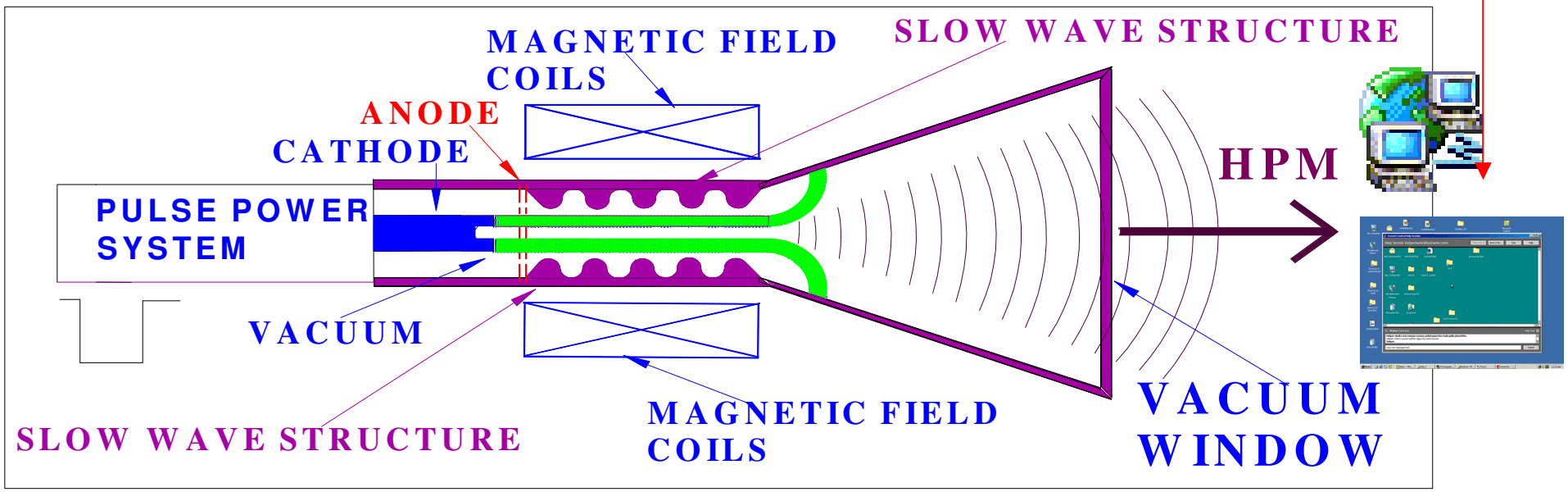
Backward Wave Oscillator

BWO-HPM device



Efficiency: 20%

5 MW

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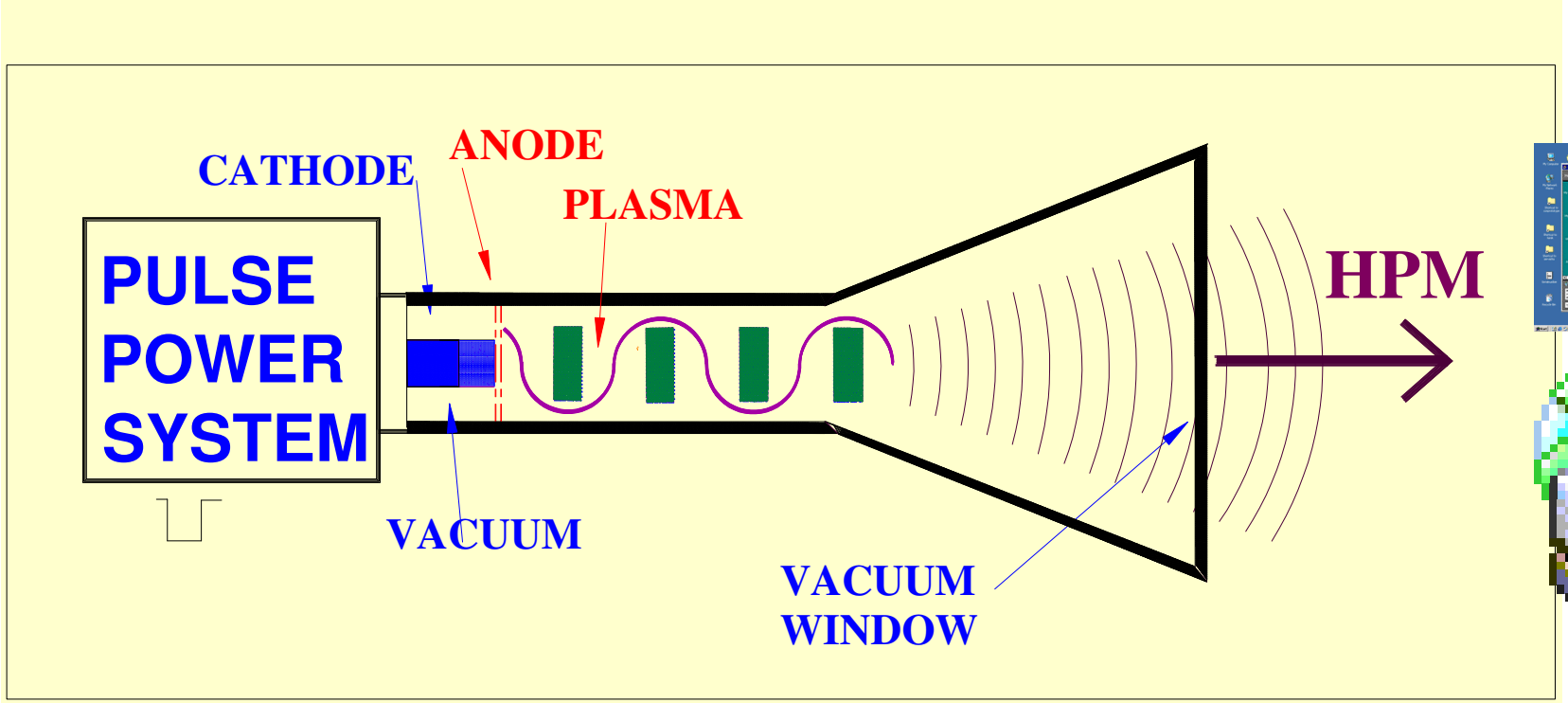
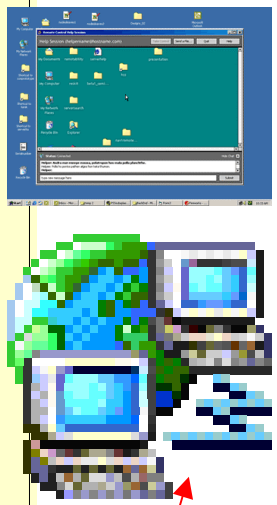
Beam Plasma Device

For HPM generation





Wide BW~100GHz,

Low Efficiency

TARGET

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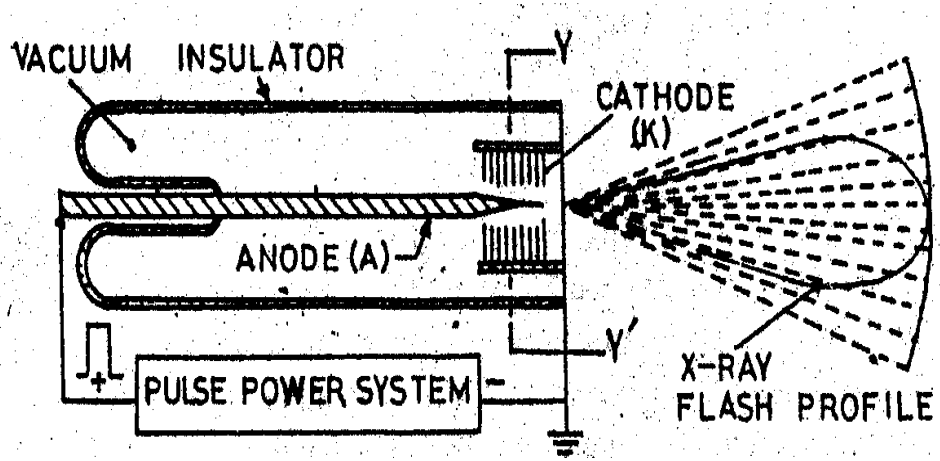
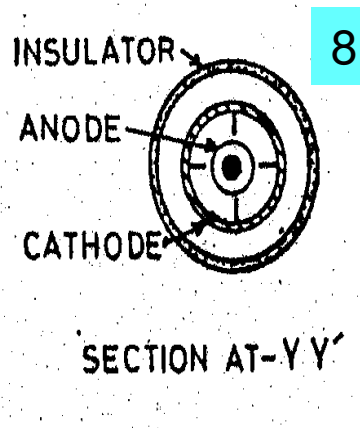
Flash X-Rays





8R/pulse

For a successful dynamic radiography,

(i) If higher the velocity of the moving object,
smaller duration of the X-ray flash will be needed.

(ii) Blurr produced on the stop motion radiography = VxT
for an object moving with velocity 'V' &
X-ray pulse duration 'T'

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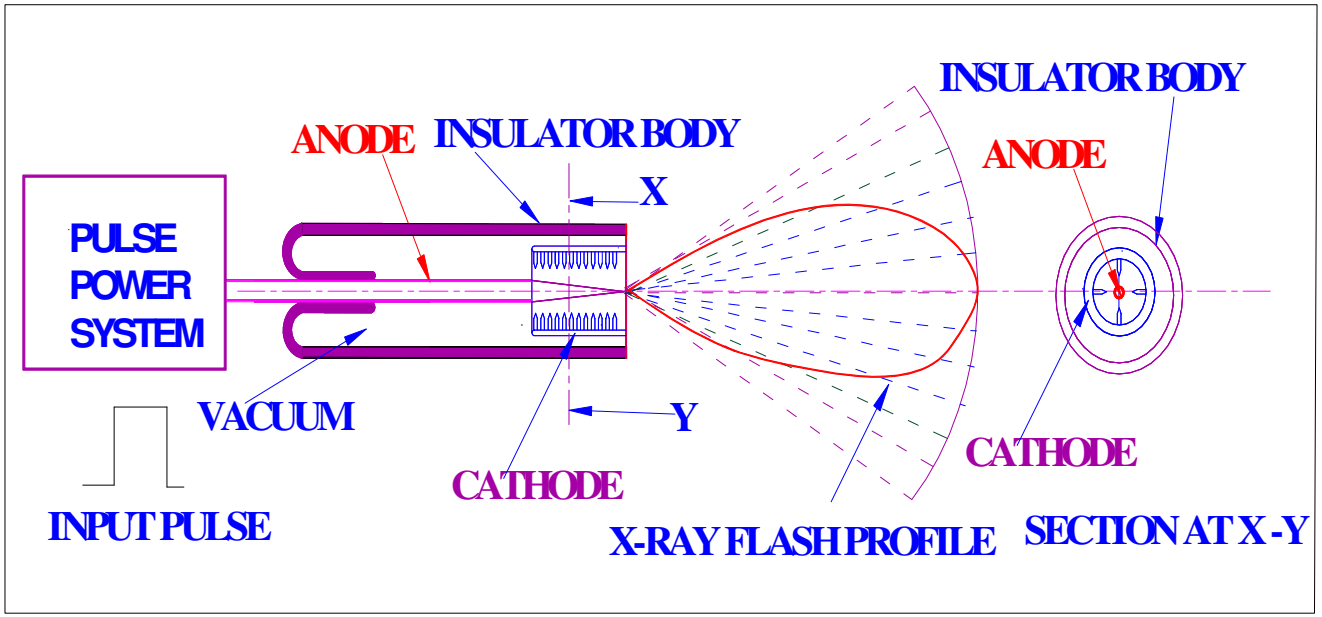
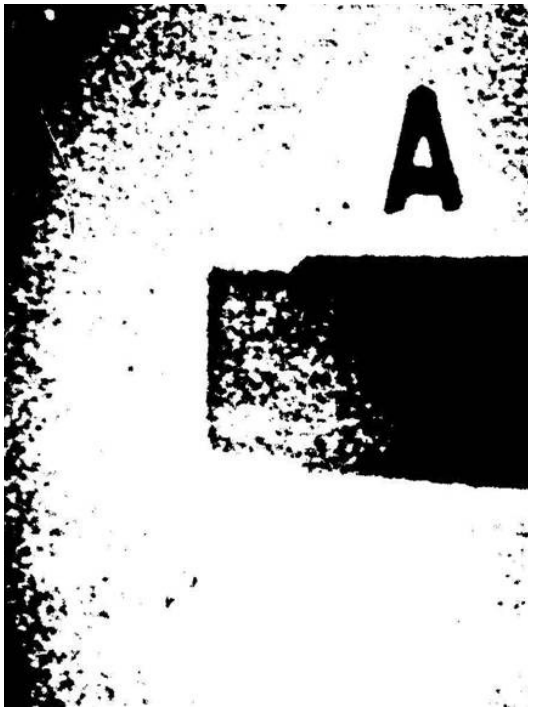
FLASH X-Ray Generation





APPLICATIONs of FXR:

(i) Radiography of radioactive sources:

8Ci Ir-192 source radiographed (KALI-200)

(ii) Imaging the impact of projectile in or on a target,

(iii) Imaging an explosively driven object during acceleration

(iv) Observing the mechanics of detonation

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Flash X-Ray Generation

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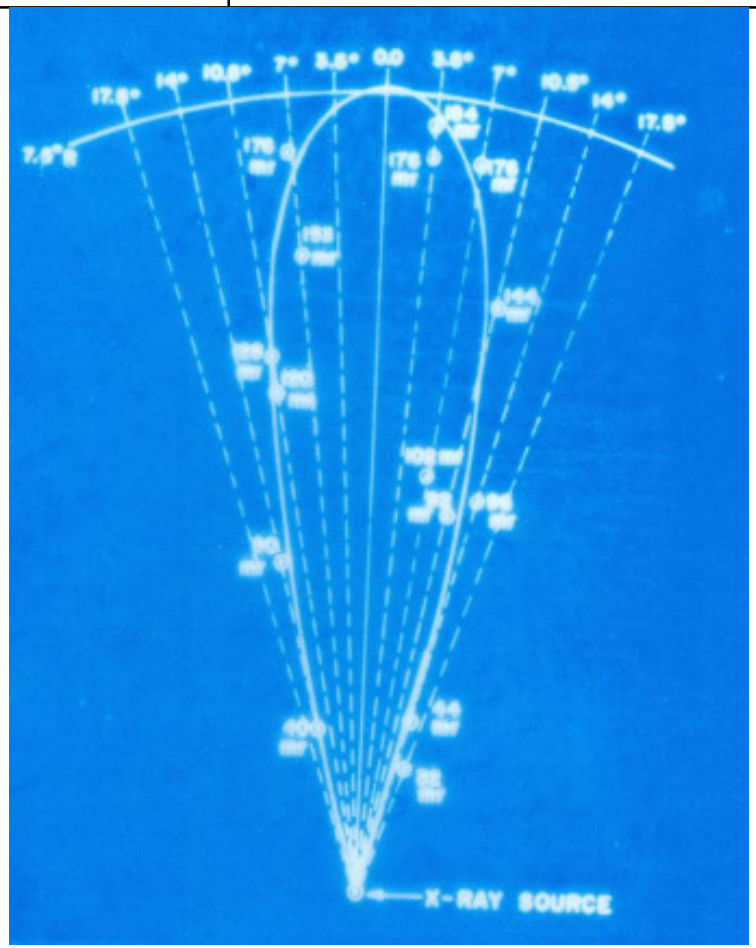
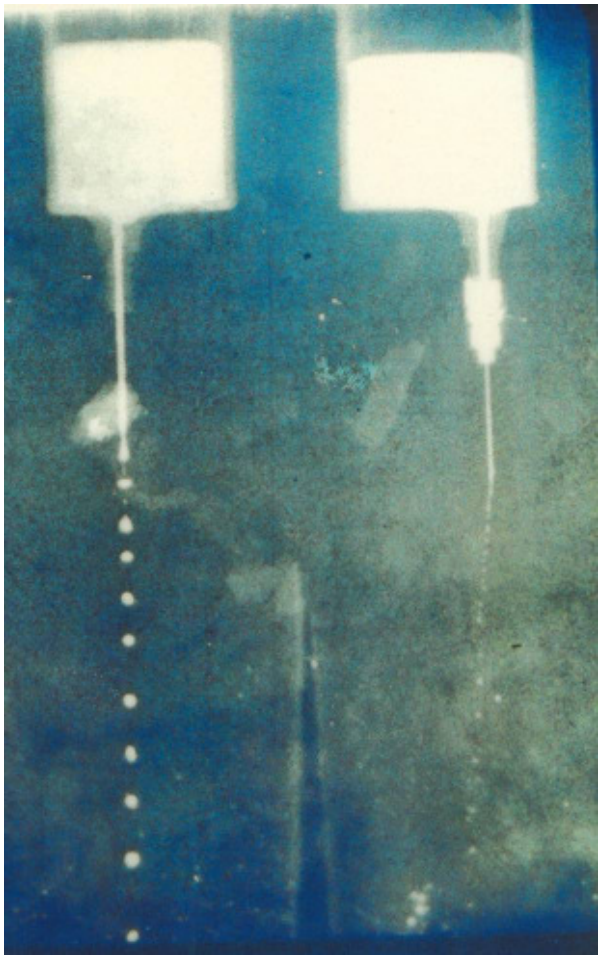


Flash X-ray from KALI-75



Normal X- ray Photograph of water drops

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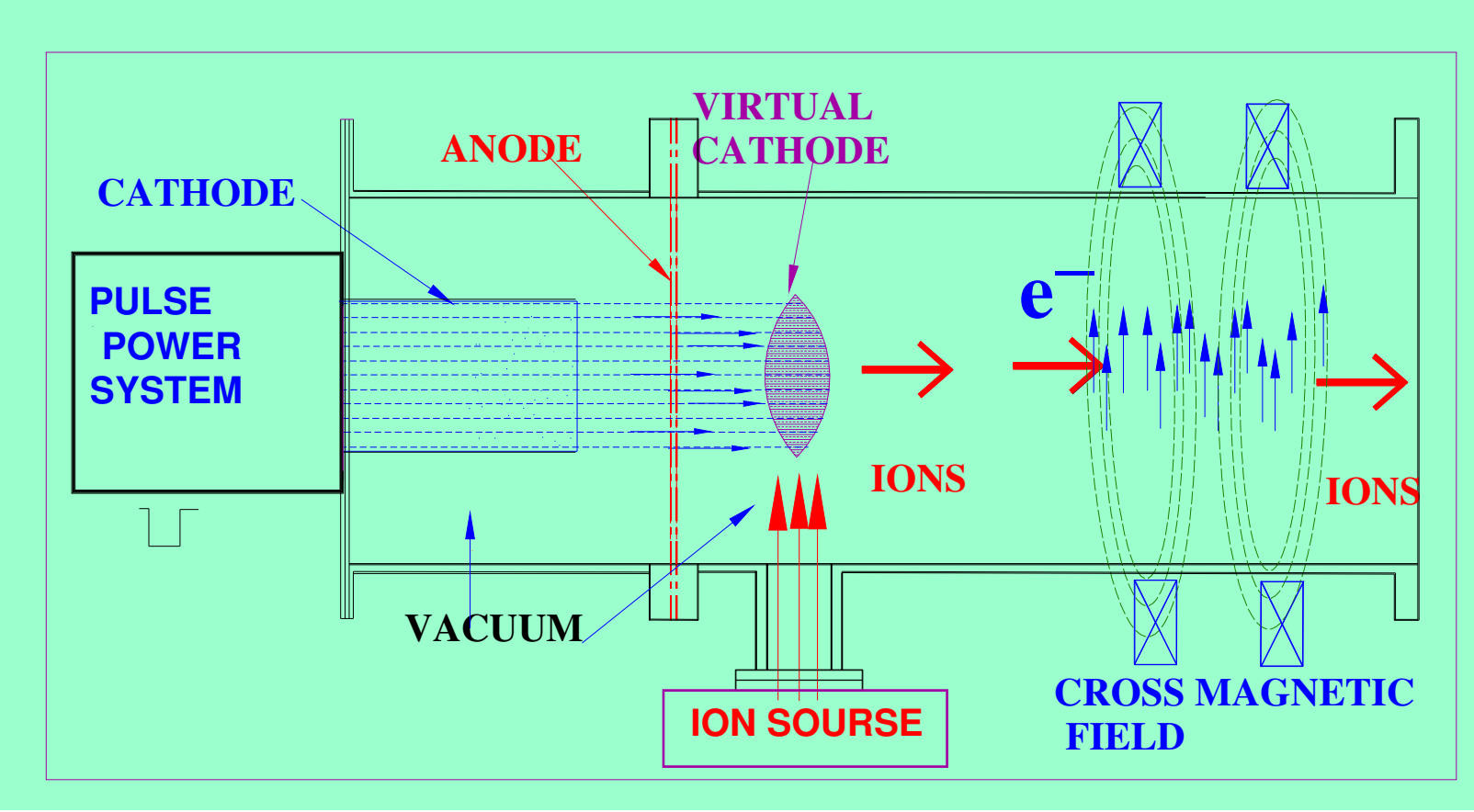
Collective Ion Acceleraion



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CONCLUSIONS

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- AN ELECTRON BEAM OF 600kV, 70kA, 100ns has been produced.
- HPM ~**1GW** POWER, for shielding applications.
- FLASH X-RAYs for deeper & faster radiography
- **ION IMPLANTATION for various Industrial Applications**

THANK YOU