Accelerators for

AB – NCT

Maud BAYLAC, LPSC

AB-NCT Workshop, October 15-16, 2015, LPSC-Grenoble (France)

Context

- Neutron Capture Therapy requires an intense flux of epithermal neutrons
  - $n + {}^{10}B \rightarrow \alpha + {}^{7}Li$
- Neutrons are produced by nuclear reactions, before moderation
  - $p + {}^{7}Li \rightarrow n + {}^{7}Be$
  - $d + {}^{9}Be \rightarrow n + {}^{10}B$
- Required energy corresponds to process optimum
  - deutons: 1.5 MeV
  - protons : 2.5 MeV
- Intensity requirement for acceptable treatment duration
  - 10 mA-20 mA
- Accelerator requirements of NCT = Accelerator requirements of BNCT

Possible accelerators

- 3 types of accelerators considered to produce beams for AB-NCT
  - Cyclotrons
  - Electrostatic machines
  - Linear accelerators : Radiofrequency quadrupole (RFQ)

- Most inputs from *Workshop of Accelerator Based Neutron Production ABNP*, held in Legnaro (Italy), April 2014

AB-BNCT projects worldwide

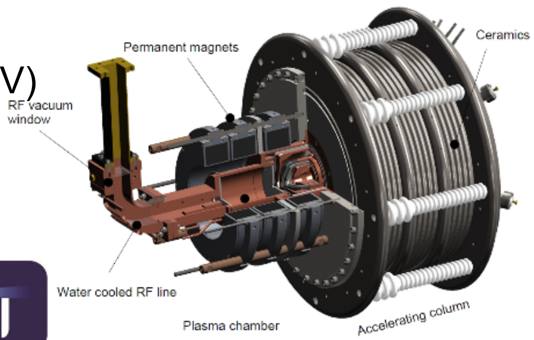
- Major AB-BNCT projects under development or in operation
  - Kyoto university (Japan) : 30 MeV, 1 mA, cyclotron
  - Birmingham university (UK) : 3 MeV, 5 mA, dynamitron
  - Budker institute (Russia) : 2.5 MeV, 10 mA, tandem
  - Argentina, commission atomic energy : 2.4 MeV, 30 mA, tandem
  - Legnaro (INFN) : 5 MV, 30 mA, RFQ

Ion sources (ECRIS)

- Specifications : H or D, with 10-20 mA
- Positive ions :
  - Industrial solutions are available :

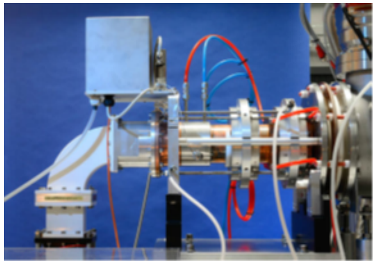
40mA H+ @ 60 kV
(up to 100 mA @ 100 kV)

1200 W - 2.45 GHz



SILHI

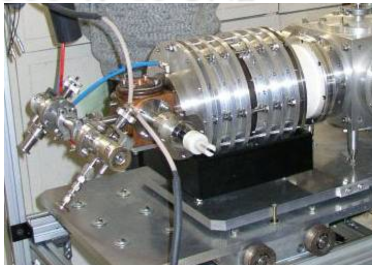
MONOGAM M1000 by Pantechnik
(used for MYRRHA project)

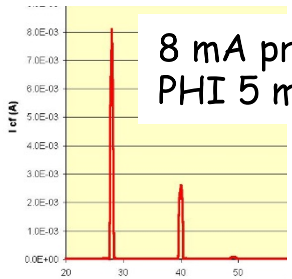


15 mA H+@ 30 keV

  - Many lab solutions also exist:

LPSC (2002) MicroPHOENIX for SPIRAL2,
300 W-10 GHz

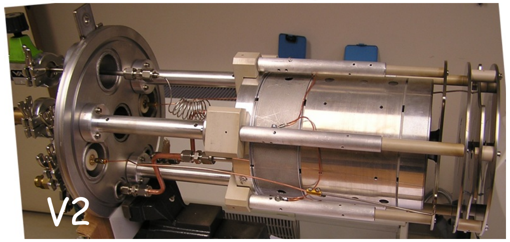




8 mA protons
PHI 5 mm @ 40 kV

R&D for compact, low power, intense proton sources

SUPERCOMIC
80 W - 5.8 GHz
2 mA protons
PHI 6 mm @ 40 kV

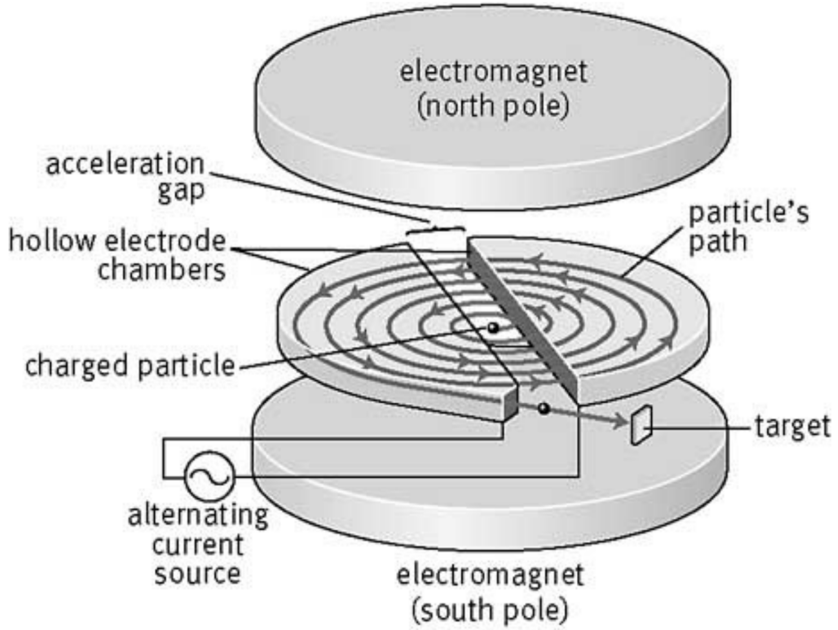


- Negative ions :
  - Currents above 10 mA seem achievable, but complicated (reliability?)

From T. Lamy, LPSC

Cyclotrons

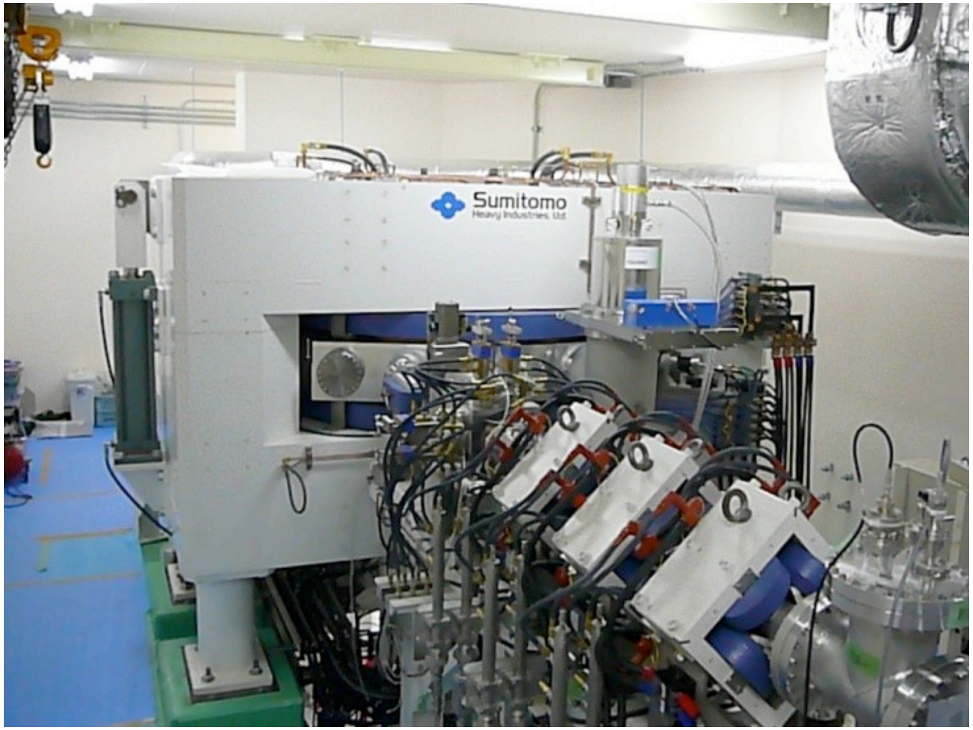
- Acceleration in gaps between 2 D-shaped magnetic field region to guide the particles with synchronization particle orbits and RF field
- Typical energies : few MeV and higher ➔ main drawback
- Current limitation : few mA at most
- Commonly produced by industrial companies
- Used in hospitals for hadrontherapy and isotope production



Proton therapy (Sumitomo Heavy Industries)

Kyoto university (Japan)

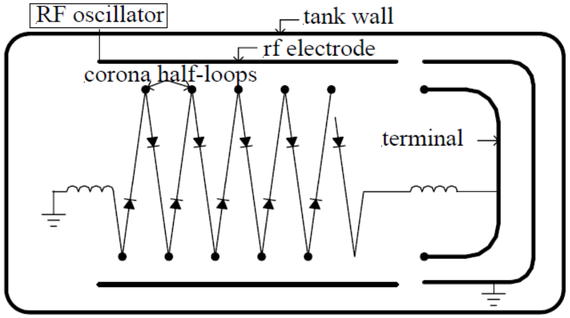
- Cyclotron HM-30 : 30 MeV, 1 mA proton beam (Sumimoto Heavy Industry)
- Epithermal neutron flux of 1.2 x10^9 n.cm^{-2}.s^{-1} with target and moderator
- Cyclotron installed in Innovation Research Laboratory Medical Area (2008)
- Test of neutron production started in March 2009
- After the physical and biological irradiation using small animals and cells, the first clinical trial in the world was started on October 2012



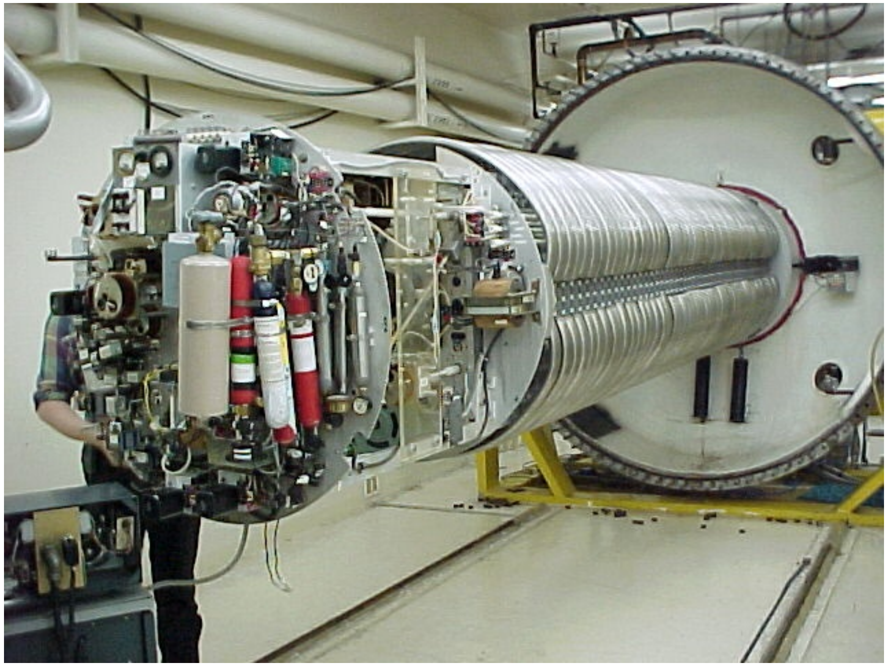
H. Tanaka et al. Appl. Radiat. Isot. 69(2011) 1631.

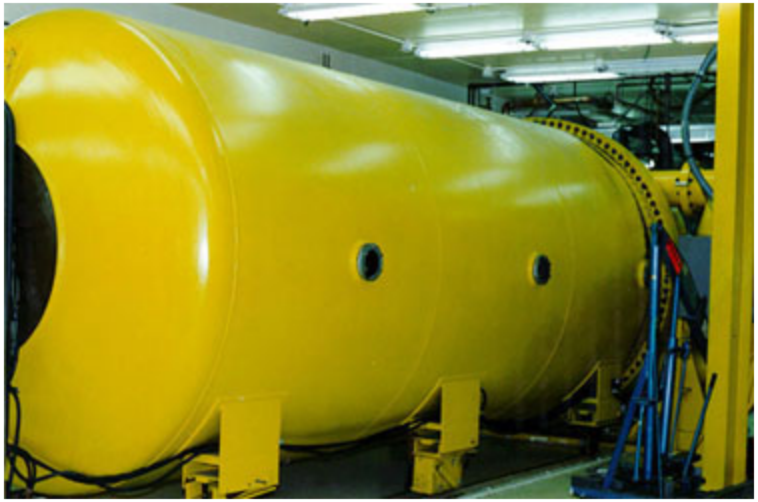
Electrostatic machines - 1

- Dynamitron : Cockcroft-Walton type
- Single-ended machine with ion source (compact) at HV terminal within tank
- HV generated through rectified RF power
- Typical operating voltages: few MV
- Typical intensities : few mA -tens of mA



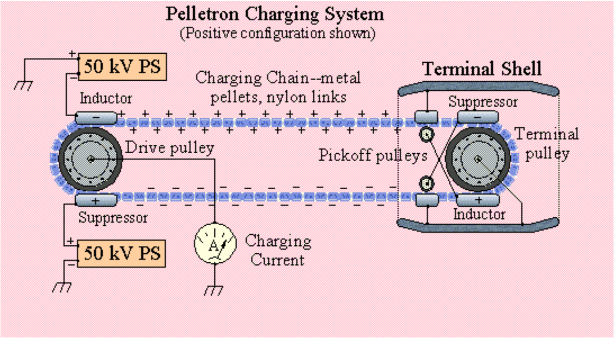
Dynamitron





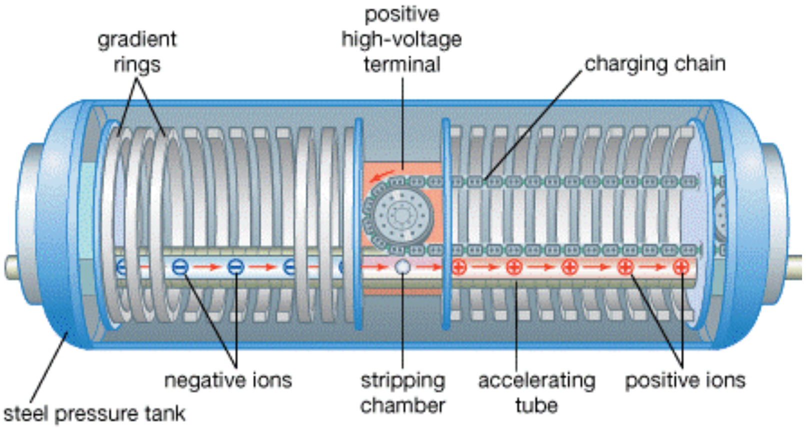
Electrostatic machines - 2

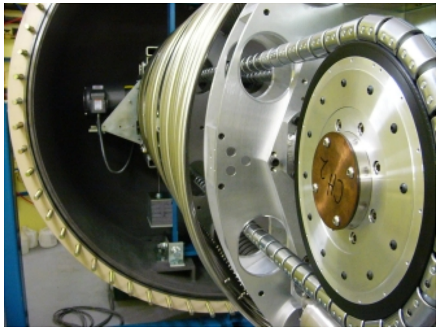
- Van de Graaf type : Pelletron
- HV brought to the terminal by a charging chain
- Single-ended :
    - Positive ion source : high current
- Tandem :
    - Ions charge flipped to be accelerated twice
    - Energy doubled for a given voltage
    - Negative ion source : difficult for high intensities



Pelletron

Tandem



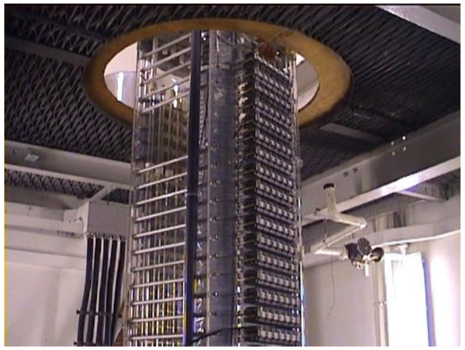


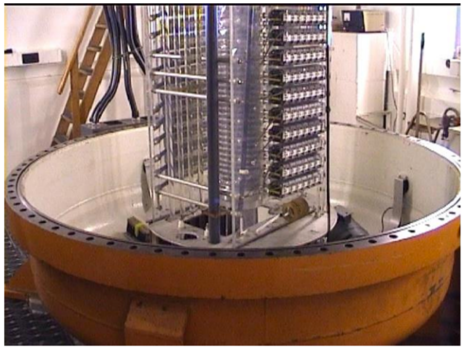
Charging chain

- Commercialized by High Voltage Engineering Europa (HVEE), Netherlands or National Electrostatic Corporation (NEC), USA

Birmingham university (UK)

- Singled-ended dynamitron, vertical orientation
- Parameters used routinely : 2.8 MV and 1 mA



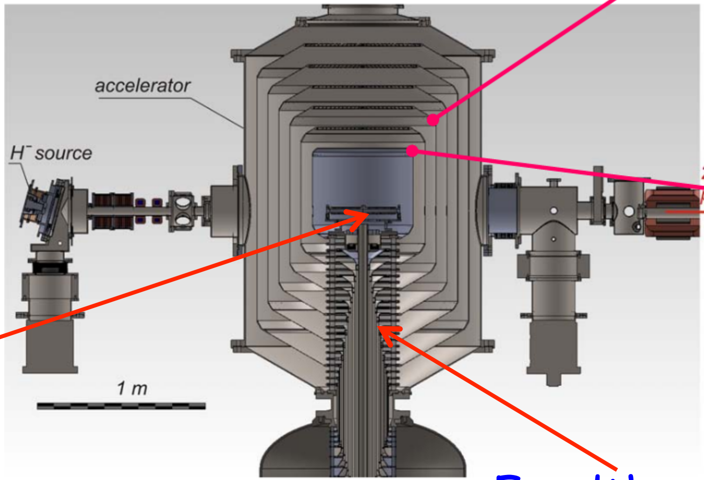


- Status : operational
- Expect ion source from IBA to provide current up to 15 mA

Budker Institute (Russia)

- Vacuum insulation tandem accelerator (VITA)
- High electric field (compactness)
- Remoteness of insulator (high current expected)
- Negative ion source : up to 3 mA

Intermediate electrodes



Gas stripper

Feedthrough insulator

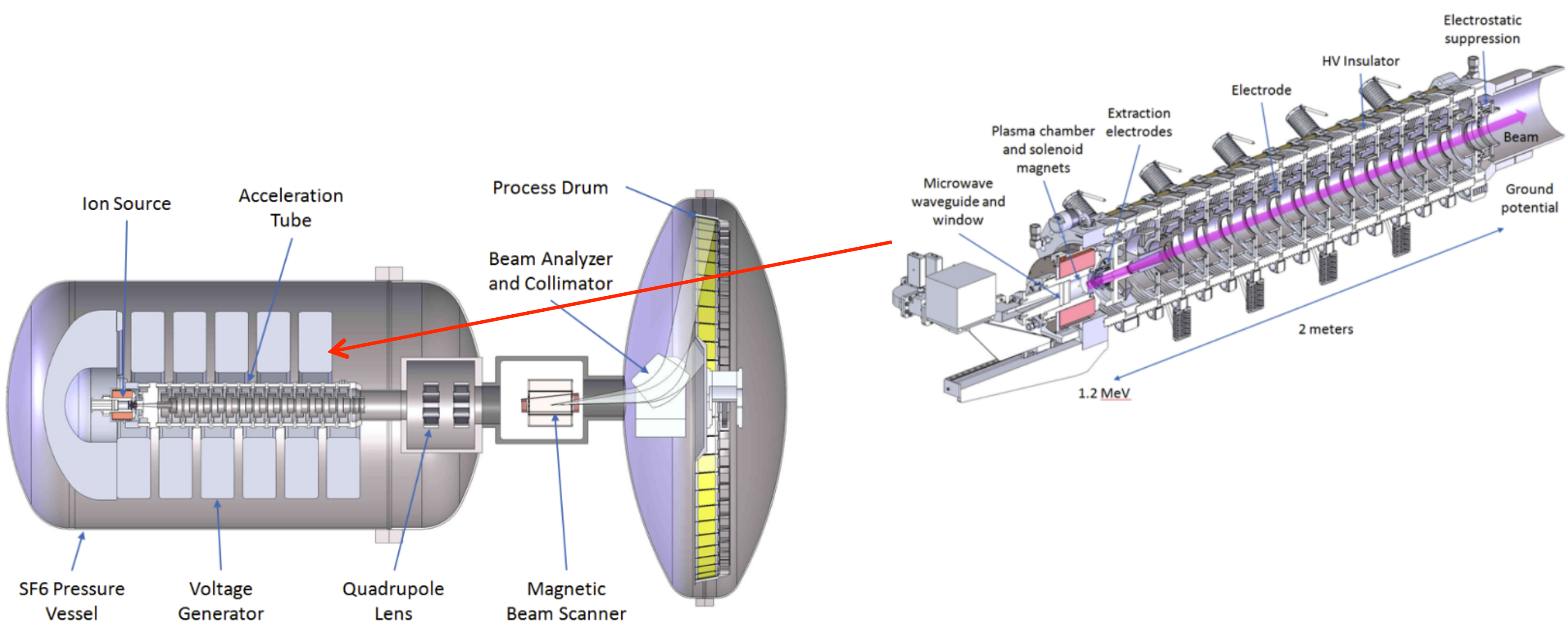
HV electrode

- Status : 2 MeV 1 mA proton beam stable for operation > 1h

S. Taskaev, Workshop on accelerator based neutron production ABNP 2014, Legnaro (Italy)

Dynamitron from GT Advanced Technology - 1

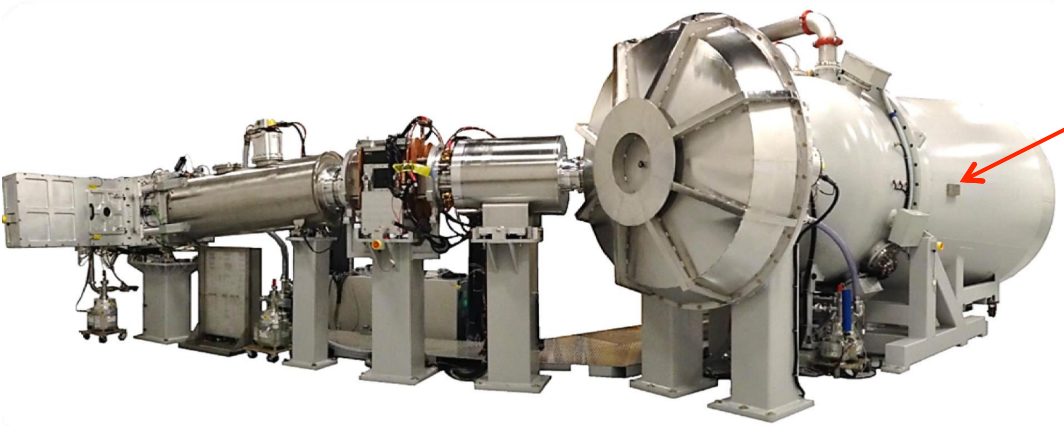
- Hyperion™ : commercial solution proposed by GT Advanced Technology
- H^+ implanter for solar cells
- Design specifications : protons, 2 MeV, 50 mA, CW (single-ended)
- Power supply concept (Directly Driven Electrodes) to limit perturbations from beam loss on accelerating electrodes and enhance beam intensities

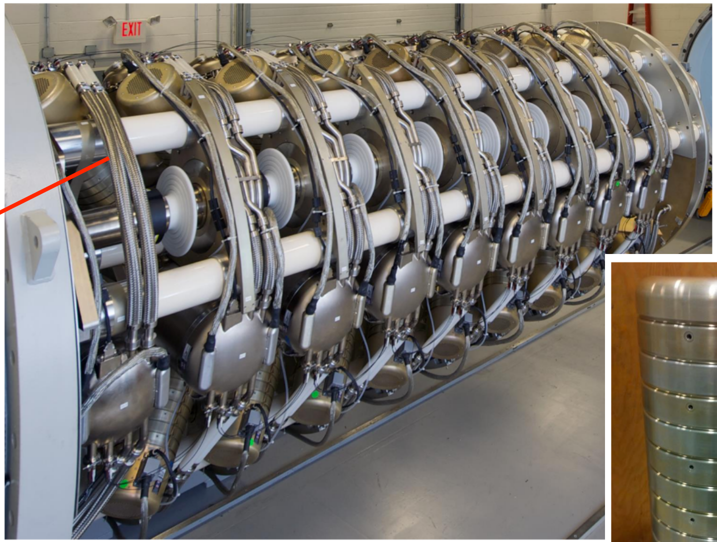


S. Felch *et al*, Ion implantation for semiconductor devices, PAC2013

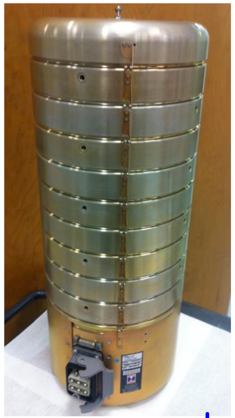
Dynamitron from GT Advanced Technology - 2

- Status (April 2014) : 33 mA at 2 MeV and 50 mA at 1.87 MeV





Accelerator



HV power supply

N. Smick, Workshop on ABNP 2014, Legnaro (Italy)

- From New Hampshire Business Review (oct 16, 2015):
  - GT AT filed for bankrupcy in oct 2014 (failed contract for Apple)
  - GT AT to sell its Hyperion technology to Neutron Therapeutics Inc. for $M 1.1

High current dynamitron from IBA

- IBA : Ion Beam Applications, world leader in accelerators for cancer diagnostics and treatment

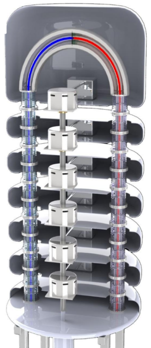
- 2005 : BNCT project with Japan (Yagami Seisakusho Corporation)
  - R&D for dynamitron, gantry, Li target and BSA
  - Proton dynamitron at 2.5 MeV, 20 mA
  - Very limited business and project cost
    - ➔ scope reduced to 15 mA (2012), dynamitron functional
    - ➔ end of BNCT at IBA

- Second dynamitron for Silicon slicing for photovoltaic applications
  - machine developped for protons at 4 MeV, 15 mA
  - company went bankrupt (SIGEN)
  - accelerator was functional

From A. Blondin (IBA)

Tandem-ESQ (Argentina)

- Differents accelerators under development, including
  - 700 kV tandem
  - **1.4 MV tandem (or single-ended)**
- Folded tandem (vertical orientation) with 1.4 MV terminal in air
- Electrostatic quadrupoles (ESQ) to provide beam focusing
- Ion source: protons
  - Tested on teststand : 30 mA
  - Transported through 200 kV machine up to 10 mA
- 700 kV tandem : assembly underway
- 1.4 MV tandem under development

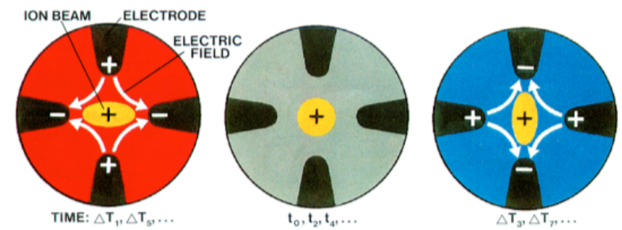


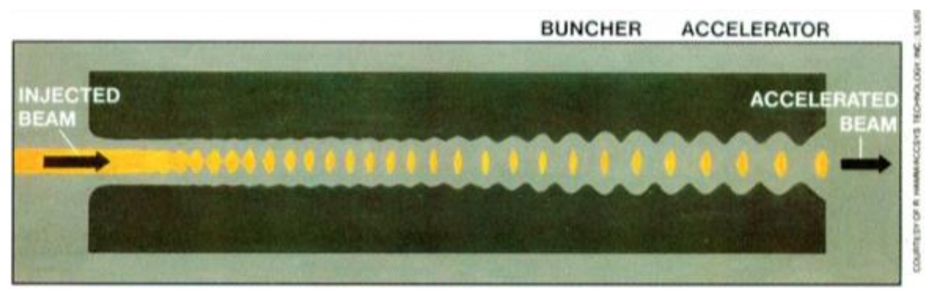
1.4 MV Tandem Accelerator or single ended

700 kV tandem

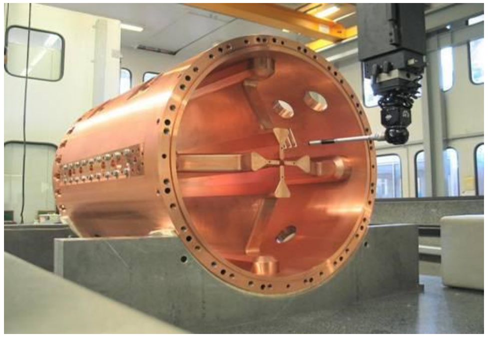
RFQ

- RFQ : Radio-Frequency Quadrupole
- High current linear accelerator
- Combined function structure:
  - Bunching : DC beam ➔ RF buckets
  - Radial focusing
  - Acceleration



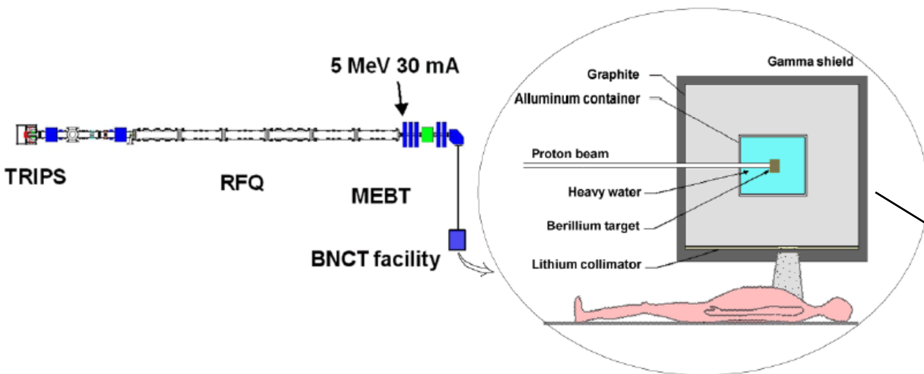


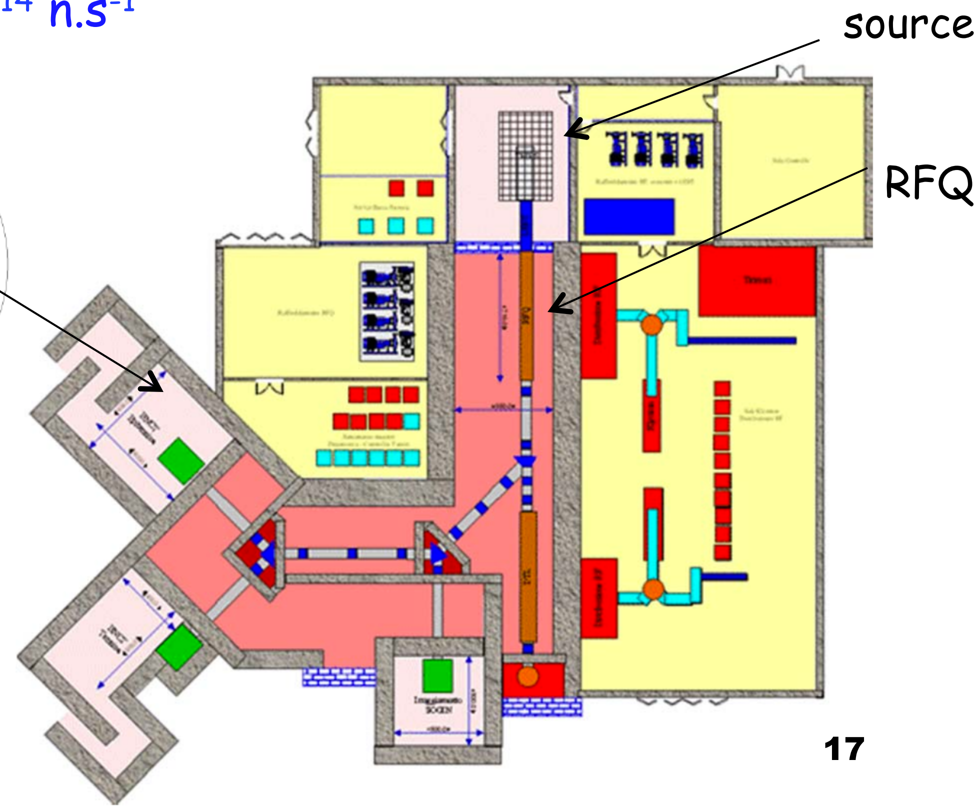
- Output energy : several MeV
- Current : up to 100 mA (IPHI)
- See next talks by
  - Jérôme Schwindling (CEA activities)
  - Jean-Michel Lagniel (SPIRAL2 RFQ)



INFN Legnaro (Italy) - 1

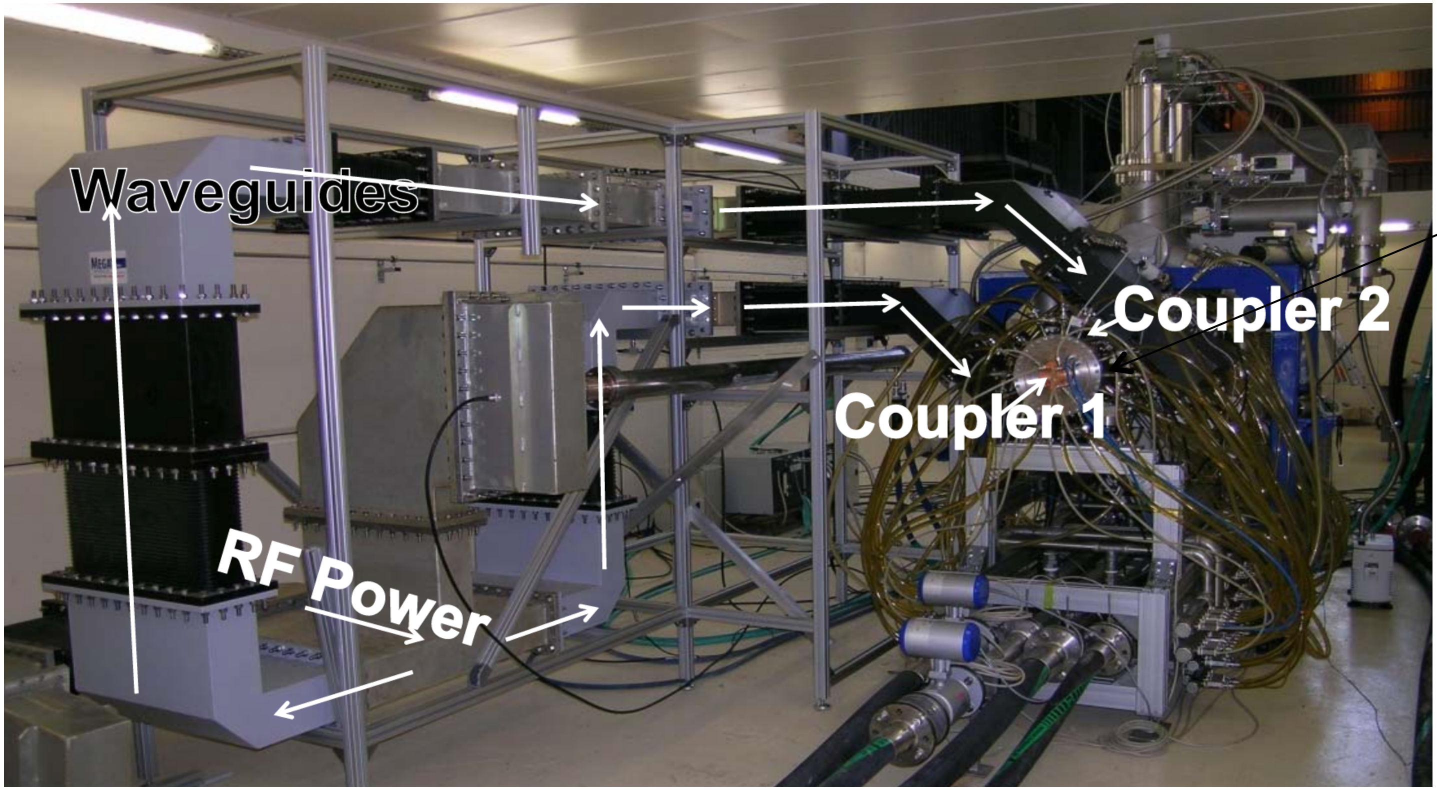
- Selective Production of Exotic Species (SPES) : radioactive ion beams to study nuclear physics and astrophysics
- Facility under construction at INFN-LNL
- Ion source (TRIPS) : 50 mA of protons at 80 keV
- Radio Frequency Quadrupole (RFQ) : 5 MeV
- High-power beryllium target in the center of the Beam Shaping Assembly
- Expected intensity : approximately 10^{14} $n.s^{-1}$

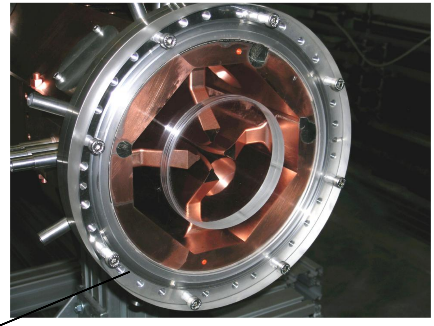




INFN Legnaro (Italy) - 2

- Accelerator comissionning under way
- RFQ succesfully passed the RF power tests :
  - Stable operation at nominal conditions (60kV)





A. Pisent, Workshop on accelerator based neutron production ABNP 2014, Legnaro (Italy)

SOREQ - 1

- Soreq Applied Research Acelerator Facility (SARAF) : nuclear physics, astrophysics, material science, radiopharmaceuticals, therapy ….

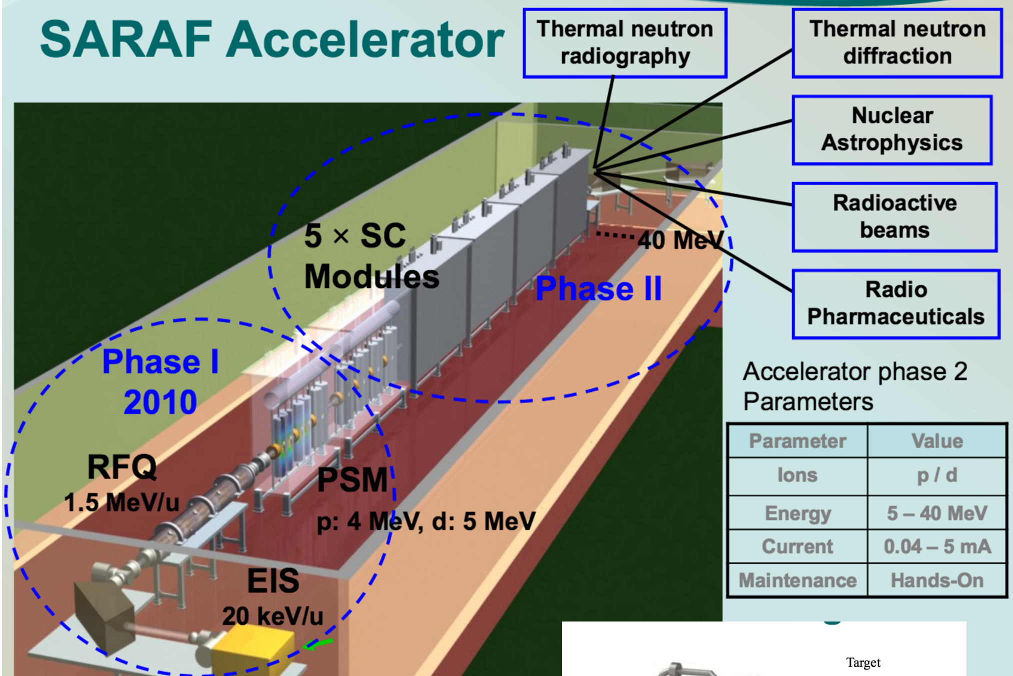
- SARAF: protons or deutons 5 mA, up to 40 MeV

- Make use of SARAF phase I (until 2019) for NCT
  - source, LEBT, RFQ, PSM (6 supraconducting cavities HWR 176 MHz)
  - phase I : p (4 MeV) or d (5 MeV)
  - Liquid Li target to study feasibility of AB-NCT

- Current status of SARAF : phase I functional
  - RFQ : CW proton or pulsed deutons
  - high power target

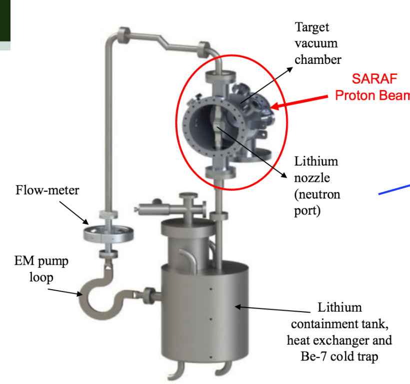
SOREQ - 2

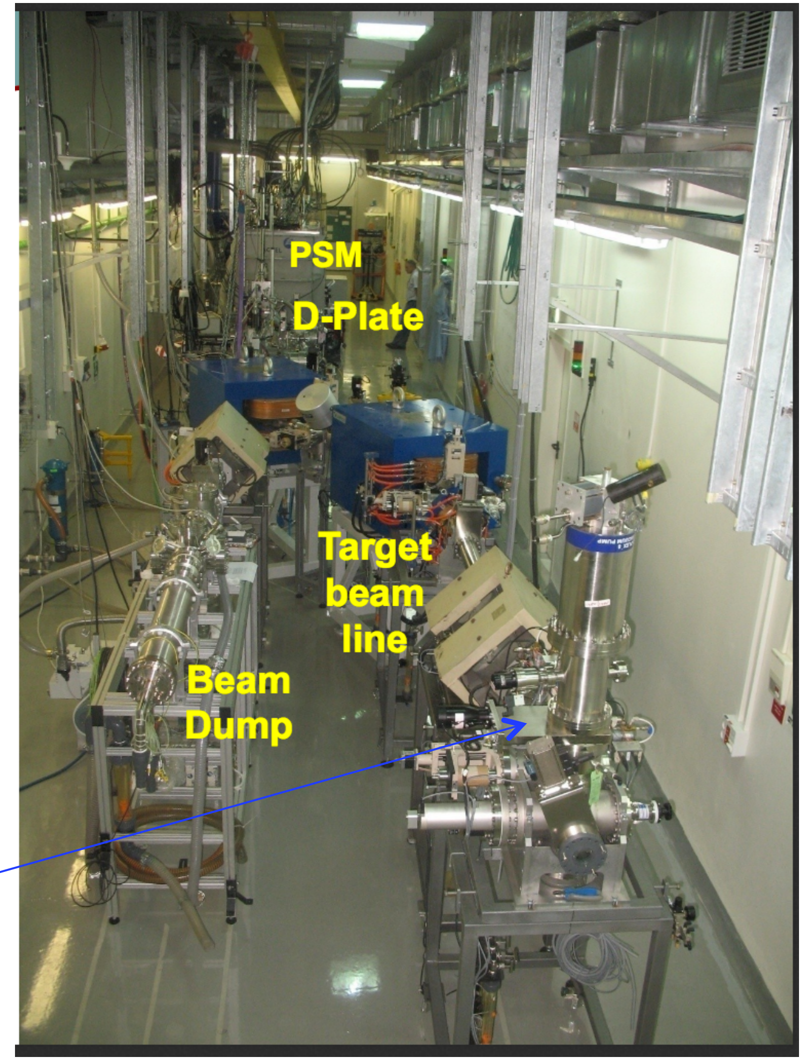
SARAF Accelerator



Accelerator phase 2 Parameters

Parameter	Value
Ions	p / d
Energy	5 – 40 MeV
Current	0.04 – 5 mA
Maintenance	Hands-On





Shlomi Halfon, Workshop on accelerator based neutron production ABNP 2014, Legnaro (Italy)

Conclusions

- Many accelerator options to meet the specifications of AB-NCT
- Solutions developped by industry and research communities
- Multiple projects under development, construction and in operation
  - Presented here
  - Projects in Japan: Tsukuba (Japan) : RFQ+DTL, 8 MeV, 10 mA, …
  - Others …

- RFQ by IAP Frankfurt
  - RFQ for MYRRHA project, under construction:
    - protons, 1.5 MeV (176 MHz)
    - possible extension for AB-NCT?
  - FRANZ :
    - ambitious neutron source project : 2 MeV protons, 50-200 mA
    - RFQ (700 KeV) + IH-DTL (8 gaps)

- RFQ developped by CEA-Saclay including SPIRAL2

Thanks for your attention