Development and Utilization of Accelerators in BARC

Pramod V. Bhagwat & S. Kailas

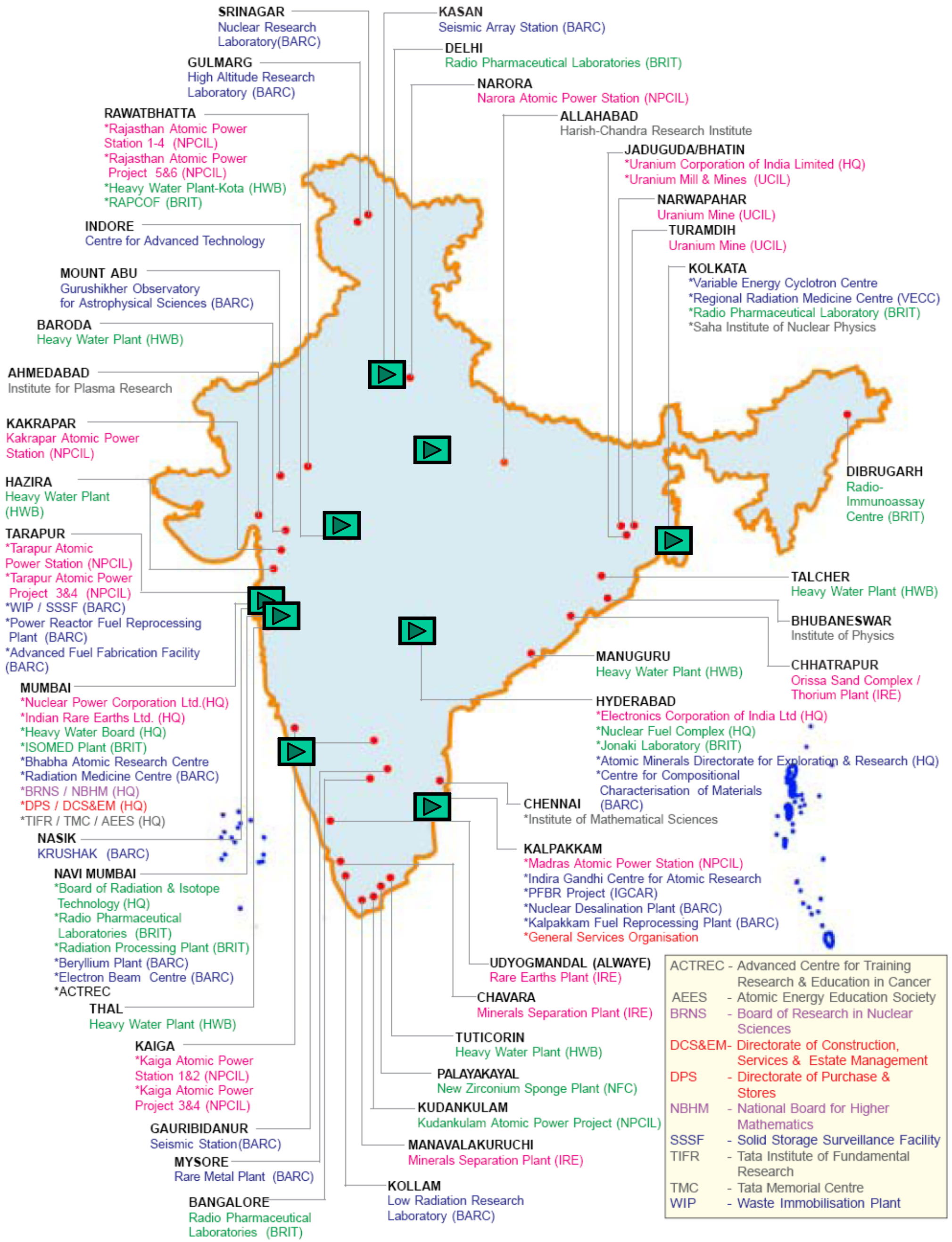
Pelletron Accelerator Facility

Nuclear Physics Division

Bhabha Atomic Research Centre

Mumbai, INDIA

Atomic Energy Establishments in India



ACTREC	-	Advanced Centre for Training Research & Education in Cancer
AEES	-	Atomic Energy Education Society
BRNS	-	Board of Research in Nuclear Sciences
DCS&EM	-	Directorate of Construction, Services & Estate Management
DPS	-	Directorate of Purchase & Stores
NBHM	-	National Board for Higher Mathematics
SSSF	-	Solid Storage Surveillance Facility
TIFR	-	Tata Institute of Fundamental Research
TMC	-	Tata Memorial Centre
WIP	-	Waste Immobilisation Plant

Introduction

A 5.5 MV Van-de-graaff single ended machine was commissioned in the sixties at BARC. This machine was utilized for various applications. In 1982, the project MEHIA started, where a 14 UD Pelletron Accelerator was purchased from M/s NEC, USA and installed at Tata Institute of Fundamental Research, Colaba, Mumbai. This accelerator was commissioned in 1988 and since then it has been serving as a major facility for heavy ion accelerator based research in India. In 1993, a project to convert 5.5 MV Van-de-Graaff to a 6 MV Folded machine was taken up. The first beam from was accelerated in 2000. The electron accelerators on the other hand, have wide industrial applications. The Electrons Beam Center has been set up at Kharghar, Mumbai, where 0.5 MeV, 3 MeV and 10 MeV electron accelerators are under construction. The 500 KeV electron beam accelerator is operational and being used for cable irradiation etc. The medical cyclotron was set up at Radiation Medicine Centre, Parel, Mumbai for Positron Emission Tomography

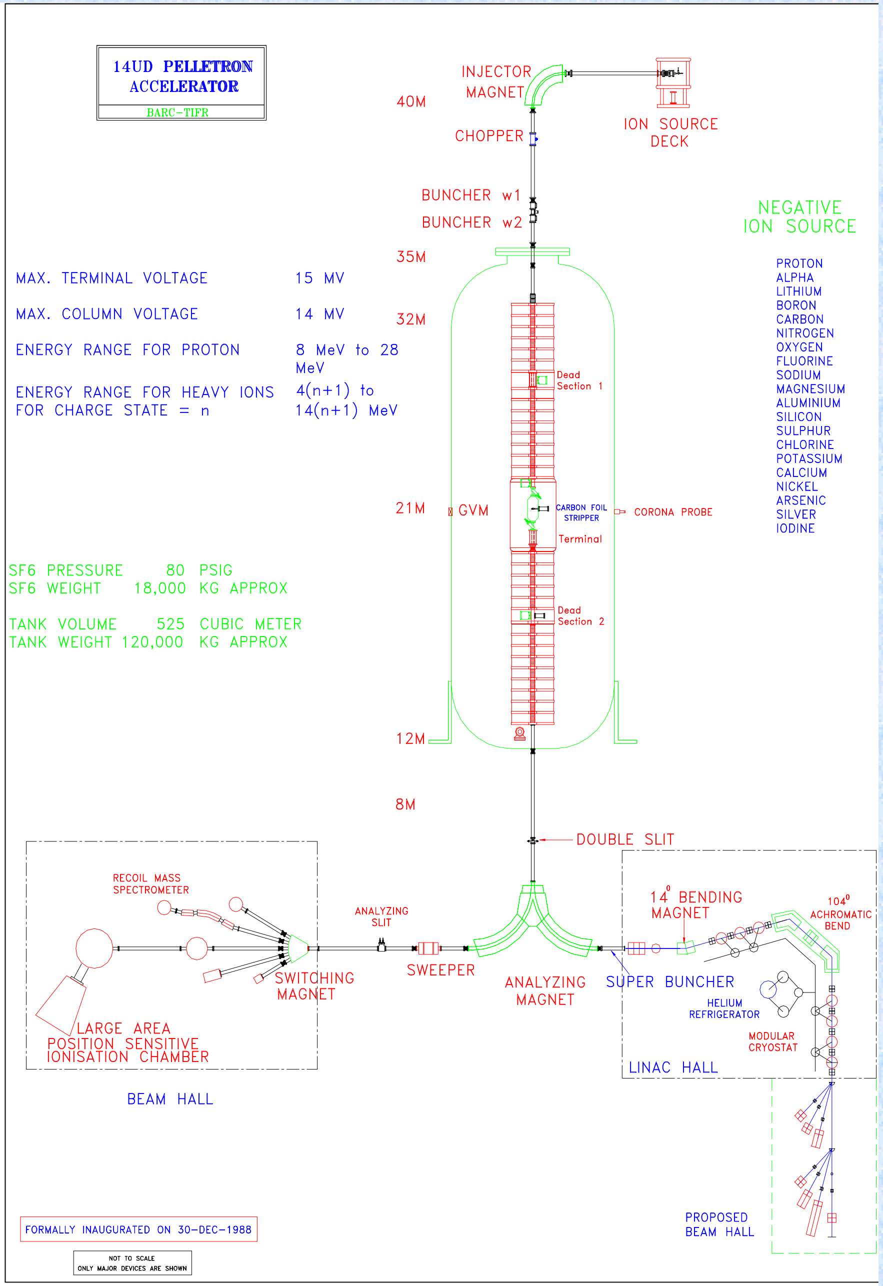
Development of Accelerators

- Pelletron Accelerator Facility, BARC-TIFR
- Folded Tandem Ion Accelerator, BARC
- 500 KeV, 10KW DC Electron Accelerator
- 3MeV, 30KW DC Electron Accelerator
- 10MeV, 10KW RF LINAC Accelerator
- 400KeV, Neutron(14MeV) Generator
- 16.5MeV, Medical Cyclotron at Radiation Medicine Centre

Pelletron

The Pelletron Accelerator facility set up as a collaborative project between BARC and TIFR, has been a major centre for heavy ion accelerator based research in India since its commissioning in 1989. Several major experimental facilities have been established at this centre to pursue research in nuclear physics, atomic physics and interdisciplinary areas. While majority of users of this facility have been from the BARC and TIFR, it has been open to users from all over the country. These past years have been extremely productive resulting in ***48 Ph.D. theses*** and ***over 300 publications in refereed international journals*** including ***12 publications in Physical Review Letters***. The Pelletron accelerator is presently being augmented with a superconducting LINAC booster comprising of seven modules, which will increase the energy of the presently available beams. For example, it will be possible to get beams in A~60 region with E~5 MeV/A.

Schematic



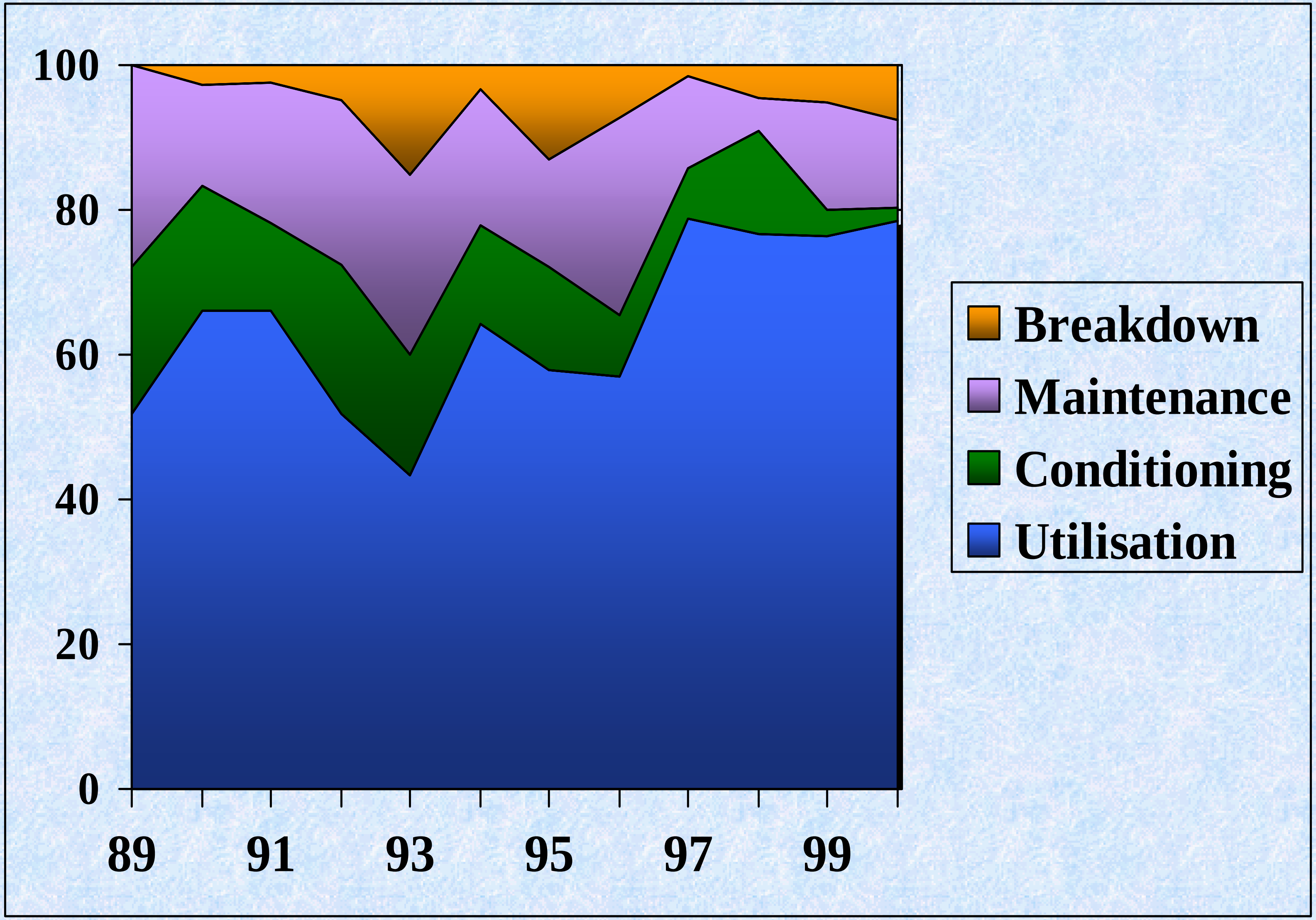
14UD PELLETRON ACCELERATOR
BARC-TIFR
INJECTOR MAGNET
40M
CHOPPER
ION SOURCE DECK
BUNCHER w1
BUNCHER w2
NEGATIVE ION SOURCE
35M
PROTON
ALPHA
LITHIUM
BORON
CARBON
NITROGEN
OXYGEN
FLUORINE
SODIUM
MAGNESIUM
ALUMINIUM
SILICON
SULPHUR
CHLORINE
POTASSIUM
CALCIUM
NICKEL
ARSENIC
SILVER
IODINE
MAX. TERMINAL VOLTAGE 15 MV
MAX. COLUMN VOLTAGE 14 MV
ENERGY RANGE FOR PROTON 8 MeV to 28 MeV
ENERGY RANGE FOR HEAVY IONS FOR CHARGE STATE = n 4(n+1) to 14(n+1) MeV
32M
Dead Section 1
21M
GVM
CARBON FOIL STRIPPER
CORONA PROBE
Terminal
SF6 PRESSURE 80 PSIG
SF6 WEIGHT 18,000 KG APPROX
TANK VOLUME 525 CUBIC METER
TANK WEIGHT 120,000 KG APPROX
Dead Section 2
12M
8M
DOUBLE SLIT
RECOIL MASS SPECTROMETER
ANALYZING SLIT
14° BENDING MAGNET
104° ACHROMATIC BEND
SWITCHING MAGNET
SWEEPER
ANALYZING MAGNET
SUPER BUNCHER
HELIUM REFRIGERATOR
MODULAR CRYOSTAT
LARGE AREA POSITION SENSITIVE IONISATION CHAMBER
LINAC HALL
BEAM HALL
FORMALLY INAUGURATED ON 30-DEC-1988
PROPOSED BEAM HALL
NOT TO SCALE
ONLY MAJOR DEVICES ARE SHOWN

Specification of Pelletron

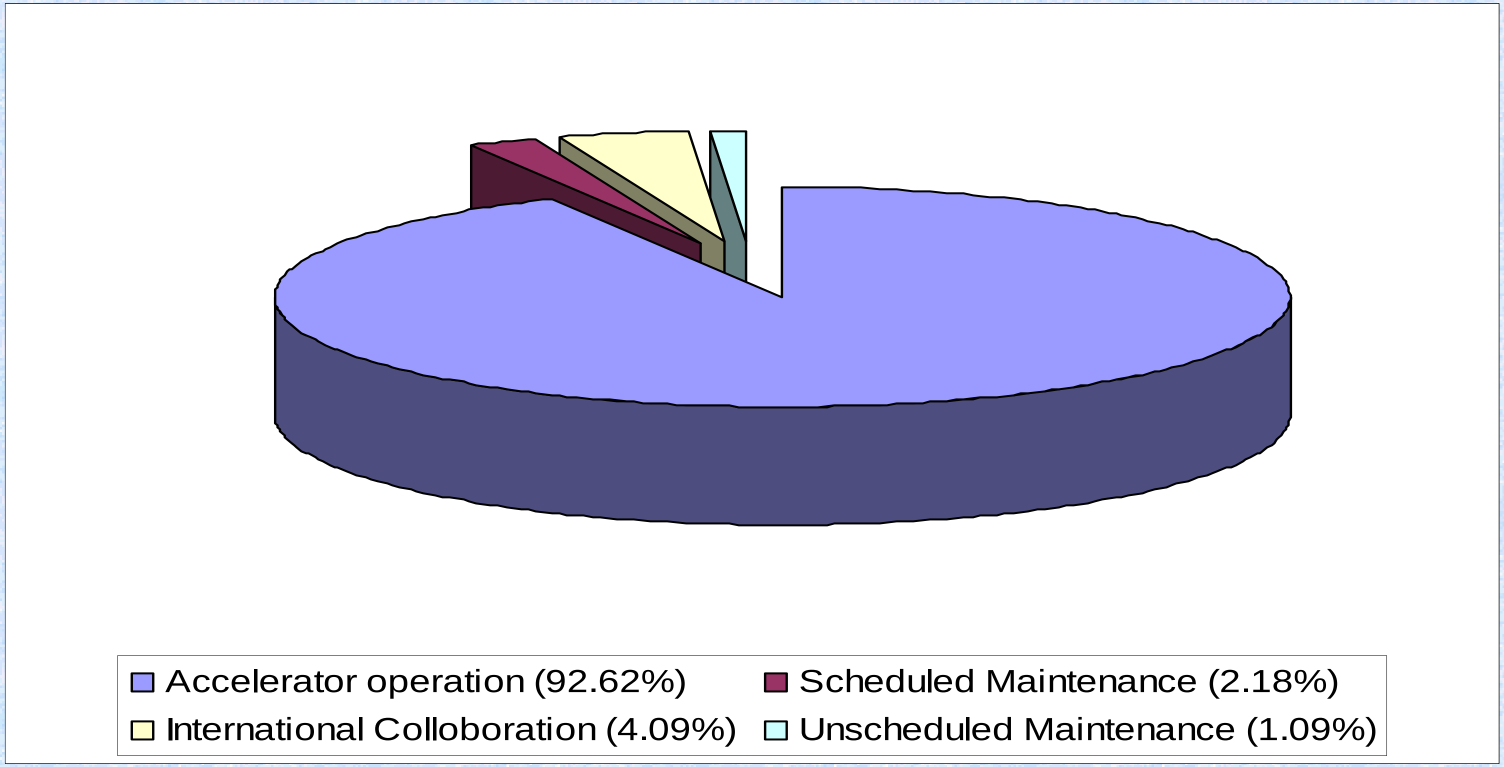
- Model 14 UD from NEC, USA
- Column voltage rating 15 MV
- Tube voltage rating 14 MV
- Voltage stability ± 2 kV
- Proton energy range 8 to 28 MeV
- Heavy ion energy range 4(n+1) to 14(n+1)MeV
- Test current values

Protons	3-5 µamps.
Alphas	2 µamps.
Heavy ions	100 ηA particle

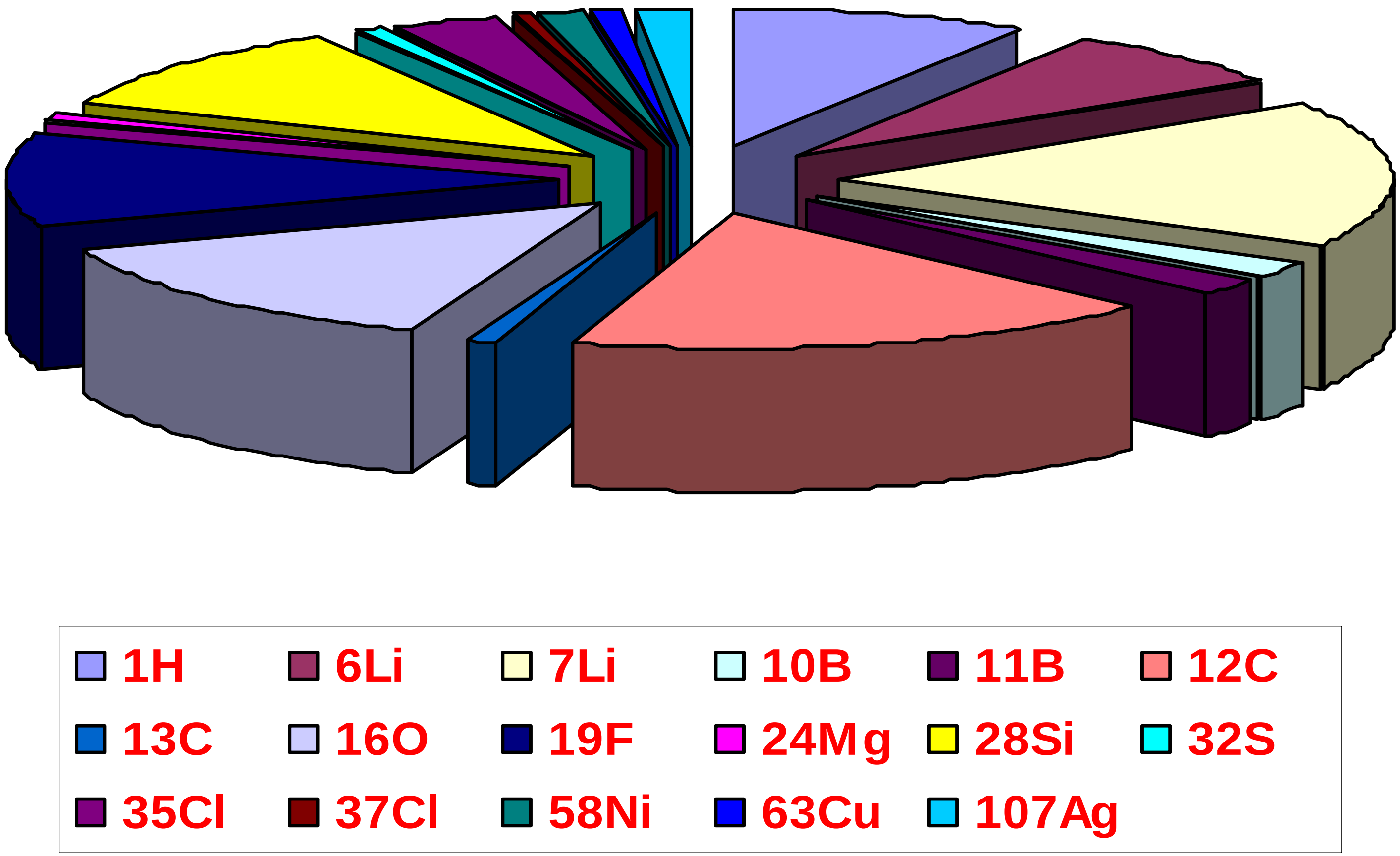
Performance



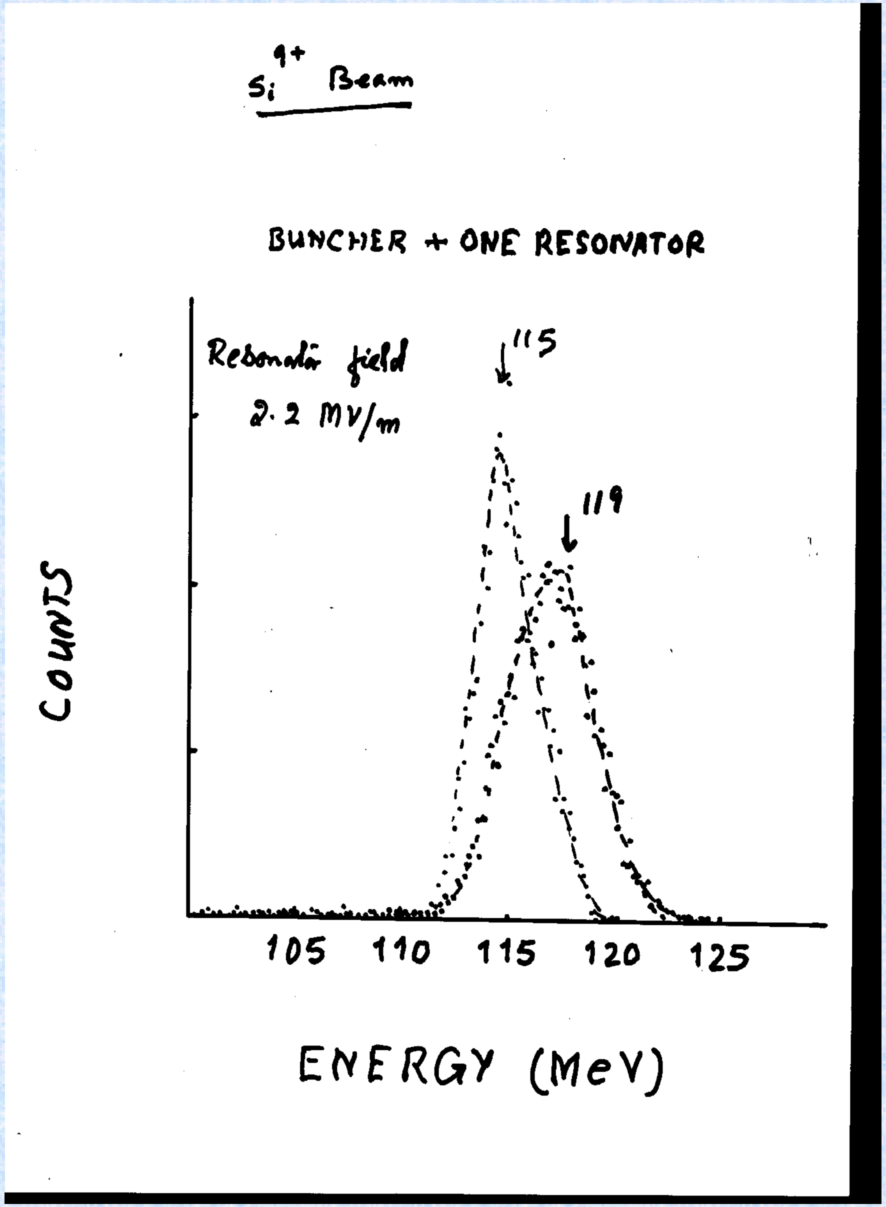
Performance 2004



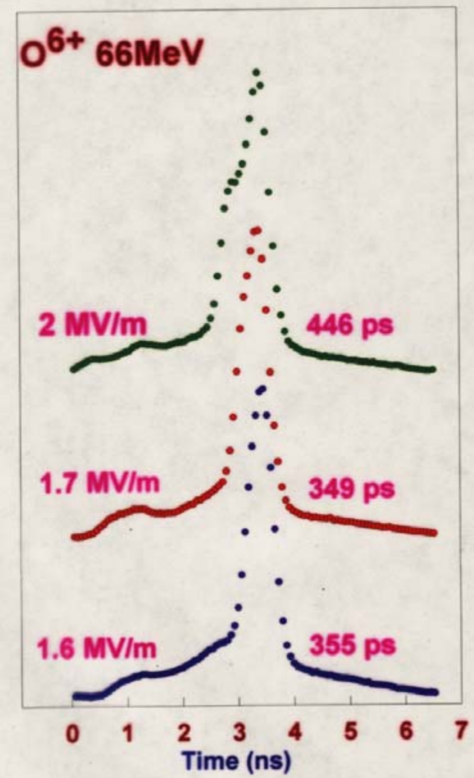
Ion Beam-2004



Beam Hall



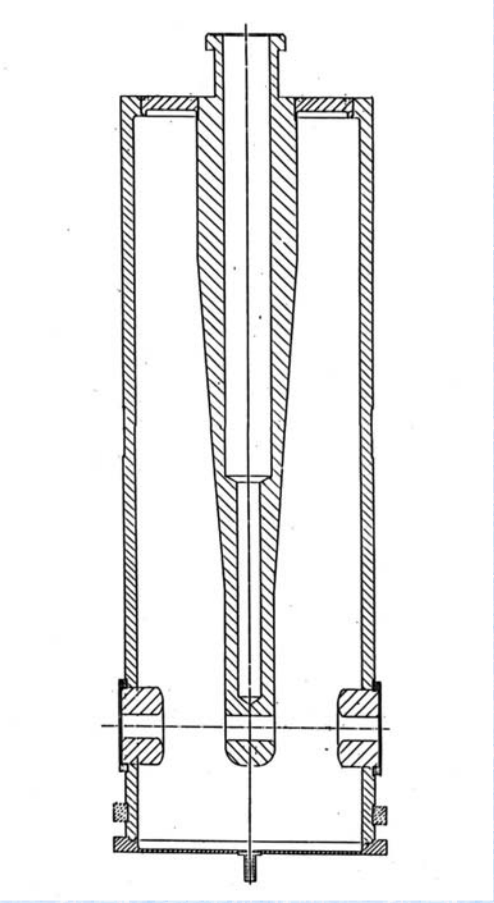
Si 9+ Beam
BUNCHER + ONE RESONATOR
Resonator field
2.2 MV/m
115
119
COUNTS
105
110
115
120
125
ENERGY (MeV)

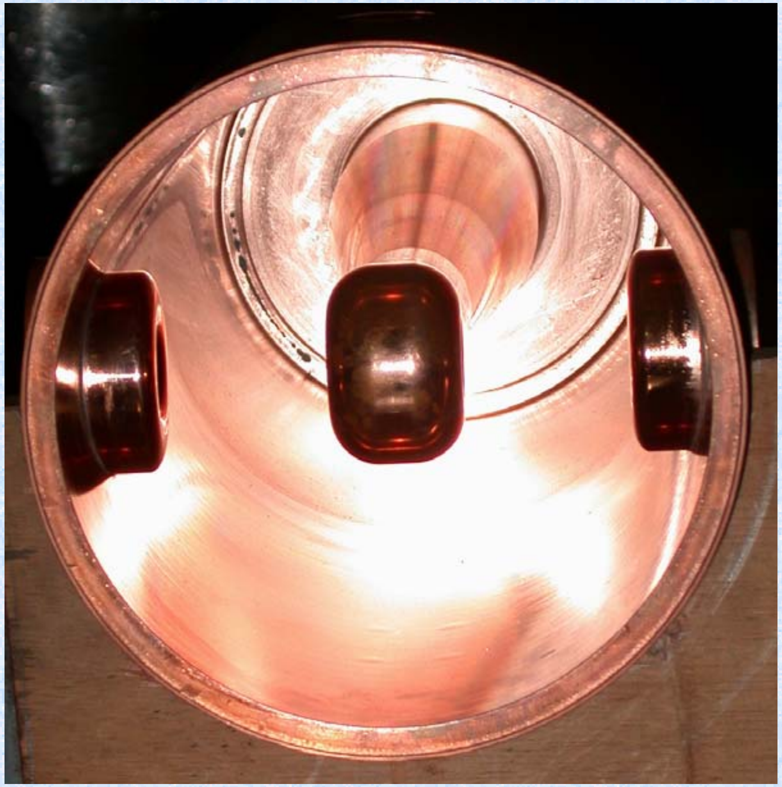


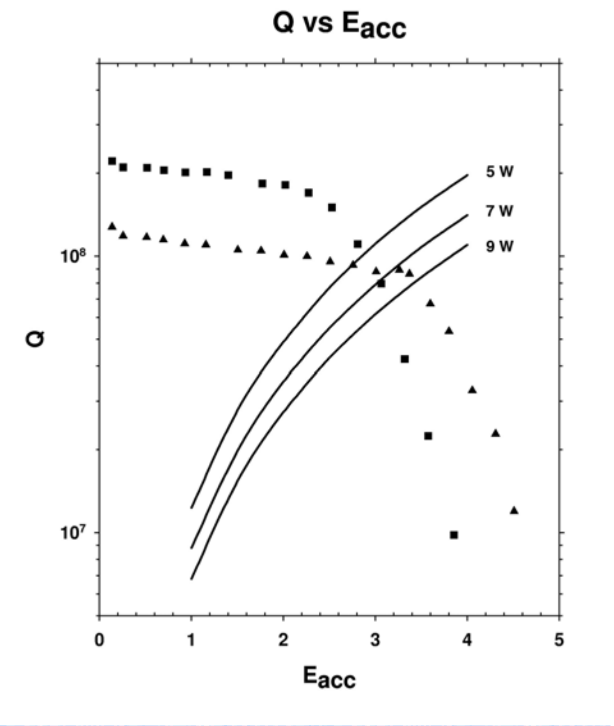
O^{6+} 66MeV
2 MV/m
446 ps
1.7 MV/m
349 ps
1.6 MV/m
355 ps
0 1 2 3 4 5 6 7
Time (ns)

Superconducting LINAC Booster for Pelletron

Quarter Wave Resonator







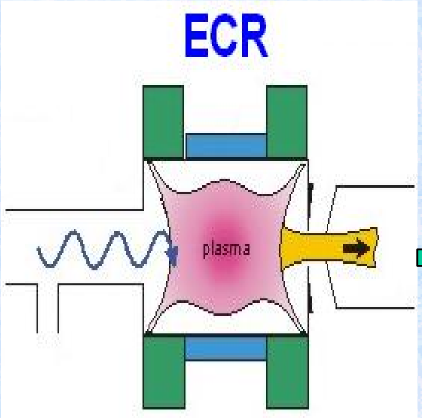
SUB SYSTEMS OF FOTIA

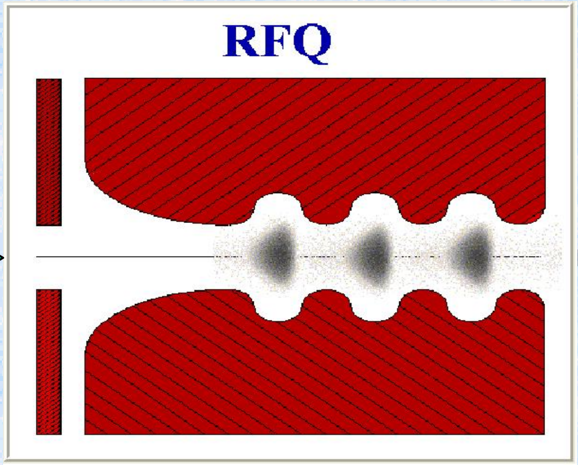
- **HIGH VOLTAGE GENERATOR**
- **MAGNETS**
- **HIGH VOLTAGE & HIGH CURRENT SUPPLIES**
- **ULTRA HIGH VACUUM**
- **COMPUTER CONTROL SYSTEM**
- **SF_6 GAS HANDLING SYSTEM ……….**

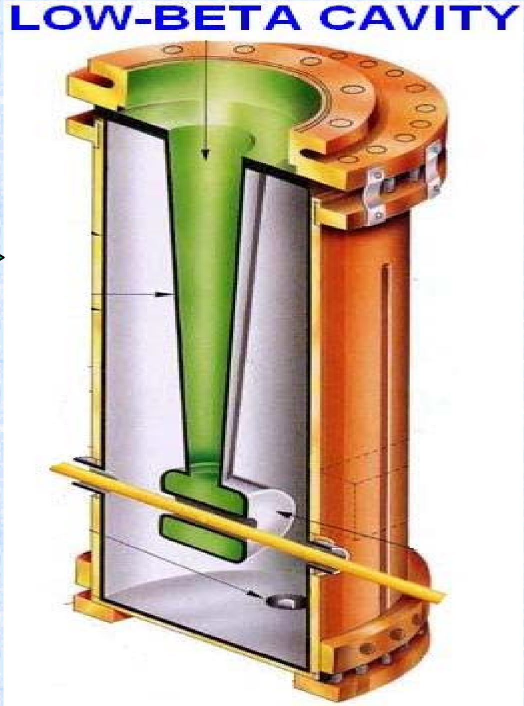
FOTIA

New Project

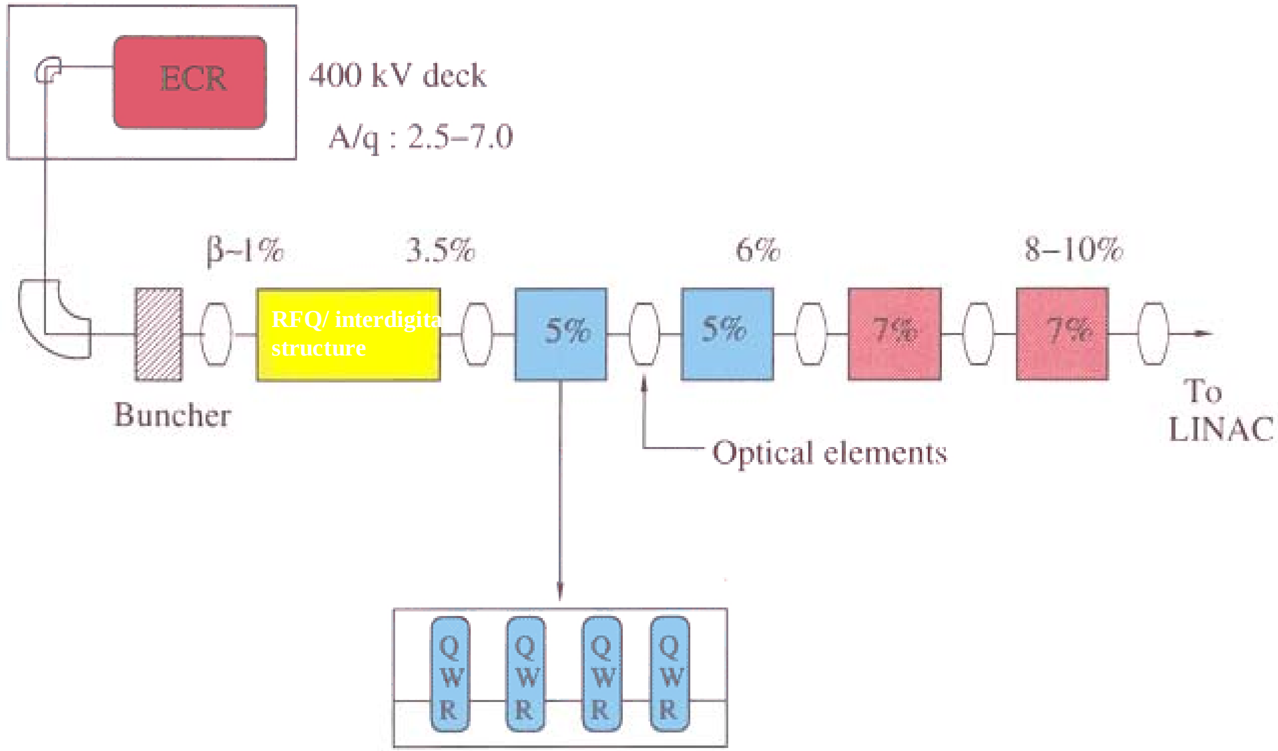
A positive ion injector consisting of an ECR Ion Source followed by a Radio Frequency Quadrupole and Superconducting Niobium Cavities will be developed for further enhancing the available beam species and energies.







Schematic layout of the injector system



Medical Cyclotron

Features of PETtrace® Medical Cyclotron

- Unshielded - placed in concrete vault with entry through a maze
- Fixed Beam Energy variable current
- 16.5 MeV (H-), 75 µA single beam, 40 µA dual beam
- 4 MeV (D-) 60 µA single beam, 30 µA dual beam
- Target: 6 Ports - liquid - 3, gas – 3
- Radionuclides that can be Produced - 18F, 11C, 13N & 15O

Accelerator Applications

- Accelerator Mass Spectrometry(AMS)
- Track-Etched Membrane
- High Current Proton Irradiation Facility
- Radiation Biology
- Material Science

➢Accelerator Mass Spectrometry(AMS)

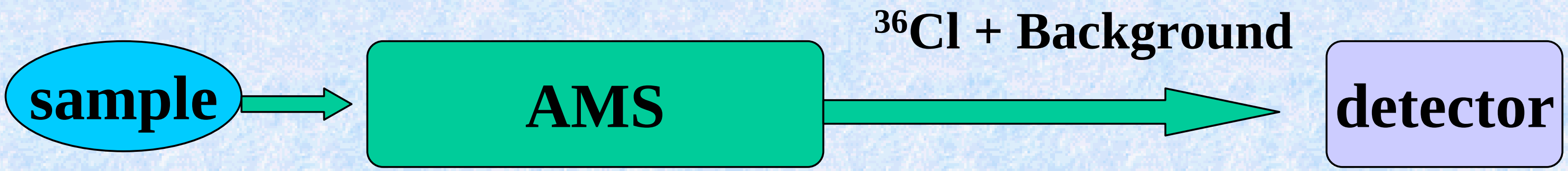
Accelerator Mass Spectrometry (AMS) overcame the fundamental limitations of conventional mass spectrometers to be able to measure isotope ratios as low as 10^{-15} on samples smaller than a milligram in about one hour. So it has become the technique of choice in recent years. Feasibility study to detect ^{3}He in He and ^{14}C in Carbon samples have been carried out. Our focus is on ^{36}Cl dating. We have built a multi anode gas detector for detection of ^{36}Cl in the presence of ^{36}S. At BARC, it is proposed to pursue program AMS program related to ^{26}Al, ^{36}Cl and ^{129}I.

Important Applications of ^{36}Cl

- measure the ages of ground water
- measure terrestrial ages of meteorites
- trace the movement of ground water
- trace the leakage of nuclear waste
- calibrate the cosmic ray flux using ice cores
- dating of exposure ages of rocks

Detection Of ^{36}Cl

$T_{1/2}$ = 301000years

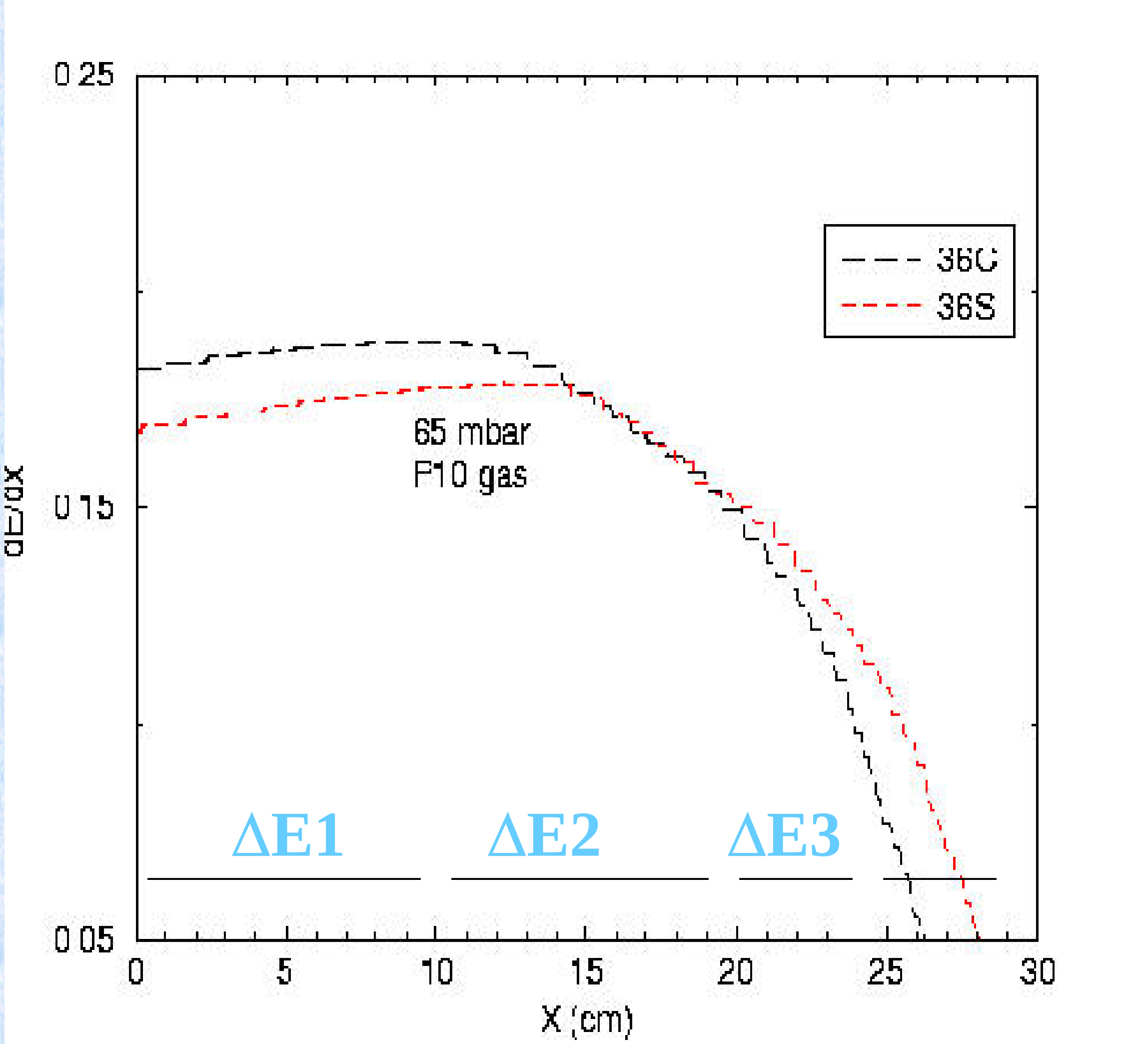


Accelerator based Mass Spectrometry (AMS) : ultra-sensitive means of counting individual atoms of long half life.

Background : Stable isotope of sulfur – ^{36}S

Detector : Multi-anode gas detector.
Length of ΔE anodes, matched according to the energy loss curves of ^{36}Cl and ^{36}S

Energy Loss Curves ^{36}Cl, ^{36}S

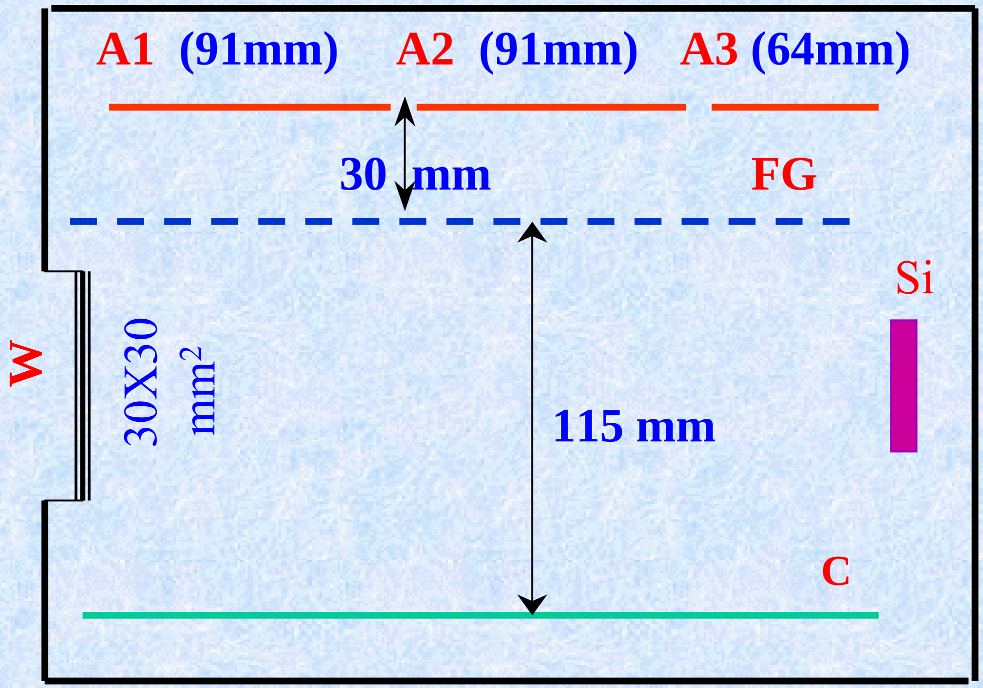


In ΔE1 & ΔE2, signal height of ^{36}Cl > ^{36}S

In ΔE3, Eres, signal height of ^{36}S > ^{36}Cl

^{36}S background can be reduced by Factor 10^4

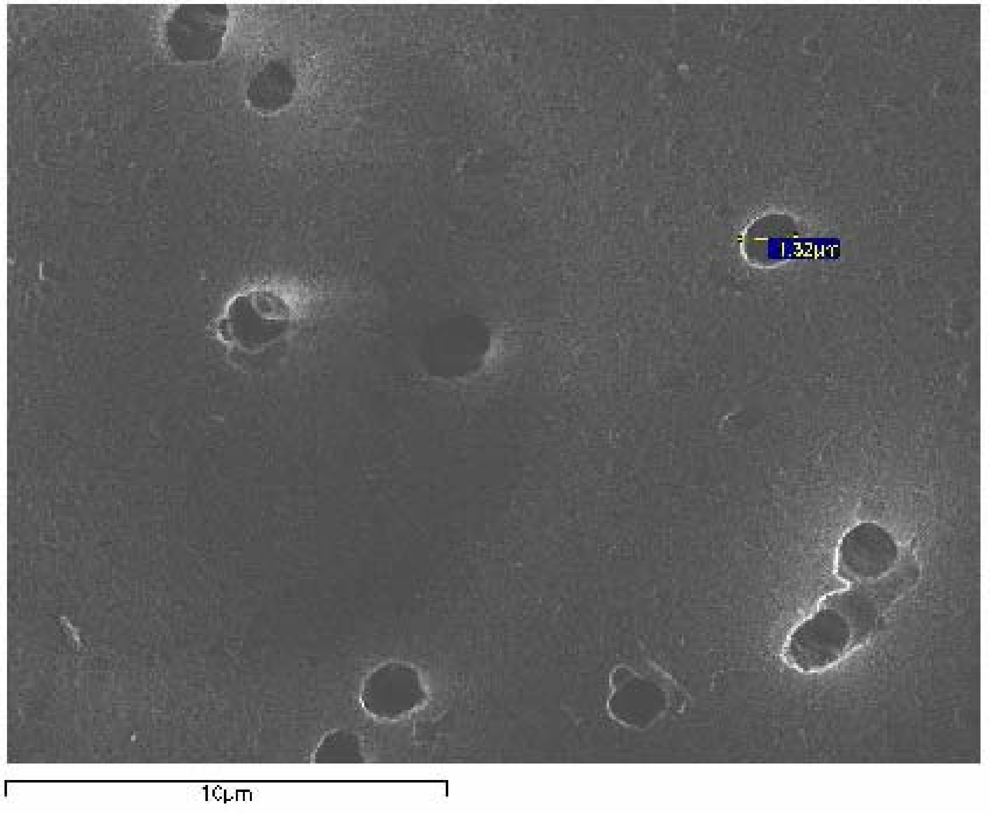
Hybrid Ionisation Chamber



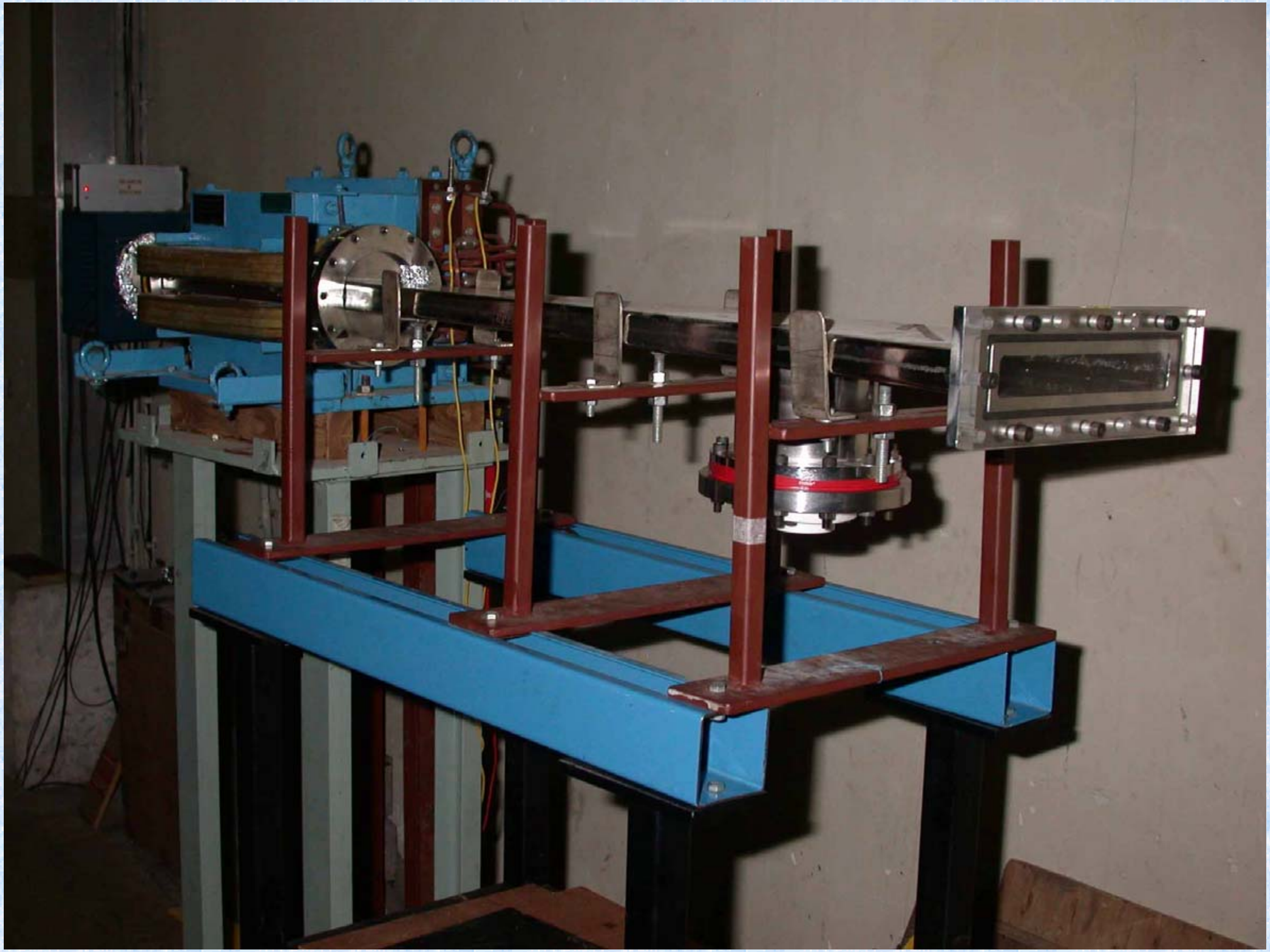
V_{anode} = +150 V
V_{grid} = +75 V
$V_{cathode}$ = -150 V
Gas : P10 (60 mbar)
Window : Mylar (3.5µm)
Si –Detector : 300µm

➢Track-Etched Membrane

The technology of production of track-etched membranes (TEMs) using accelerated heavy ions has been well established. A beam scanner magnet, vacuum chamber, power supply and rolling mechanism have been developed indigenously. The membranes produced from this facility using variety of heavy ion beams (Ni, Cl, Ag etc) are used in medical science, analytical science and micro-filtration. An SEM photograph of track-etched membrane produced from this facility is shown in Fig 4. Efforts are underway to produce large size Track-etched membranes.



Track Membrane Set-Up



A suitable arrangement has been made above analyzing magnet at Pelletron Accelerator facility for irradiation with proton beam from 4 MeV to 26 MeV up to μA current. This setup will be used for production of neutrons and for radiopharmaceutical applications. One of the important prerequisites for successful operation of a nuclear material handling facility is the effective radiation protection of its workers and the environment. Adequate radiation protection measures are followed at various stages of nuclear fuel cycle operations. With increased utilization of plutonium as a nuclear fuel in the nuclear energy program, the accurate monitoring of plutonium inhalation by radiation workers and the environmental materials has become very important. The most ideal tracer isotope is ^{236}Pu. It has a convenient half-life of 2.85 Years and alpha particle energies (5.73, 5.76 MeV) are well separated from those of reactor grade plutonium isotopes. The most promising reaction for the production of ^{236}Pu is by proton irradiation by ^{237}Np.

Material Science

Thin layer activation technique for study of wear and tear of machine parts has been standardized using the reaction $^{56}Fe(p,n)^{60}Co$. Proton beam at 16 MeV from Pelletron Accelerator was used for the production of ^{56}Co into a stack of stainless steel foils to generate the calibration curve. This facility has been used for preparation of radiotracers.

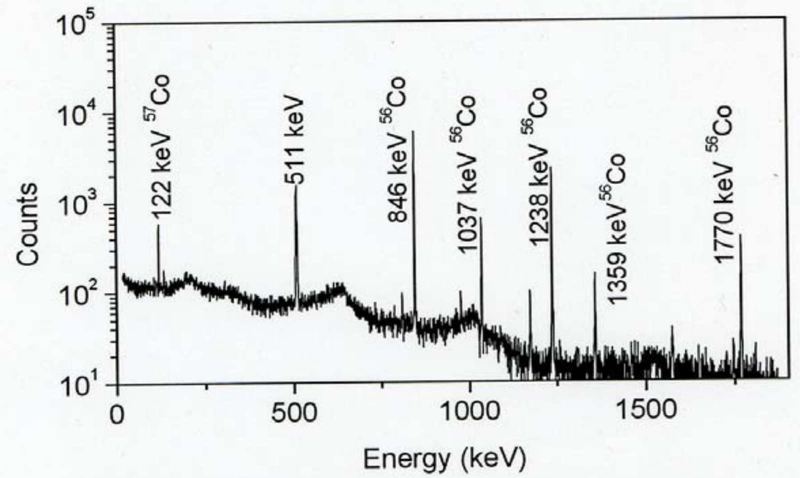


Figure 1. Gamma-ray spectrum of irradiated SS foil after seven days cooling time.

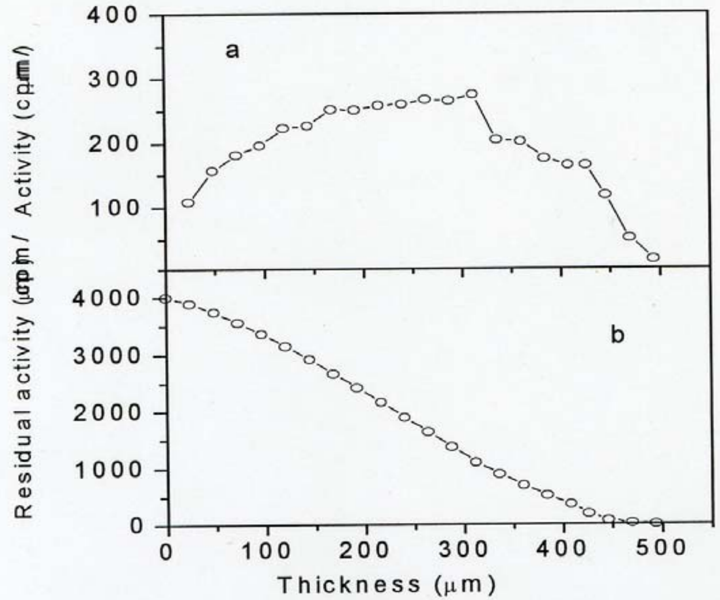
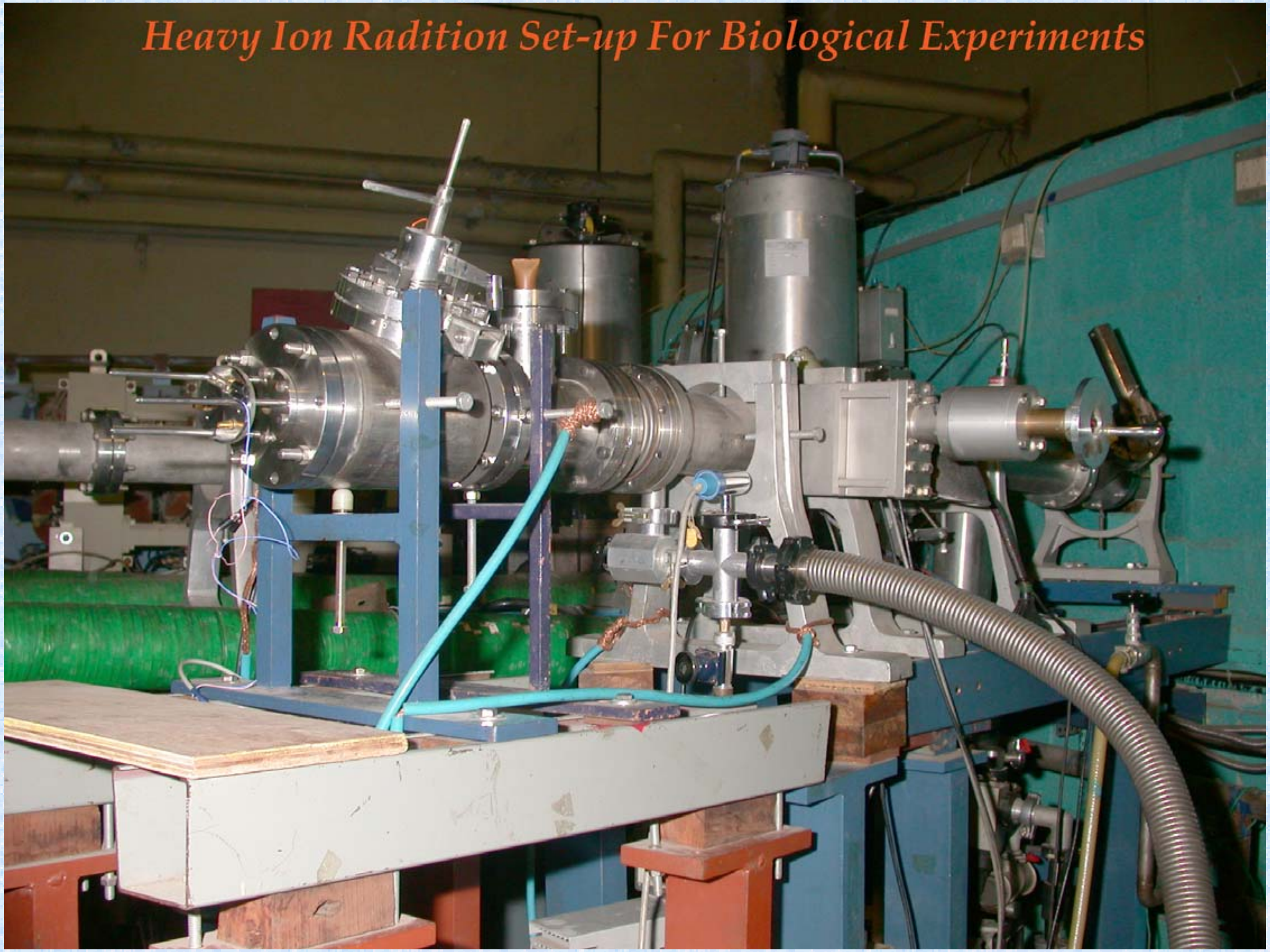


Figure 2. (a) Depth Profile of activity of ^{56}Co and (b) Calibration curve

Radiation Biology

A thin (20 μm) window of Ti has been placed at the end of beam line and proton beam of varying intensities 10^4 – 10^9 have been taken out in air for radiation biology programme.

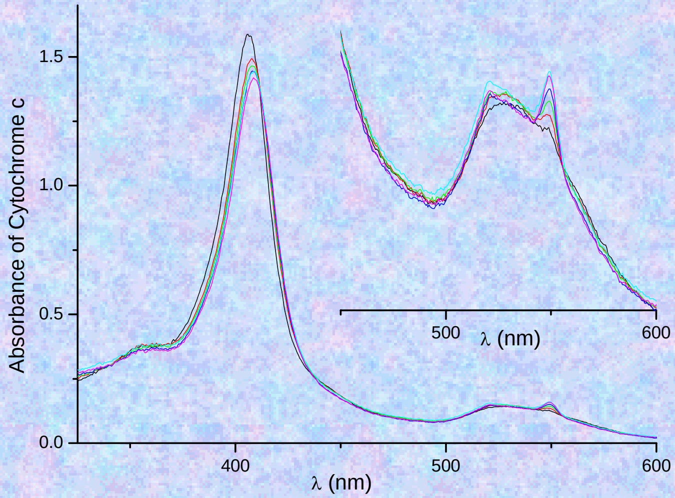


Effect of high-energy proton beams on metal containing proteins

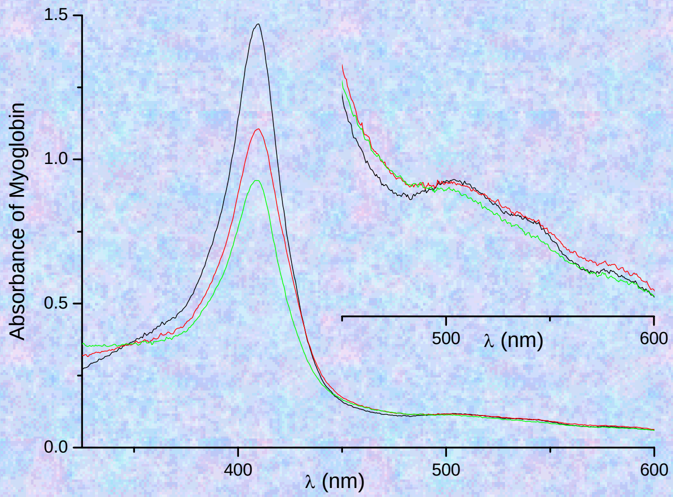
Proteins and enzymes with transition metal ions at the active centers play vital roles in life processes:

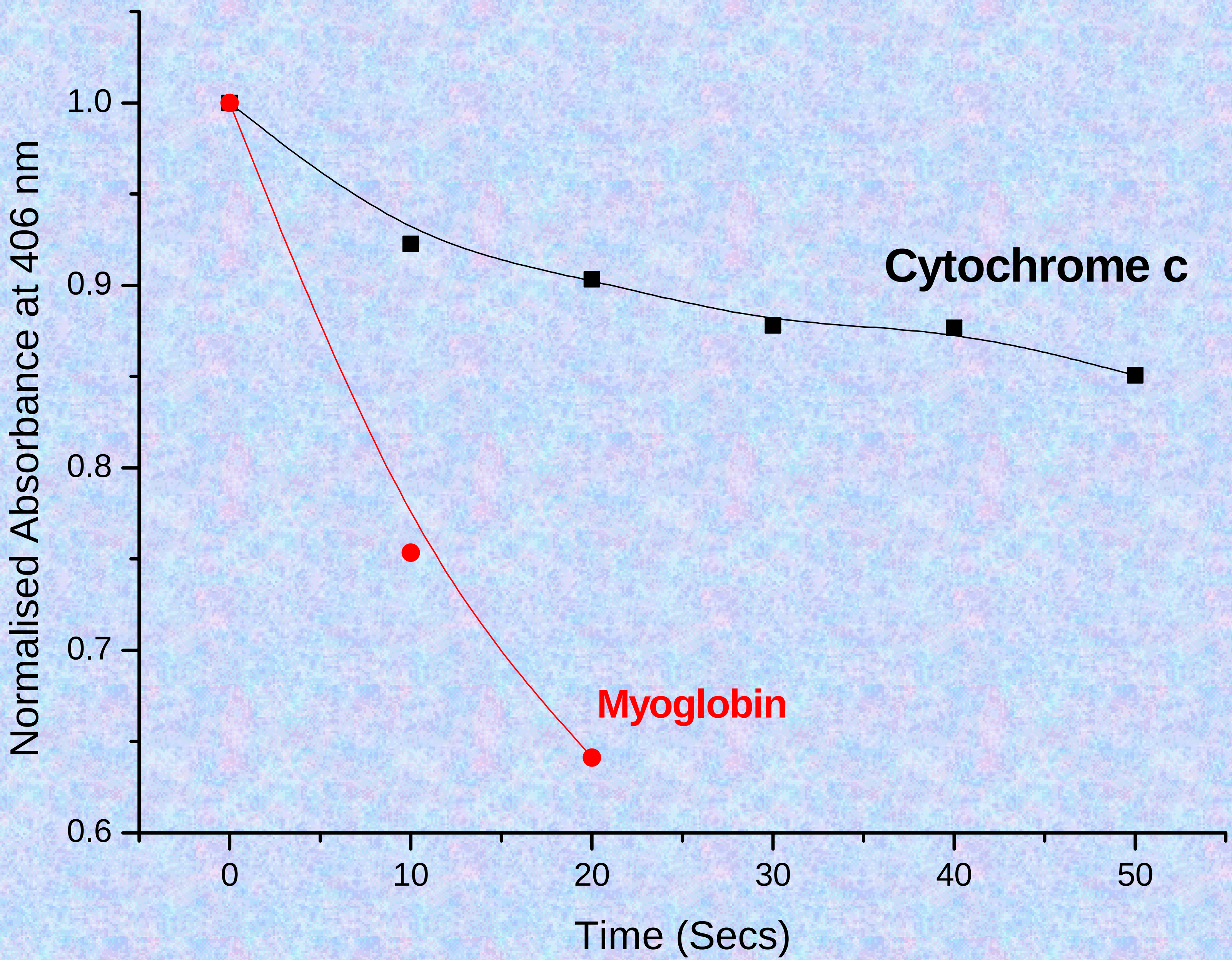
High energy radiations can have different types of effects on these vital biomolecules:

Iron Centre in Cytochrome c becomes Ferrous (Fe^{2+}) from ferric ion (Fe^{3+}) by the High Energy Proton Beams



Denaturation (Damage) of Myoglobin on irradiation by high energy proton beam





Normalised Absorbance at 406 nm
1.0
0.9
0.8
0.7
0.6
0
10
20
30
40
50
Time (Secs)
Cytochrome c
Myoglobin

Work carried out by Radiation Biology and Health Sciences Division, BARC

R C Chaubey *et al.* Genetic Toxicology & Chromosome Studies Section, RB&HSD.

Objective : Studies on the effect of proton irradiation on DNA damage in mouse peripheral blood leukocytes *in vitro* using Single Cell Gel Electrophoresis (Comet assay).

Sample : Mouse peripheral blood.

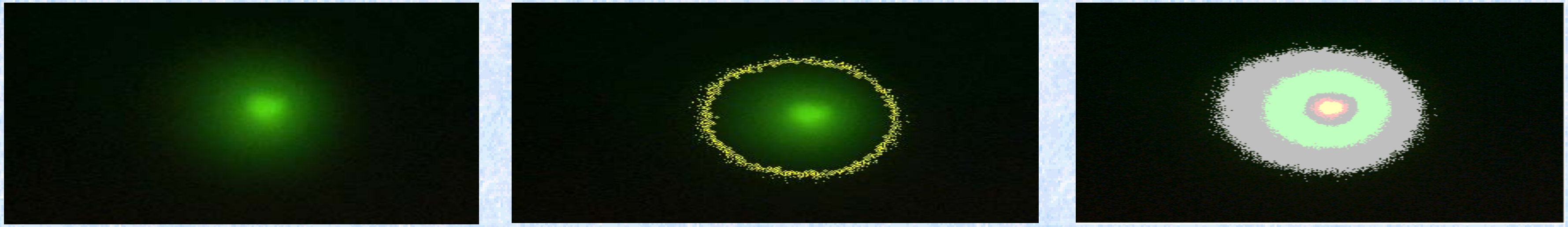
Irradiation : Whole blood samples embedded in agarose on fully frosted slides were exposed to 3.3 MeV proton, 2 nA in air.

Duration of exposure : 0, 1, 2, 4, 6 and 8 minutes at 0^0 C.

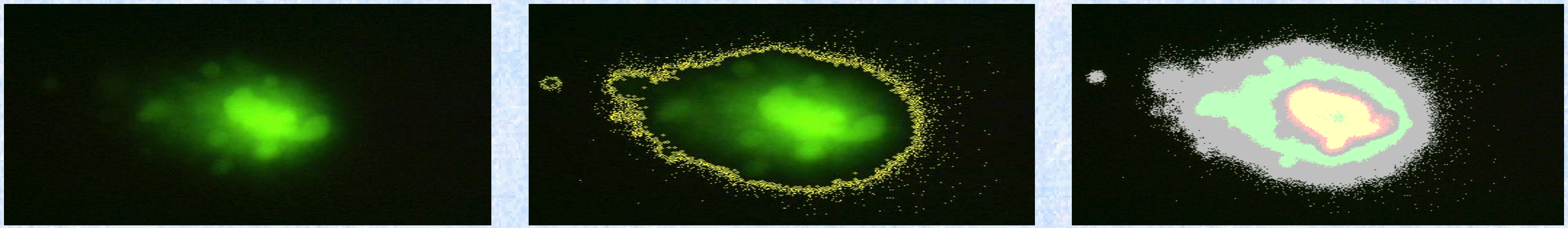
Genetic end point : DNA double strand breaks using neutral Comet assay

and analyzed using the Software ***SCGE-Pro*** developed in our Laboratory in

collaboration with Computer Division.

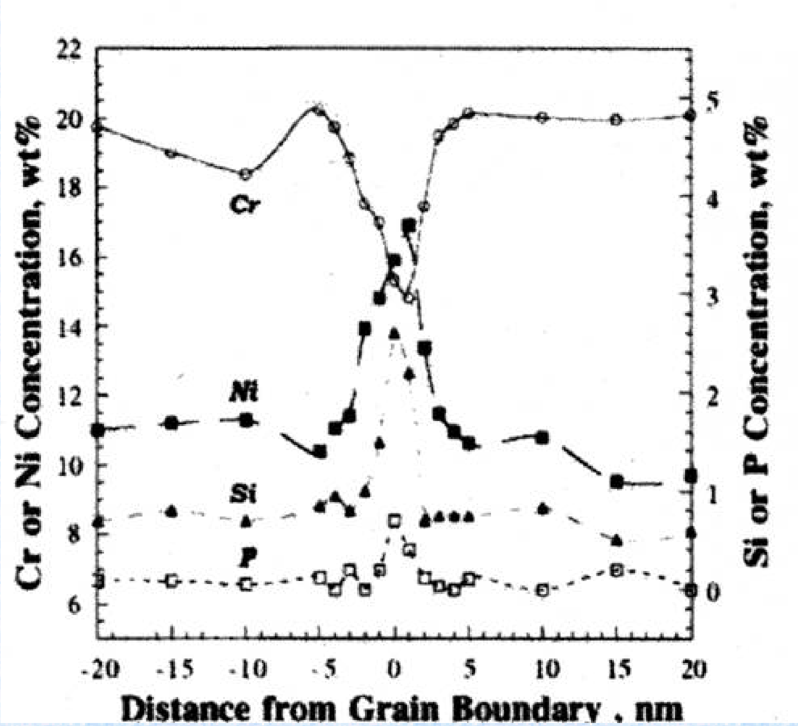


Undamaged mouse blood cell



Damaged mouse blood cell

Radiation Induced Segregation (RIS) in SS



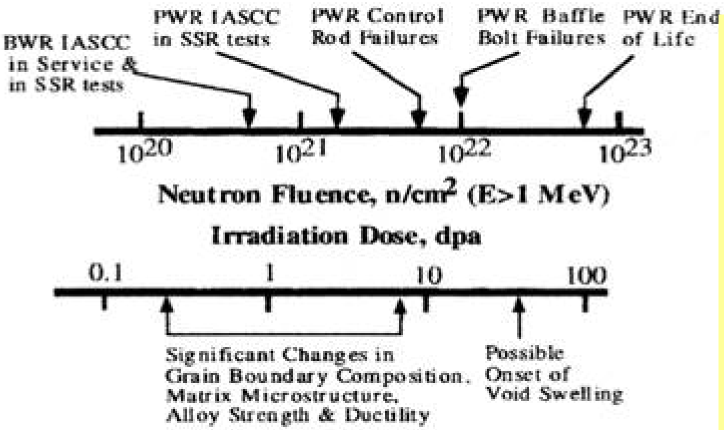
RIS :

- depletion of Cr at grain boundaries
- segregation of Ni at grain boundaries

(Inverse Kirkendall Effect)

- segregation of Si and P at grain boundaries

(Interstitial Association Mechanism)



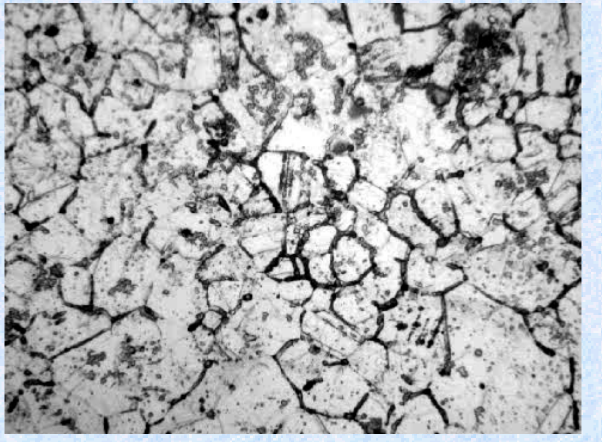
Irradiation Assisted Stress Corrosion Cracking

IASCC occurs in SS after RIS induced by neutron fluence of

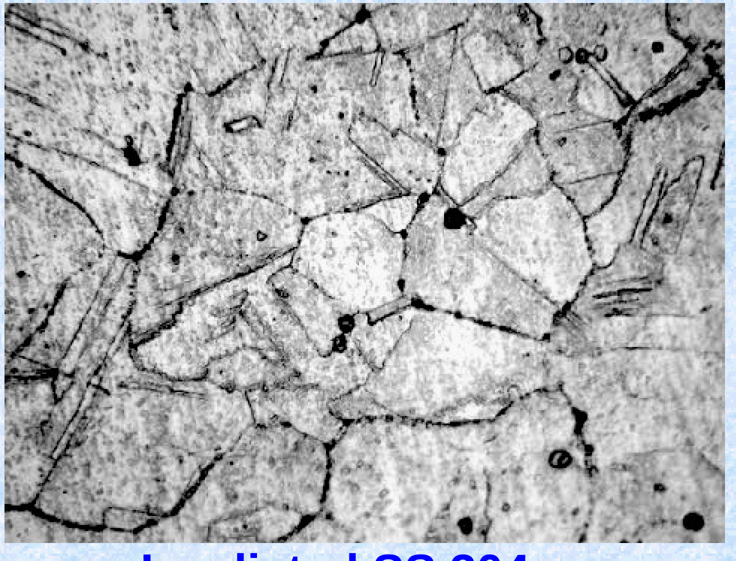
- 5×10^{20} n/cm^2 for SS 304
- 1×10^{21} n/cm^2 for SS 316

Irradiation damage measurement in irradiated SS 304: Proton irradiation in FOTIA and electrochemical measurement of irradiation damage

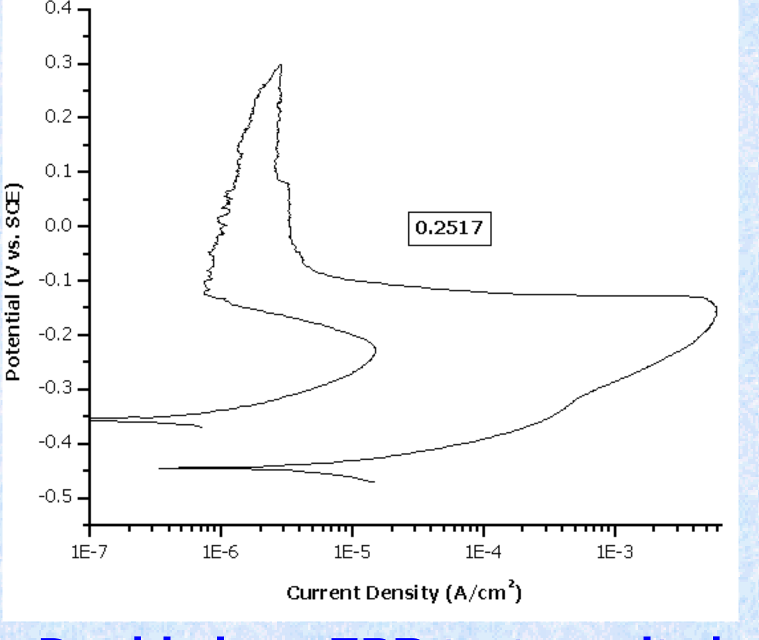
As received SS 304



Thermally sensitized SS 304 e.g. after welding



Irradiated SS 304:
4.2 x 10^{16} protons/cm^2
(0.2 dpa)



Double loop EPR test result showing reactivation from irradiated SS 304

Making SS Resistant to Irradiation Damage

APPROACHES TO BE FOLLOWED:

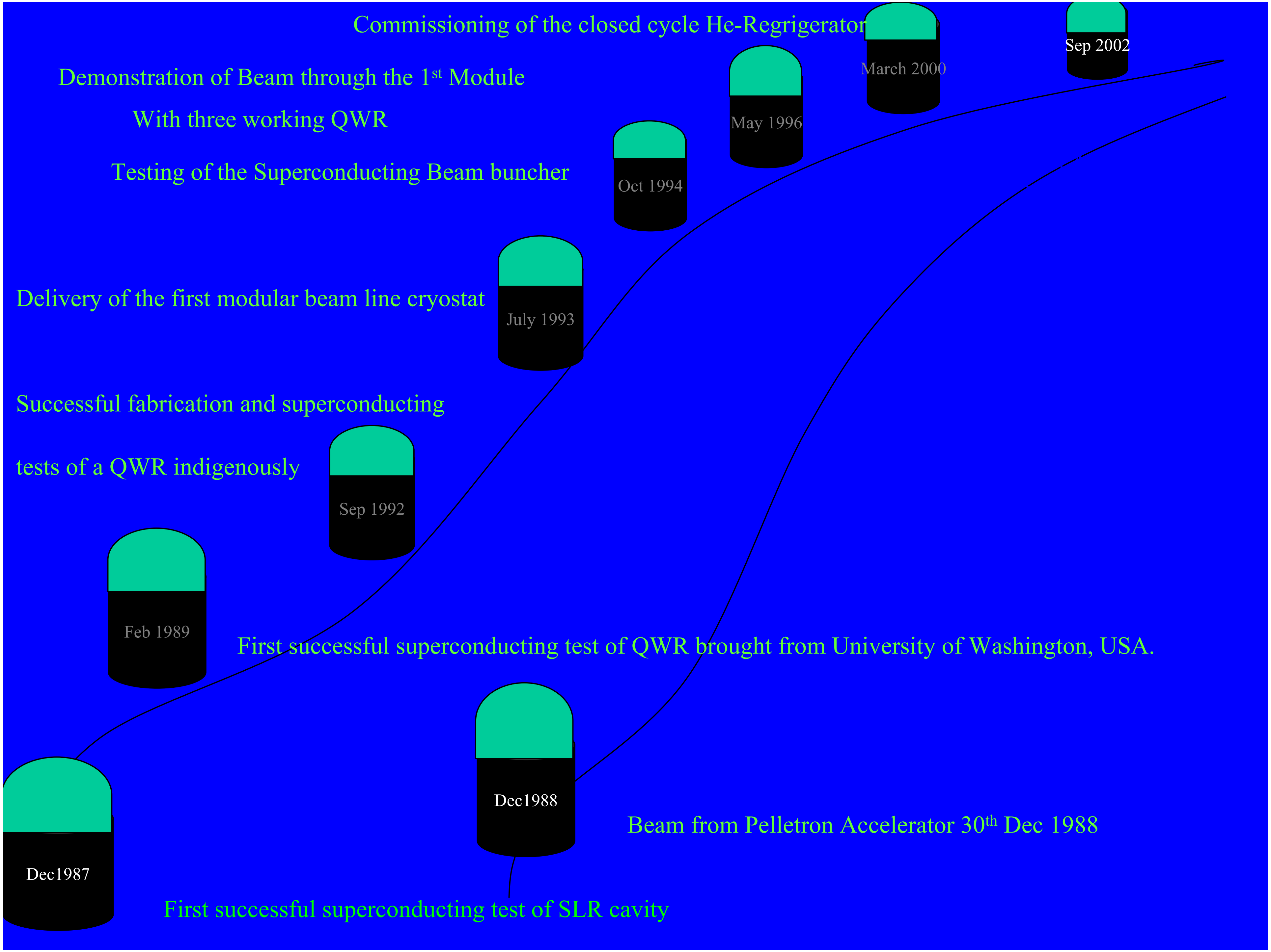
1. **Control of Grain Boundary Nature**
   - **Twin grain boundaries/Special grain boundaries**
   - **Random grain boundaries**

2. **Heat Treatment to create initial segregation of Cr. This would retard the onset of RIS**

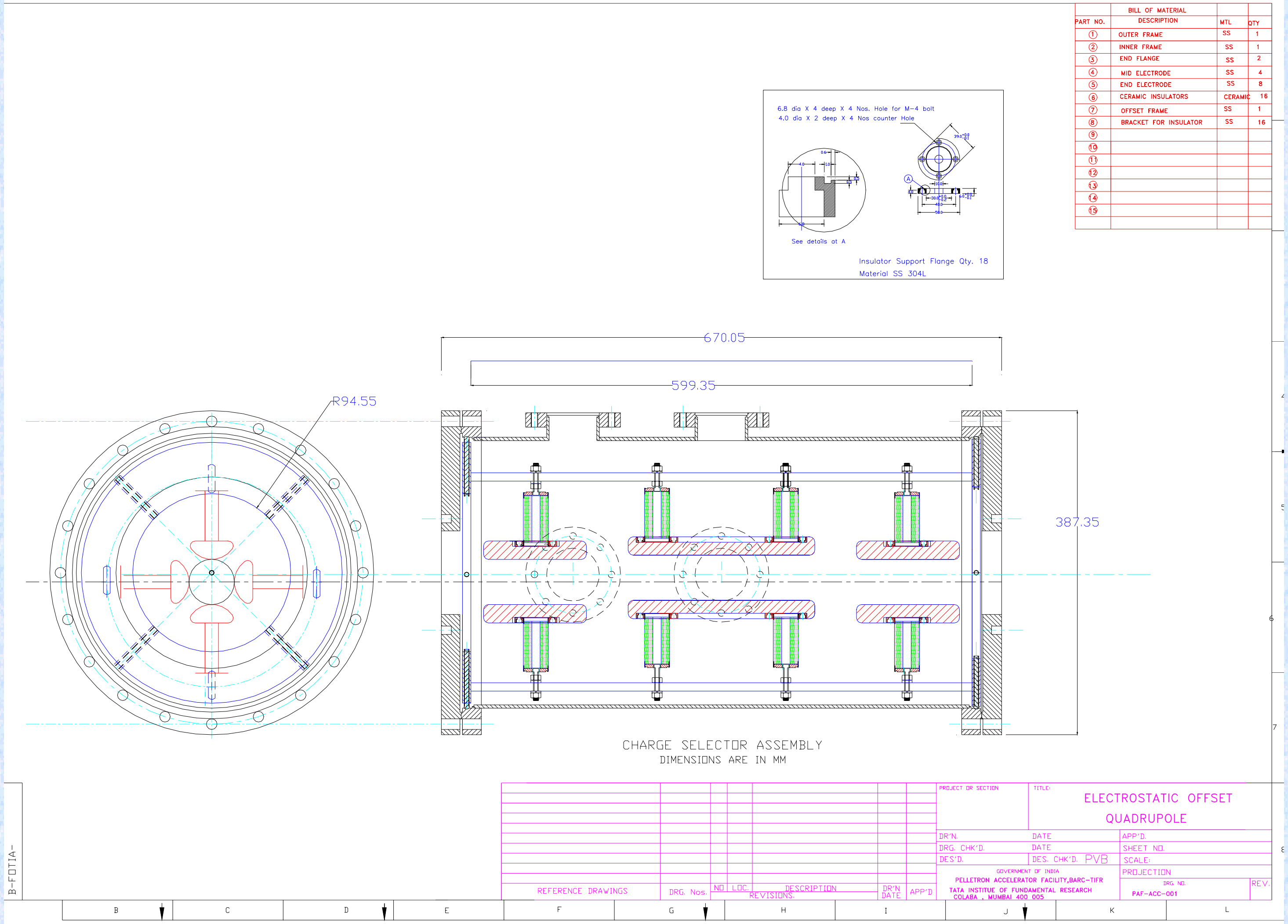
3. **Addition of <u>oversized</u> solute alloying elements like Ce, Hf, Zr, Gd, and Pt etc**

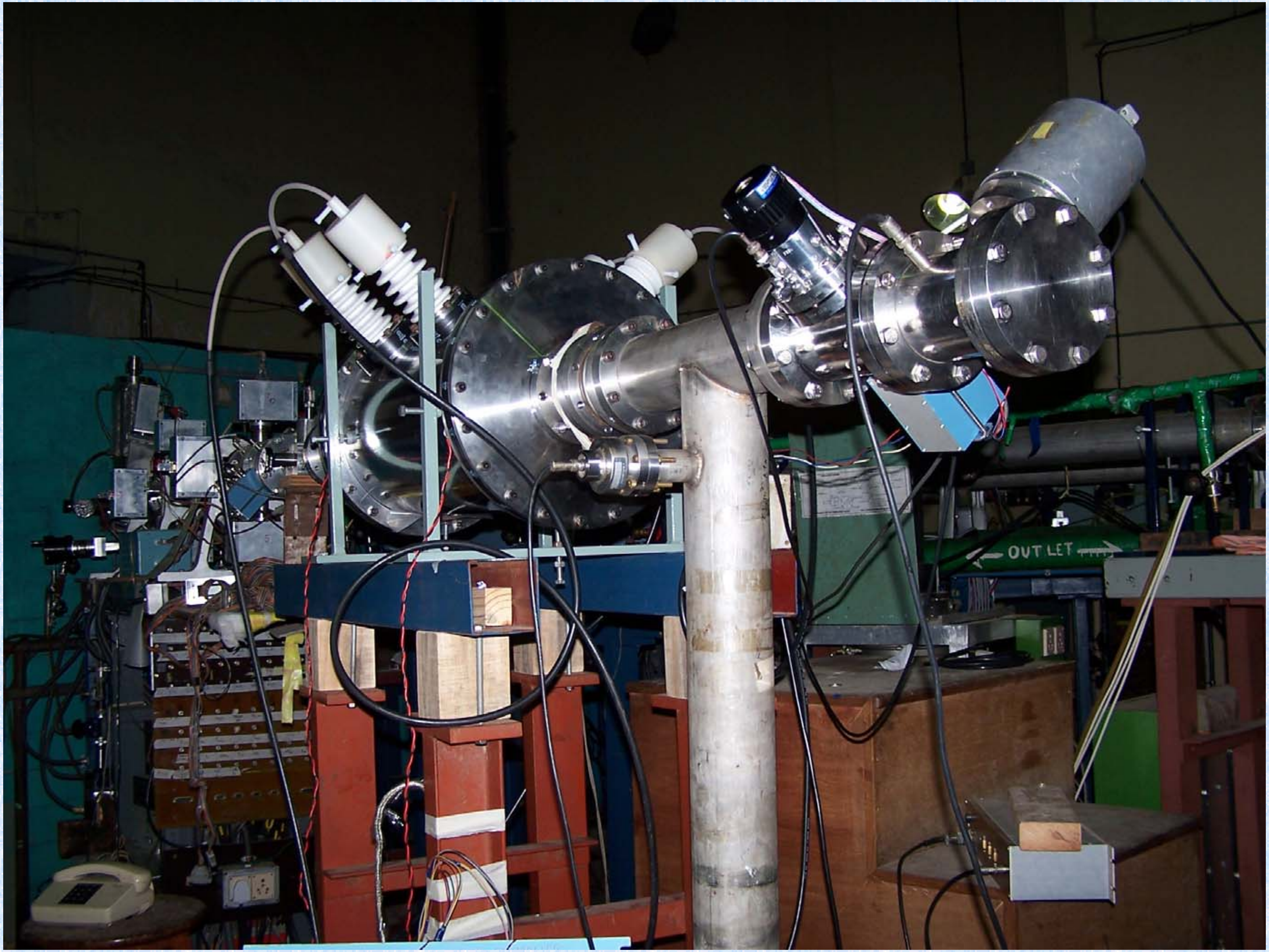
- **Neutron irradiation damage simulation by proton irradiation in FOTIA/Pelletron**
- **Measurement of RIS by electrochemical techniques**
- **Measurement of nature of grain boundaries by Orientation Imaging Microscopy**
- **Measurement at individual grain boundary or a selected region by micro-electrochemical techniques**

View of Tower and Lab- Block

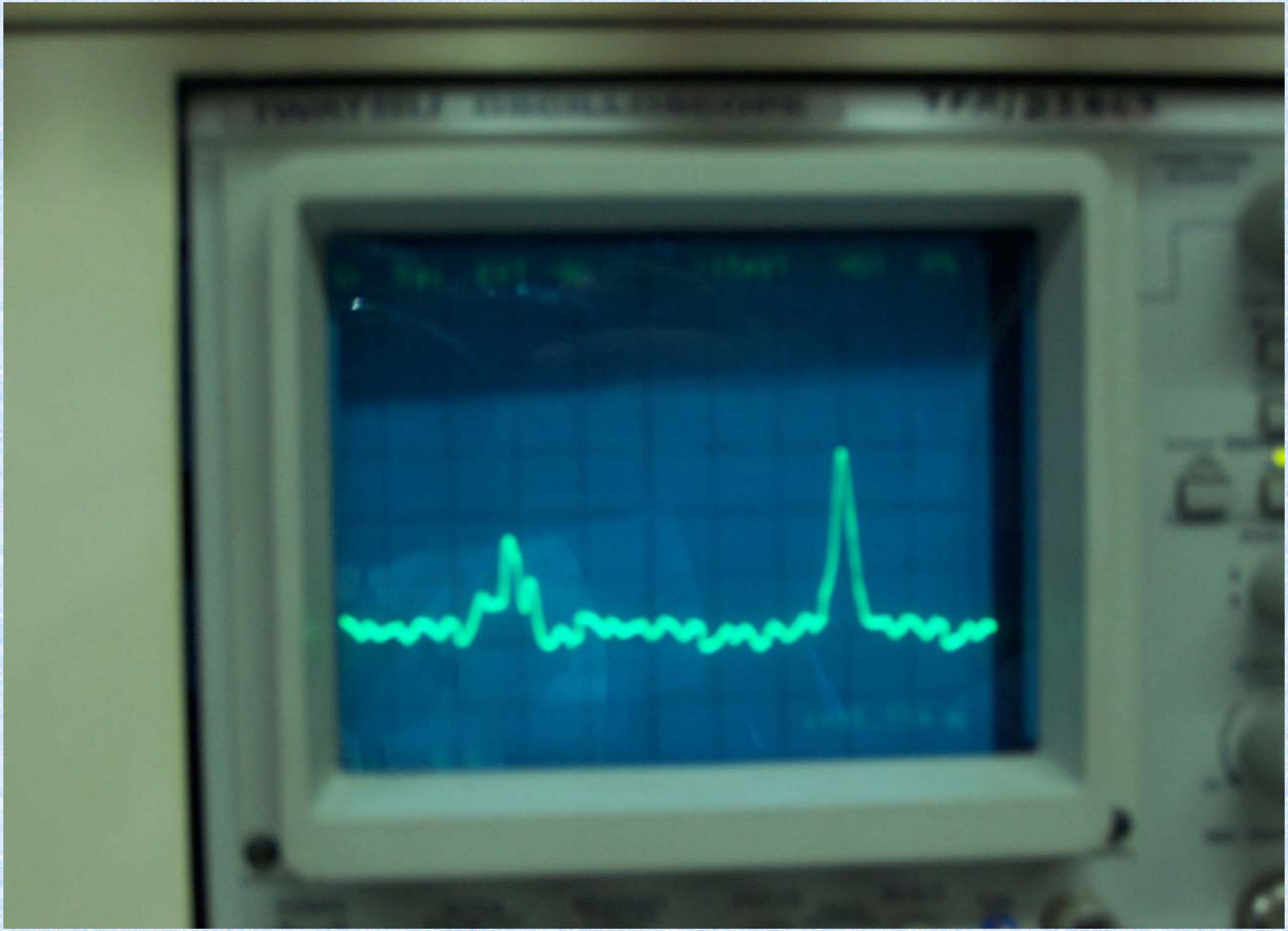

Commissioning of the closed cycle He-Regrigerator
Sep 2002
March 2000
Demonstration of Beam through the 1st Module
With three working QWR
May 1996
Testing of the Superconducting Beam buncher
Oct 1994
Delivery of the first modular beam line cryostat
July 1993
Successful fabrication and superconducting
tests of a QWR indigenously
Sep 1992
Feb 1989
First successful superconducting test of QWR brought from University of Washington, USA.
Dec1988
Beam from Pelletron Accelerator 30th Dec 1988
Dec1987
First successful superconducting test of SLR cavity

Offset Quadrupole

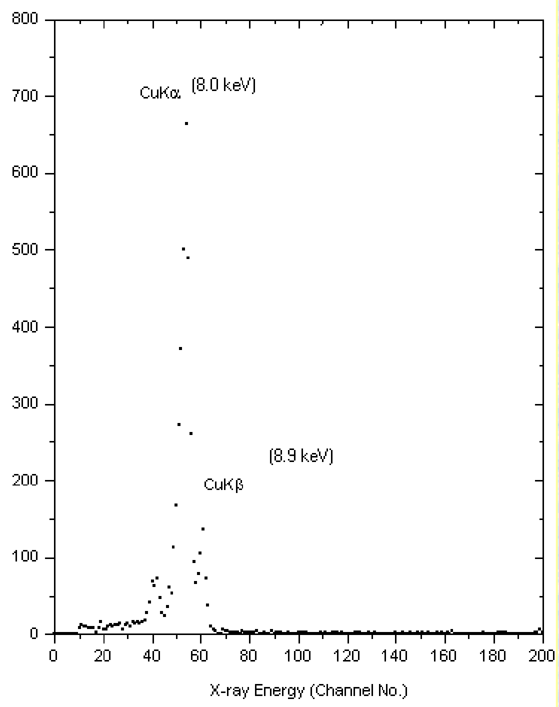



OUT LET

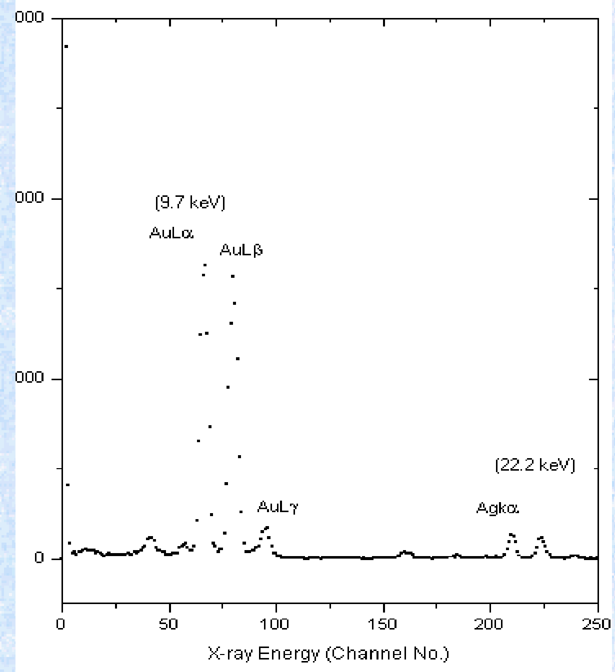
Charge Selector



- AN OVER VIEW OF EXPERIMENTAL SETUP FOR PIXE & RADIATION BIOLOGY STUDIES, SETUP ON 45^0 LINE AT FOTIA FACILITY.
- BEAM CAN BE EXTRACTED IN AIR FROM 20μ THICK TITANIUM WINDOW
- Si(Li) DETECTOR HOUSING WITH MILAR WINDOW.
- LOADLOCK MECHNISM FOR ONLINE TRANSFER OF TARGETS



PIXE X-ray spectrum of Cu solution



PIXE STUDIES

Proton Induced X-ray Emission An ideal technique for material characterization has been set up at FOTIA. A separate beam line at 45° port in which a dedicated PIXE chamber has been installed. PIXE studies on gold standards were carried out using protons of energy 3.3 MeV. Caritage value of gold standards were obtained which agree well with the certified values.

- Single element standard solutions (100 μg/ml) for low Z elements such as Cr, Mn, Fe, Co, Cu and Zn were analyzed by PIXE. Well resolved α and β components of the X-rays were seen with detection limits in the range of 0.8- 4 μg/g

BEAM LINES

1. Nuclear Physics
2. Accelerator Mass Spectrometry (AMS)
3. Trace Element Analysis (RBS, PIXE, etc.)
4. Atomic Physics (BFS)
5. Irradiation line