Electron Linac Development for Radiation Processing and Neutron Production

K.C. Mittal

Electron Beam Center, APPD, BARC

kcm@barc.gov.in

IVS2012 February 17, 2012, VECC Kolkatta

ELECTRON BEAM APPLICATIONS

Application	Energy	Dose
○Cross Linking of PE	0.3-10 MeV	50-300 kGy
○Thermo Shrinkable Plastics	0.5-4	100-250
○ Teflon Degradation	2	
○Curing of Coatings on wood	0.15-0.5	20-500
○Exotic Colors in Diamonds	2-10	few MGy
○Sewage & Sludge Treatment	0.5-4	0.5-1.0
○Food Preservation	5-10	5-10
○Disinfestation of Grain	1	0,5-1.0
○Purification of Exhaust Gases	0.3-1.5	10-15
○Sterilization of Medical Prodts	1-10	20-50
○Vulcanization of Rubber	0.5-1.5	20-500
○Graft polymerization	0.3-2.5	10-300

Industrial & Research Electron Accelerator Program

Indigenous Technology Development

Accomplished

- DC Accelerator : 500 keV, 10 kW
- RF Accelerator : 10 MeV, 10 kW
- RF Accelerator : 9 MeV, 1 kW x-ray source (Technology demonstration)

In progress

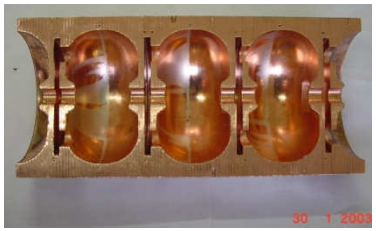
- DC Accelerator : 3 MeV, 30 kW
- RF Accelerator x-ray source for cargo-scanning (dual energy) 6/3 MeV for production

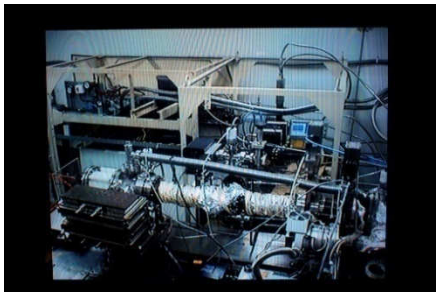
Projects

- DC Accelerator : 700 keV, 7 kW
- RF Accelerator : 30 MeV, 3.5 kW for neutron generation
- RF Accelerator : 100 MeV, 100 kW for exptl neutron facility

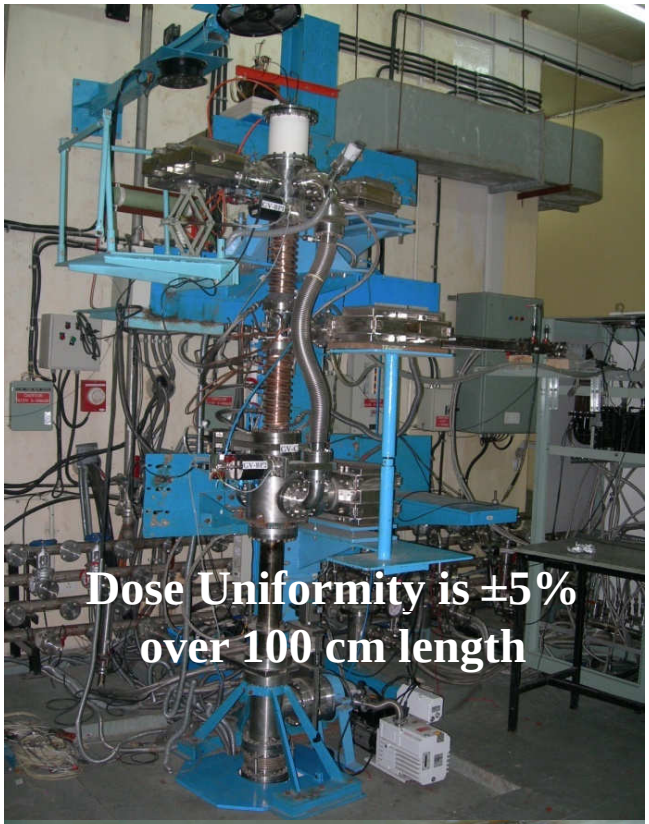
Future

- DC & RF Accelerators : 150 kW and above





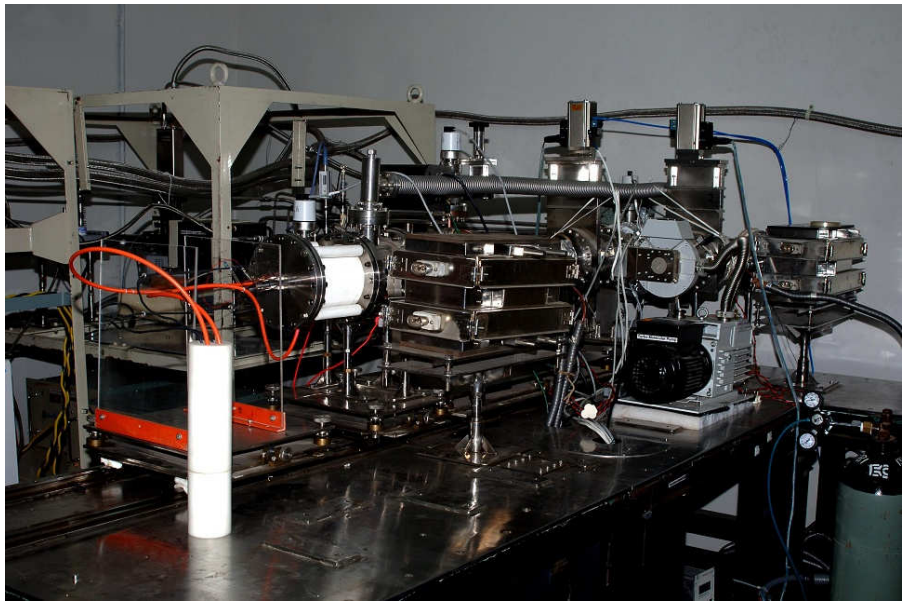
Electron Irradiation for Industry & Research with RF Linac

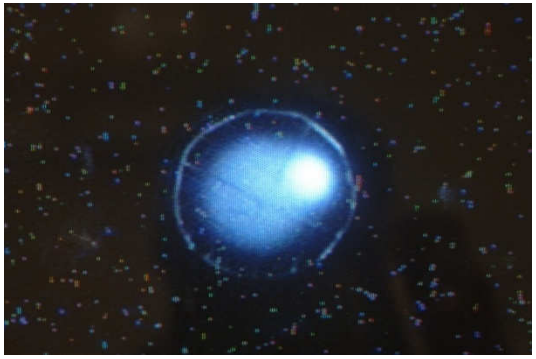


10 MeV RF Linac Utilization

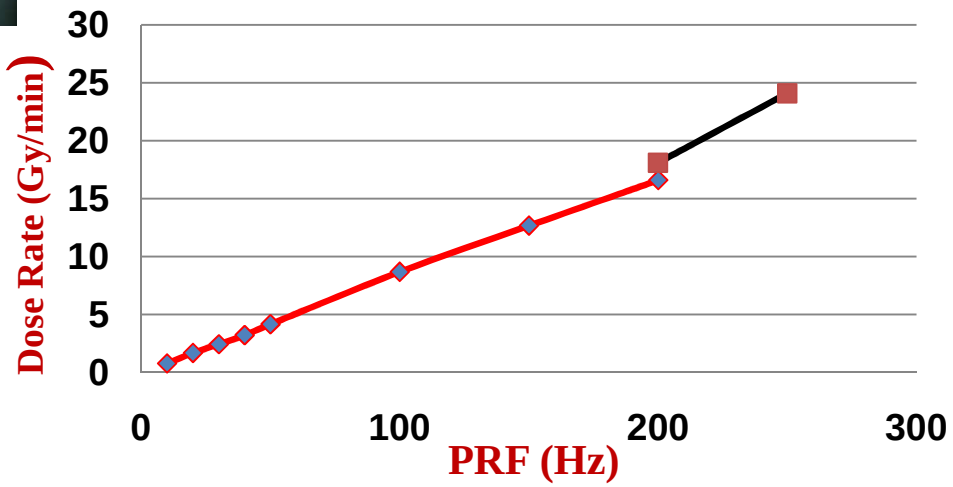
- Polyethylene o-rings for use up to 250ºC
- Reverse recovery time (trr) of Diodes reduced from 15 us to 7us (BHEL production trials)
- Potato irradiation (Food Technology Division ,BARC)
- Cross-linking of heat shrinkable rubber (Raychem)
- Gelation of Polyvinyl acetate (Pidilite Industries)
- Fissile material detection development by measurement of neutron fraction (BARC)
- Photofission data for Mo-99 (BARC)
- Utilized for many more research projects of Universities

9 MeV RF Linac x-ray source at ECIL Linac Test Facility
Demonstration for cargo-scanning





X-ray Spot diameter ~ 2.5 mm



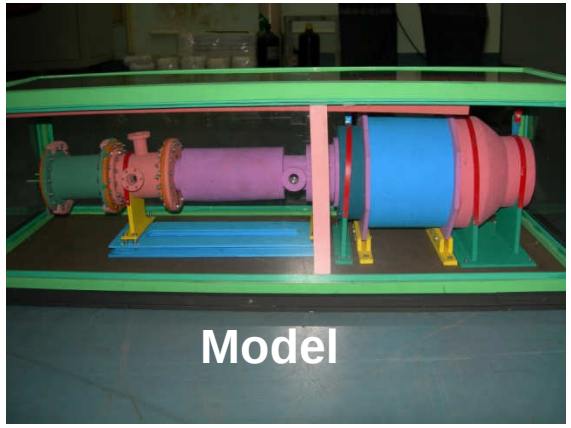
X-ray measured = 24 Gy/min/m

Prototype Dual Energy (6/3 MeV) Compact Linac for Material Discrimination - Assembly & Testing

Egun

Magnetron

Magnetron modulator

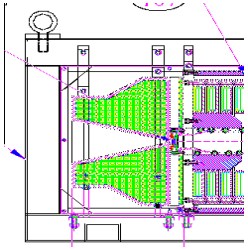


Linac structure

Egun modulator

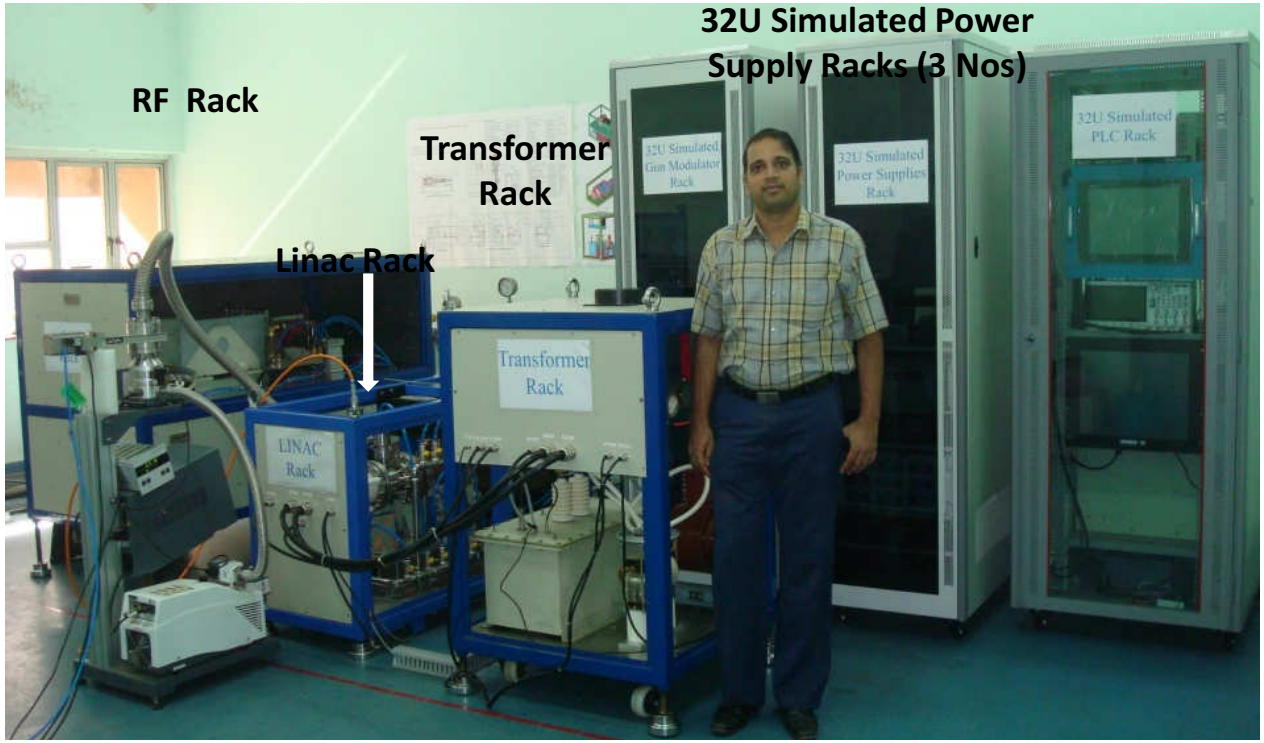
X-ray target

X-ray collimator



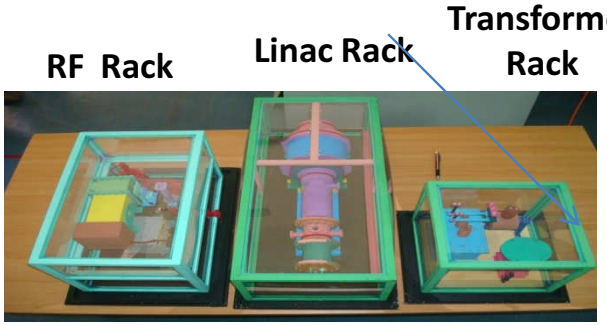
6MeV/3MeV Dual Energy Compact Linac X-Ray Source for Container Cargo Scanning

Prototype System for Productionisation by M/S ECIL



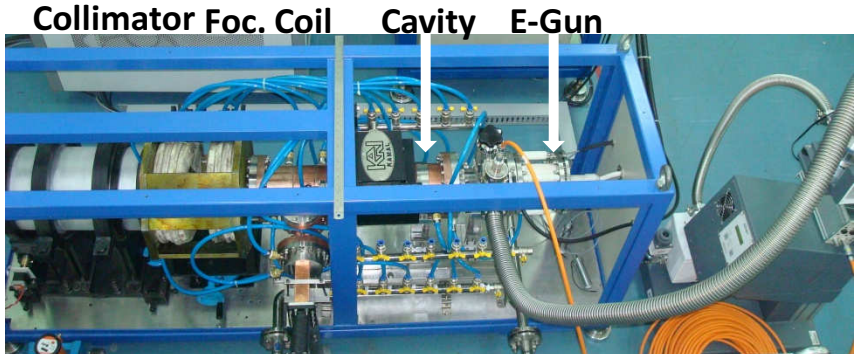
Compact LINAC X-Ray Source System for Mobile Platform

Dual energy for Z (material) discrimination



Model of Compact Linac

Cold Conditioning of Linac



Electron linac technology development for next 5 years

10 MeV, 10 kW Linac (at EBC, Kharghar) Utilization and Upgradation of Facility	2856 MHz	0.9 m
Compact Linac 9 MeV, 6/3 MeV X-Ray source for cargo scanning, research accelerators- productionization at ECIL	2856 MHz	0.9 m and 0.6 m
30 MeV, 7 kW neutron generator for shielding & nuclear physics (n-TOF) studies (IGCAR, Kalpakkam)	2856 MHz	2.5 m
100 MeV, 100 kW neutron generator for ADS and material related studies	2856 MHz	11 m
Superconducting linac	1497/ 1300 MHz	9 cavity cells

Electron Accelerators as Drivers for ADS

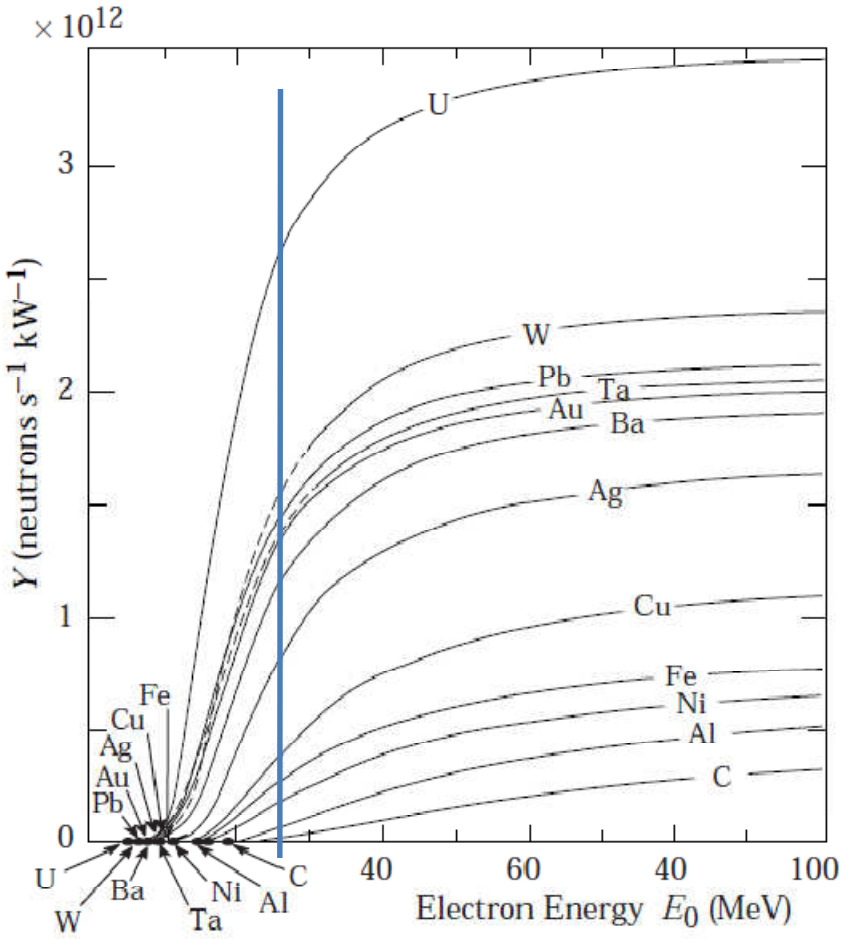
1. Electron accelerator technology is a mature technology
2. Easily used for Bremsstrahlung / photoneutron source
3. Isotope production for medical diagnosis and therapy
4. Nuclear physics studies related to ADS spallation, higher energy neutron reactions
5. Less efficient than proton machines in neutron production but has lower capital cost and comparable energy cost
6. ADS application is reliable because of less beam trips

A thorough evaluation is required for ADS application on a larger scale;

its suitability for experimental ADS studies is generally accepted.

Electron Beam as a neutron source

- neutrons are generated via photonuclear and photo fission reactions from Bremsstrahlung photons.
- In the photon energy range from threshold (few MeV) to about 30 MeV, neutron production is via the Giant Dipole Resonance (GDR) mechanism.
- For 5 MW, 100 MeV e- beam, in a dual zone reactor, power increases by 12 times for k=0.98
- Output Power will be ~ 5 x 12 = ~ 60 MW.



Ref:Swanson, IAEA Tech Rep 188 (1979)

Beam Energy (MeV)	Neutron Yeild ($n\ s^{-1}\ kW^{-1}$)	Beam Current (mA)	Beam Power (MW)	Neutron Flux (n/s)
100 (U – Target)	$3.25X10^{12}$	50-100	5-10	$1.625\text{-}3.2X10^{16}$
100 (W –Target)	$2.17X10^{12}$	50-100	5-10	$1.085\text{-}2.17X10^{16}$
100 (Pb – Taget)	$1.97X10^{12}$	50-100	5-10	$0.985\text{-}1.97X10^{16}$
100 (Ta–Target)	$1.91X10^{12}$	50-100	5-10	$0.955\text{-}1.91X10^{16}$

Specifications of Linacs for Neutron Production

The Electron Linac facility specifications are

Phase-I: Linac comprising 10 modules of room temp 10MeV RF electron accelerators

Targeted parameters: 70-100MeV, 70-100 kW, pulsed normal conducting Linac (f = 2856 MHz),

Pulsed neutron flux ~ 10^{14} n/cm^2/s.

Phase –II: Superconducting cw electron Linac

Target parameters : 100-150MeV, 200-400 kW, cw - superconducting Linac (L-band, f = 1300 MHz),

CW Neutron flux ~ 2X10^{12} n/cm^2/s

Specification of Normal Conducting 100 MeV LINAC

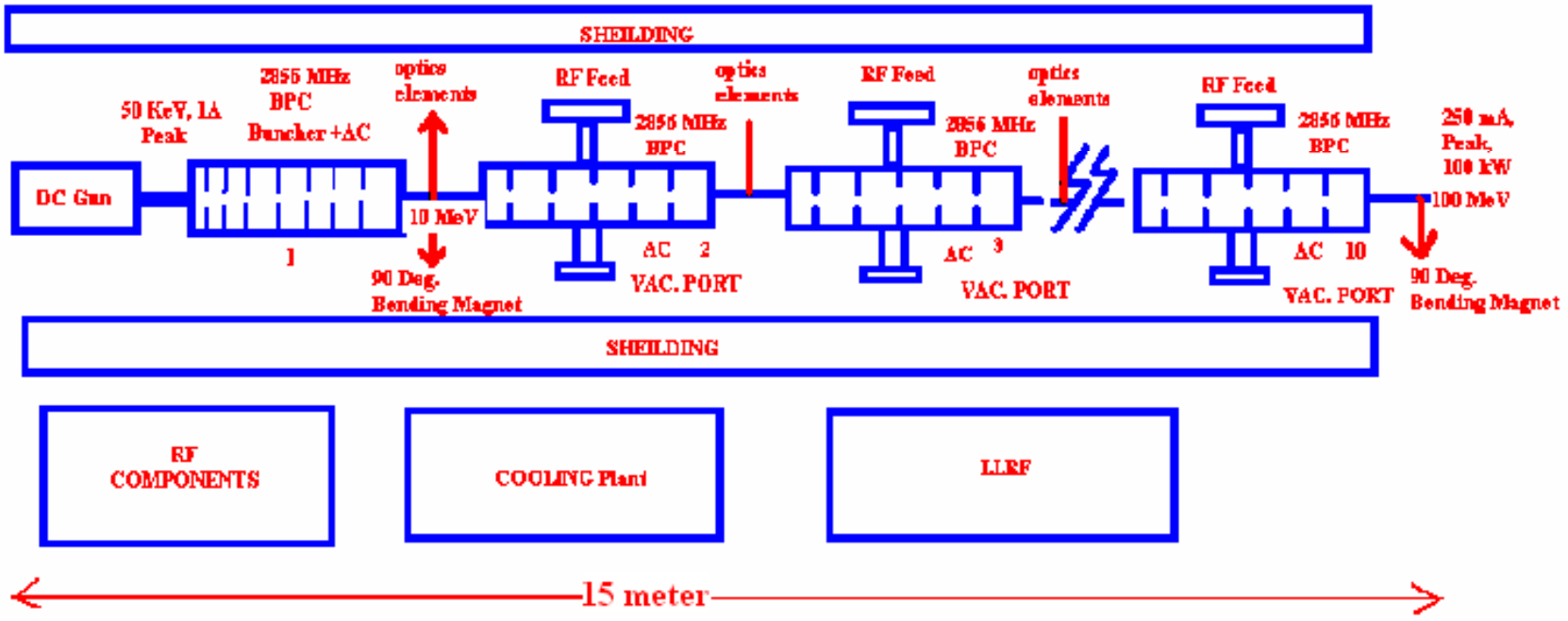
1.	Operating Frequency	: 2856 ± 2 MHz
2.	Beam Energy	: 100MeV
3.	Beam Current	: 250mA (peak)
4.	Beam Pulse Width	: 10 µsec
5.	Pulse Repetition Frequency	: 400Hz
6.	Beam Power	: 100 kW
7.	Total Microwave Power	: 50MW peak, 200 kW avg
8.	Photo neutron target	: Ta / W(H2O / D2O cooled)
9.	RF Source	: Klystron based
10.	Klystron modulators (each)	: 130 kV, 36 kW avg. (nominal)

Note: Considering the maximum LINAC efficiency (RF to beam conversion) of ~60%, 1 LINAC section can give maximum beam power output of ~ 20kW.

RF Electron Linac for Neutron Generation

PHASE I:

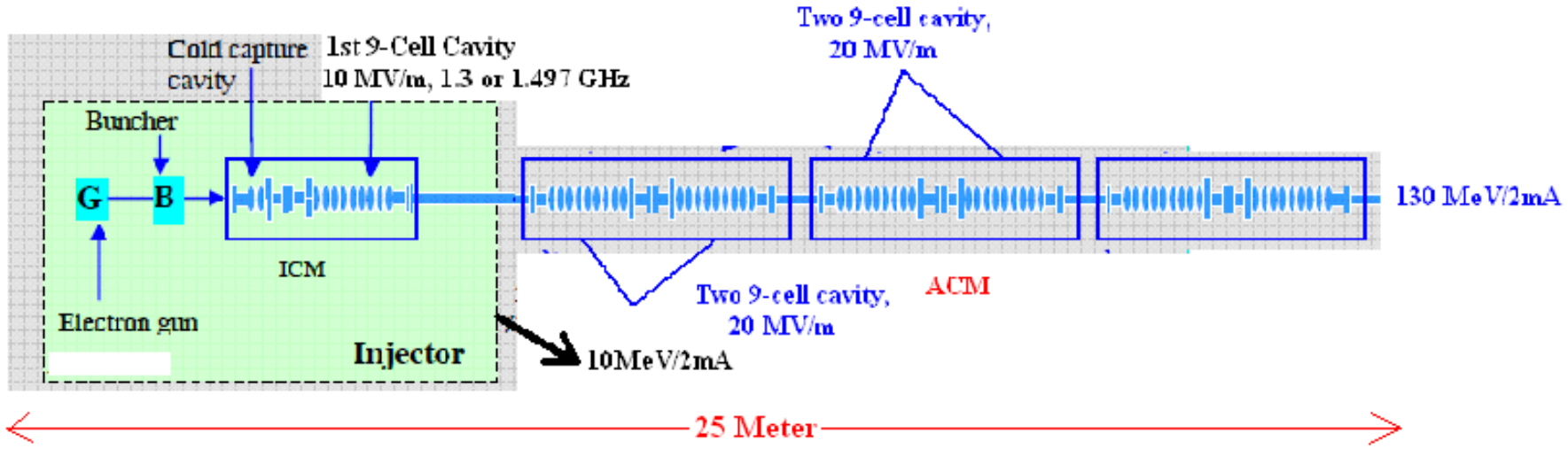
100MeV, 100 kW, pulsed normal conducting Linac (S-band, f = 2856 MHz), avg. neutron flux ~ 10^{13} n/cm^2/s



RF Electron Linac for Neutron Generation -2 contd

PHASE II

150MeV, 200-300 kW, cw -superconducting Linac (L-band), neutron flux ~ 10^{15} n/cm^2/s



Summary

- Electron Accelerators from 0.5 – 10 MeV are employed for Industrial Radiation Processing
- 9 MeV, 6 MeV and 9/6/3 MeV Dual Energy Linacs are used for Security Applications
- 50 MeV to 100 MeV Linacs are employed for Neutron Production and can have a role in energy multiplication in ADS Systems
- BARC is developing this technology for various applications

Electron Linac Development for Radiation Processing and Neutron Production

K.C. Mittal

Electron Beam Center, APPD, BARC

kcm@barc.gov.in

IVS2012 February 17, 2012, VECC Kolkatta

ELECTRON BEAM APPLICATIONS

Application	Energy	Dose
○Cross Linking of PE	0.3-10 MeV	50-300 kGy
○Thermo Shrinkable Plastics	0.5-4	100-250
○ Teflon Degradation	2	
○Curing of Coatings on wood	0.15-0.5	20-500
○Exotic Colors in Diamonds	2-10	few MGy
○Sewage & Sludge Treatment	0.5-4	0.5-1.0
○Food Preservation	5-10	5-10
○Disinfestation of Grain	1	0,5-1.0
○Purification of Exhaust Gases	0.3-1.5	10-15
○Sterilization of Medical Prodts	1-10	20-50
○Vulcanization of Rubber	0.5-1.5	20-500
○Graft polymerization	0.3-2.5	10-300

Industrial & Research Electron Accelerator Program

Indigenous Technology Development

Accomplished

- DC Accelerator : 500 keV, 10 kW
- RF Accelerator : 10 MeV, 10 kW
- RF Accelerator : 9 MeV, 1 kW x-ray source (Technology demonstration)

In progress

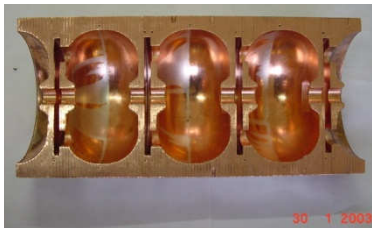
- DC Accelerator : 3 MeV, 30 kW
- RF Accelerator x-ray source for cargo-scanning (dual energy) 6/3 MeV for production

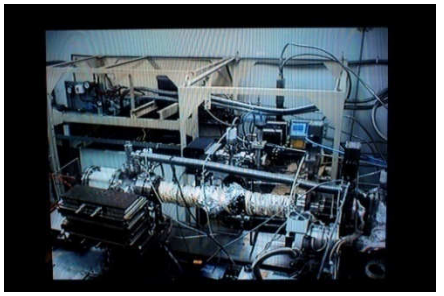
Projects

- DC Accelerator : 700 keV, 7 kW
- RF Accelerator : 30 MeV, 3.5 kW for neutron generation
- RF Accelerator : 100 MeV, 100 kW for exptl neutron facility

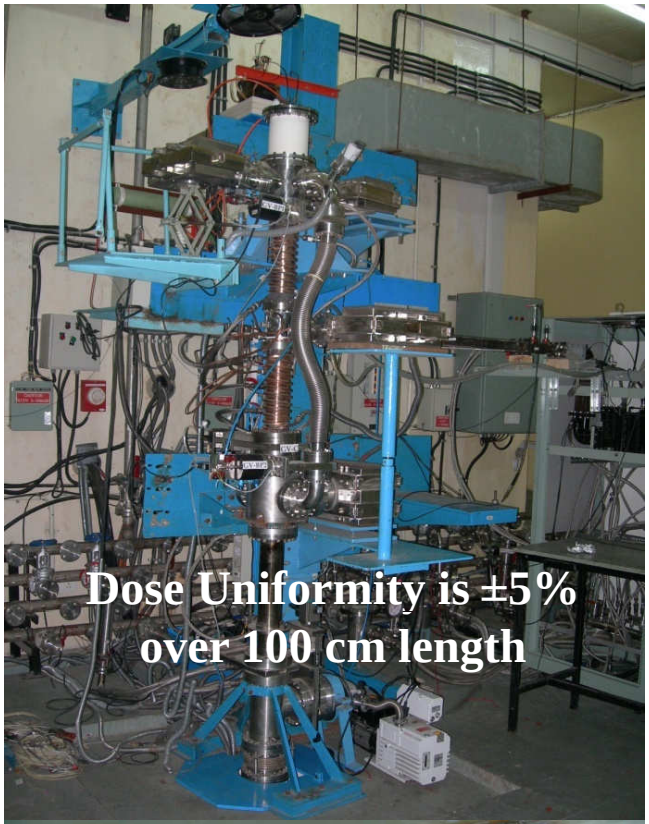
Future

- DC & RF Accelerators : 150 kW and above





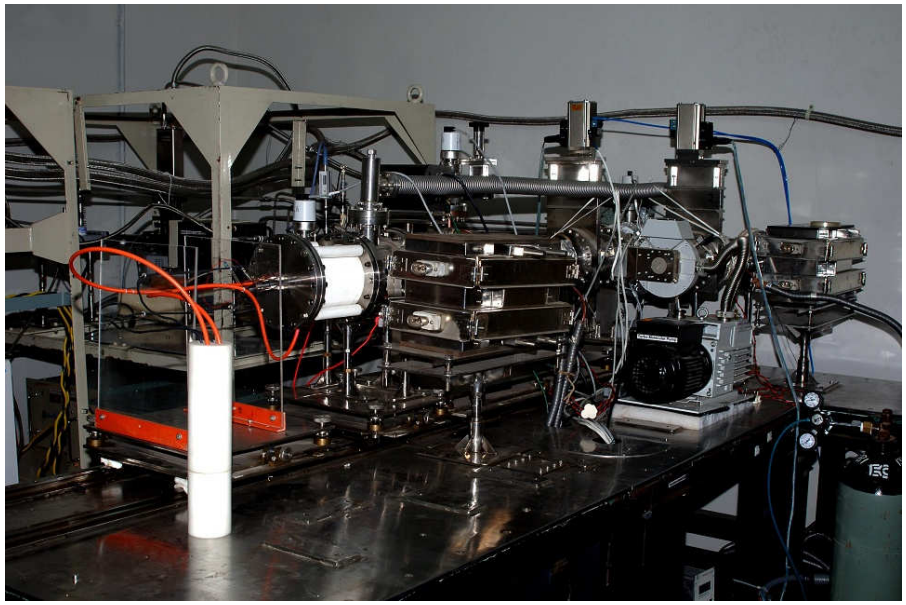
Electron Irradiation for Industry & Research with RF Linac

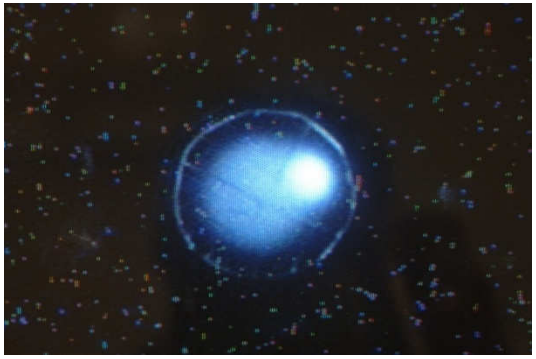


10 MeV RF Linac Utilization

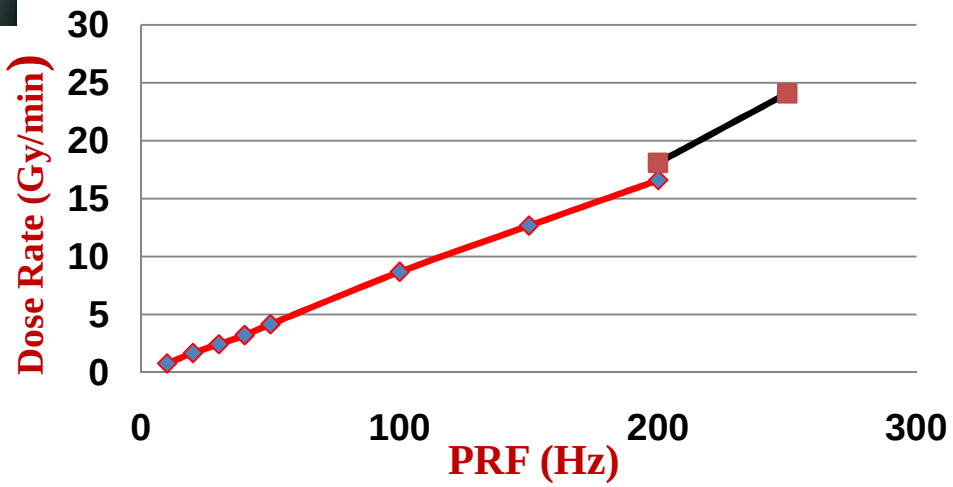
- Polyethylene o-rings for use up to 250ºC
- Reverse recovery time (trr) of Diodes reduced from 15 us to 7us (BHEL production trials)
- Potato irradiation (Food Technology Division ,BARC)
- Cross-linking of heat shrinkable rubber (Raychem)
- Gelation of Polyvinyl acetate (Pidilite Industries)
- Fissile material detection development by measurement of neutron fraction (BARC)
- Photofission data for Mo-99 (BARC)
- Utilized for many more research projects of Universities

9 MeV RF Linac x-ray source at ECIL Linac Test Facility
Demonstration for cargo-scanning





X-ray Spot diameter ~ 2.5 mm



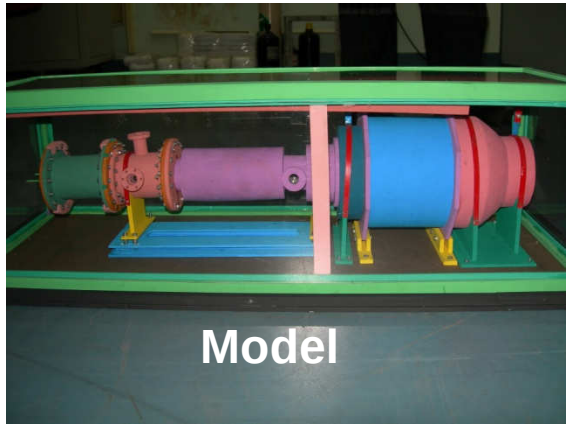
X-ray measured = 24 Gy/min/m

Prototype Dual Energy (6/3 MeV) Compact Linac for Material Discrimination - Assembly & Testing

Egun

Magnetron

Magnetron modulator

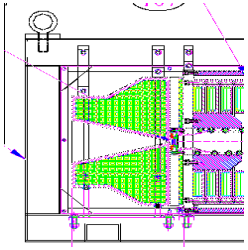


Linac structure

Egun modulator

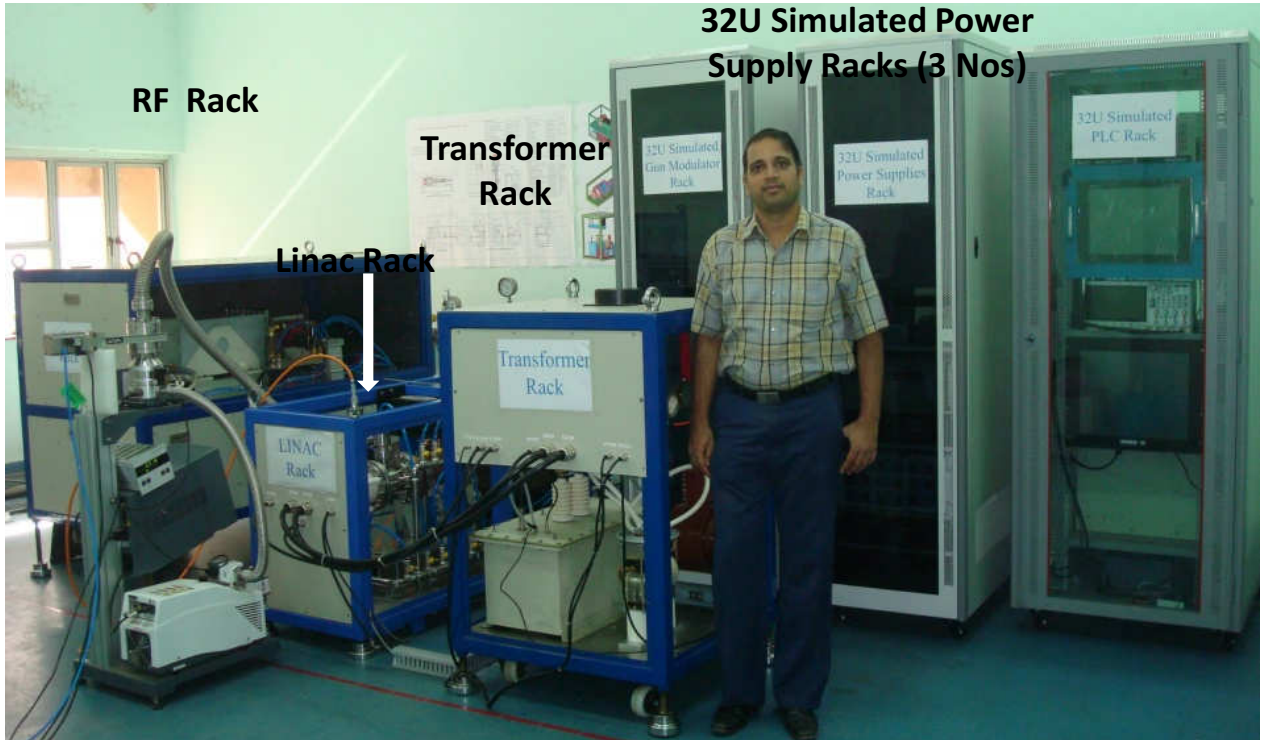
X-ray target

X-ray collimator



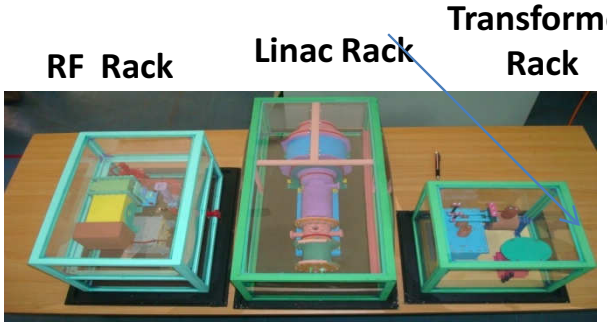
6MeV/3MeV Dual Energy Compact Linac X-Ray Source for Container Cargo Scanning

Prototype System for Productionisation by M/S ECIL



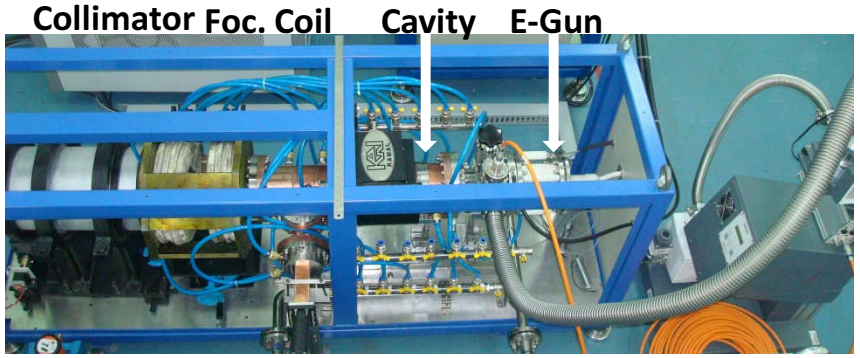
Compact LINAC X-Ray Source System for Mobile Platform

Dual energy for Z (material) discrimination



Model of Compact Linac

Cold Conditioning of Linac



Electron linac technology development for next 5 years

10 MeV, 10 kW Linac (at EBC, Kharghar) Utilization and Upgradation of Facility	2856 MHz	0.9 m
Compact Linac 9 MeV, 6/3 MeV X-Ray source for cargo scanning, research accelerators- productionization at ECIL	2856 MHz	0.9 m and 0.6 m
30 MeV, 7 kW neutron generator for shielding & nuclear physics (n-TOF) studies (IGCAR, Kalpakkam)	2856 MHz	2.5 m
100 MeV, 100 kW neutron generator for ADS and material related studies	2856 MHz	11 m
Superconducting linac	1497/ 1300 MHz	9 cavity cells

Electron Accelerators as Drivers for ADS

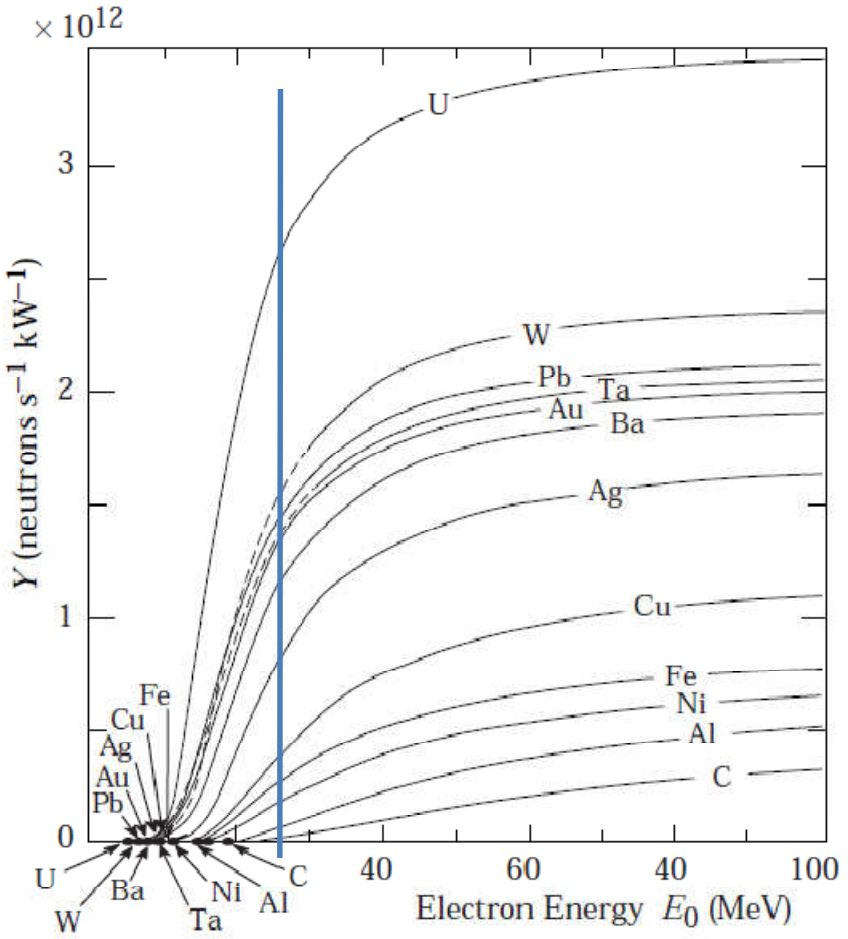
1. Electron accelerator technology is a mature technology
2. Easily used for Bremsstrahlung / photoneutron source
3. Isotope production for medical diagnosis and therapy
4. Nuclear physics studies related to ADS spallation, higher energy neutron reactions
5. Less efficient than proton machines in neutron production but has lower capital cost and comparable energy cost
6. ADS application is reliable because of less beam trips

A thorough evaluation is required for ADS application on a larger scale;

its suitability for experimental ADS studies is generally accepted.

Electron Beam as a neutron source

- neutrons are generated via photonuclear and photo fission reactions from Bremsstrahlung photons.
- In the photon energy range from threshold (few MeV) to about 30 MeV, neutron production is via the Giant Dipole Resonance (GDR) mechanism.
- For 5 MW, 100 MeV e- beam, in a dual zone reactor, power increases by 12 times for k=0.98
- Output Power will be ~ 5 x 12 = ~ 60 MW.



Ref:Swanson, IAEA Tech Rep 188 (1979)

Beam Energy (MeV)	Neutron Yeild (n s^{-1} kW^{-1})	Beam Current (mA)	Beam Power (MW)	Neutron Flux (n/s)
100 (U – Target)	$3.25X10^{12}$	50-100	5-10	$1.625\text{-}3.2X10^{16}$
100 (W –Target)	$2.17X10^{12}$	50-100	5-10	$1.085\text{-}2.17X10^{16}$
100 (Pb – Taget)	$1.97X10^{12}$	50-100	5-10	$0.985\text{-}1.97X10^{16}$
100 (Ta–Target)	$1.91X10^{12}$	50-100	5-10	$0.955\text{-}1.91X10^{16}$

Specifications of Linacs for Neutron Production

The Electron Linac facility specifications are

Phase-I: Linac comprising 10 modules of room temp 10MeV RF electron accelerators

Targeted parameters: 70-100MeV, 70-100 kW, pulsed normal conducting Linac (f = 2856 MHz),

Pulsed neutron flux ~ 10^{14} n/cm^2/s.

Phase –II: Superconducting cw electron Linac

Target parameters : 100-150MeV, 200-400 kW, cw - superconducting Linac (L-band, f = 1300 MHz),

CW Neutron flux ~ 2X10^{12} n/cm^2/s

Specification of Normal Conducting 100 MeV LINAC

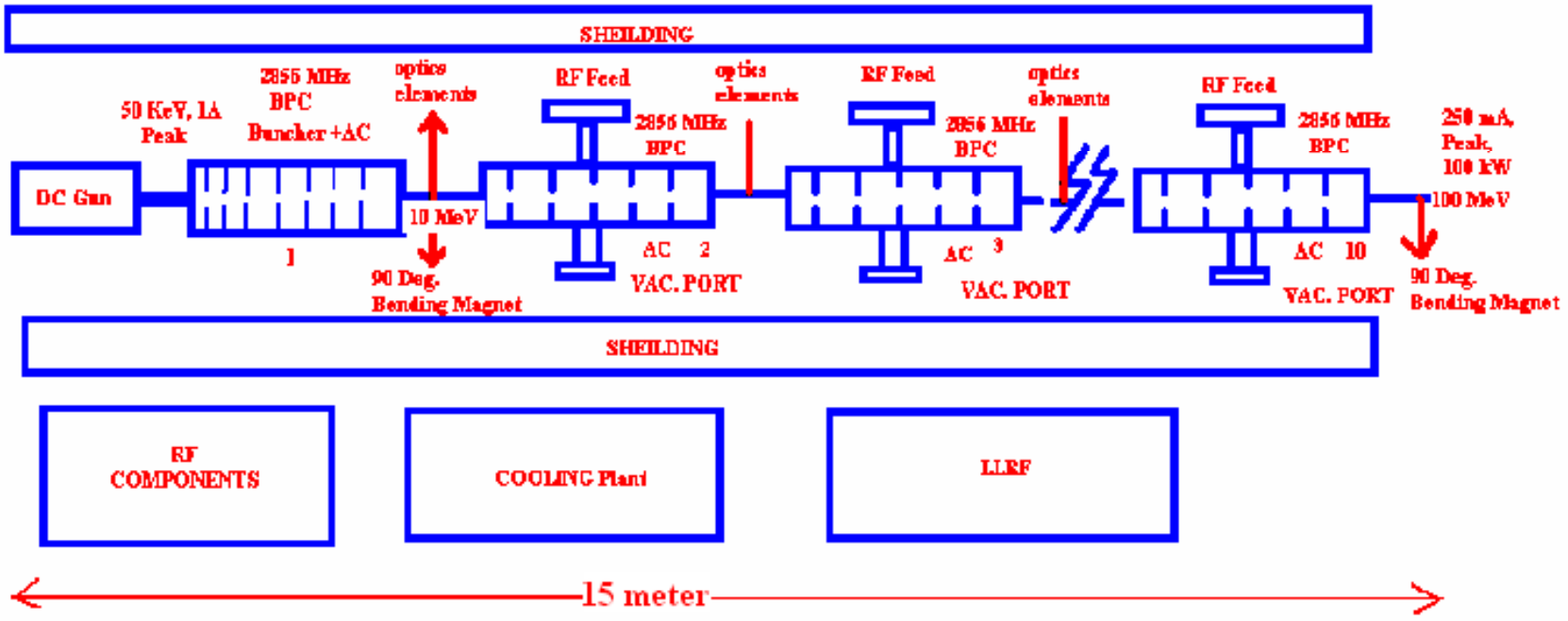
1.	Operating Frequency	: 2856 ± 2 MHz
2.	Beam Energy	: 100MeV
3.	Beam Current	: 250mA (peak)
4.	Beam Pulse Width	: 10 µsec
5.	Pulse Repetition Frequency	: 400Hz
6.	Beam Power	: 100 kW
7.	Total Microwave Power	: 50MW peak, 200 kW avg
8.	Photo neutron target	: Ta / W(H2O / D2O cooled)
9.	RF Source	: Klystron based
10.	Klystron modulators (each)	: 130 kV, 36 kW avg. (nominal)

Note: Considering the maximum LINAC efficiency (RF to beam conversion) of ~60%, 1 LINAC section can give maximum beam power output of ~ 20kW.

RF Electron Linac for Neutron Generation

PHASE I:

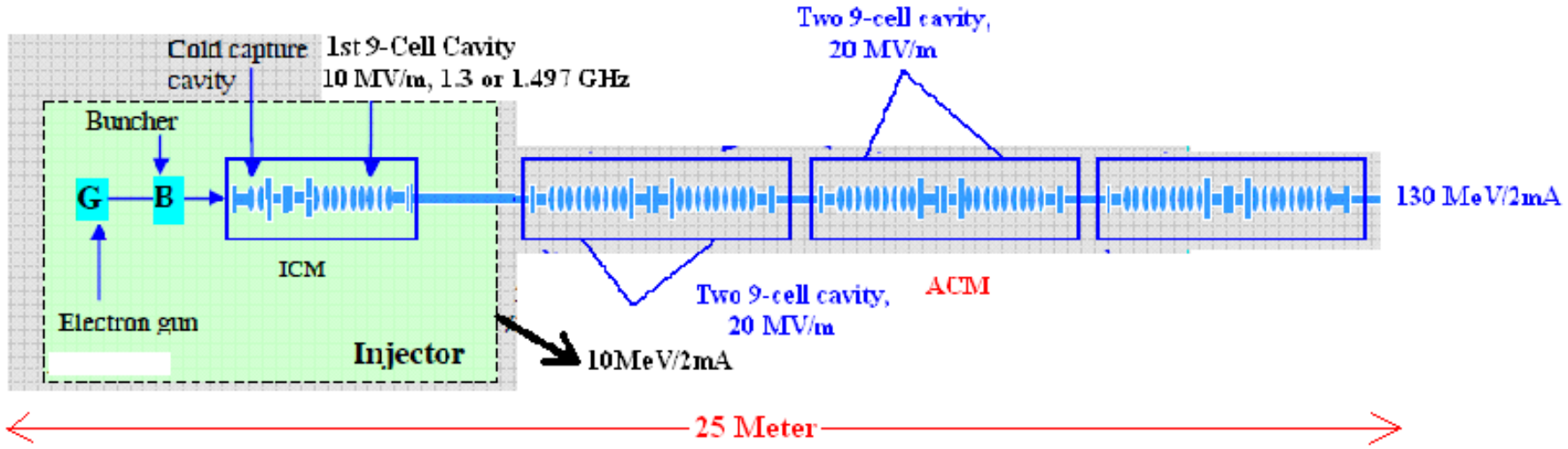
100MeV, 100 kW, pulsed normal conducting Linac (S-band, f = 2856 MHz), avg. neutron flux ~ 10^{13} n/cm^2/s



RF Electron Linac for Neutron Generation -2 contd

PHASE II

150MeV, 200-300 kW, cw -superconducting Linac (L-band), neutron flux ~ 10^{15} n/cm^2/s



Summary

- Electron Accelerators from 0.5 – 10 MeV are employed for Industrial Radiation Processing
- 9 MeV, 6 MeV and 9/6/3 MeV Dual Energy Linacs are used for Security Applications
- 50 MeV to 100 MeV Linacs are employed for Neutron Production and can have a role in energy multiplication in ADS Systems
- BARC is developing this technology for various applications