High Intensity Cyclotron Developments at IBA

HICFA – HB 2002 April 9th 2002

Yves Jongen
Founder & Chief Research Officer
Ion Beam Applications s.a.
Belgium

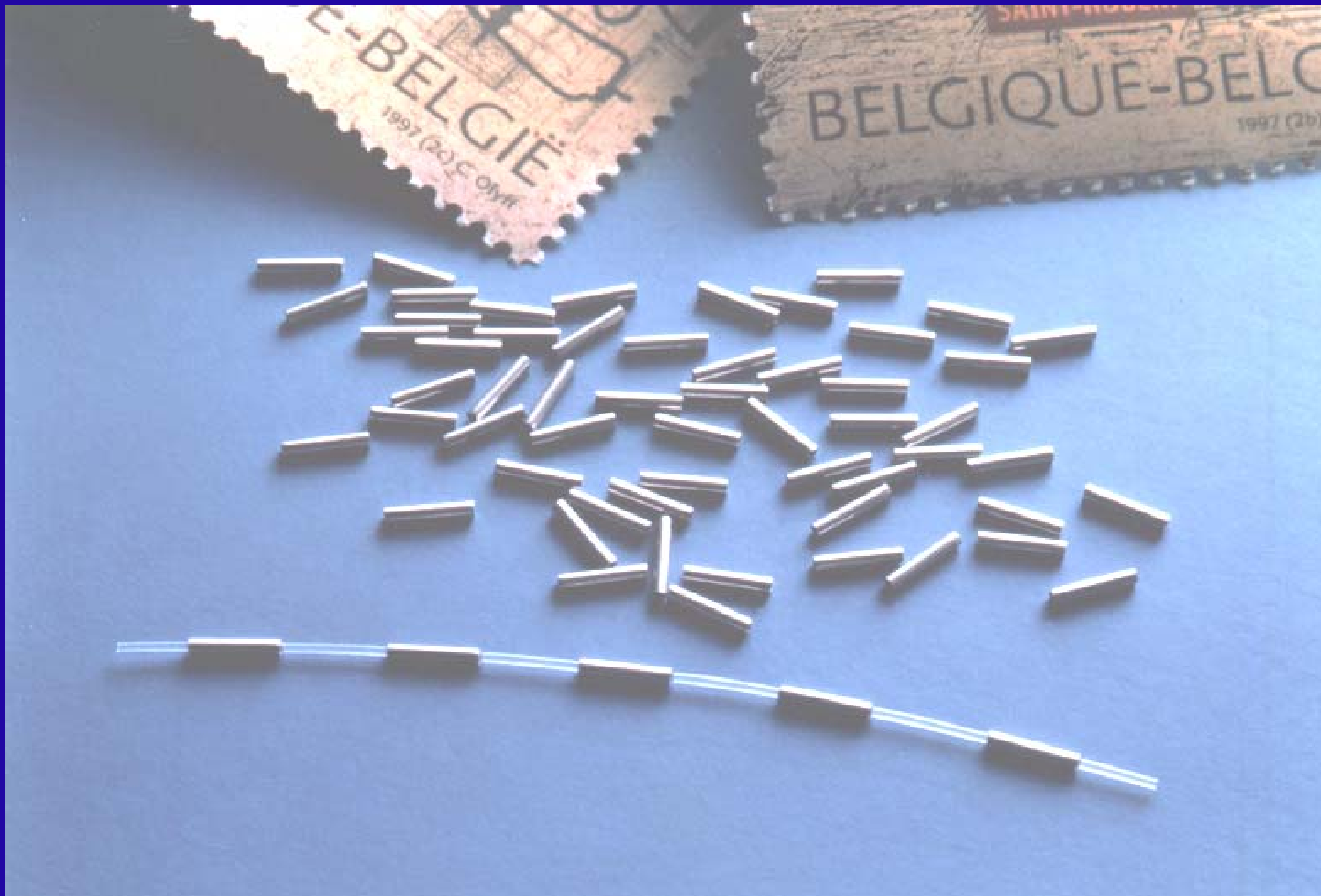
Outline

The goal of the paper is to present some high current cyclotron developments made by IBA

- Very high proton currents are required for the production of Brachytherapy isotopes such as Pd 103
- A new design of cyclotron allows to extract high currents of protons without ES deflector or charge exchange
- 1.5 MW CW, 106 MHz RF power sources are now available, using the Diacrode grid tube
- Very high beam power designs are made for nuclear waste transmutation or energy production

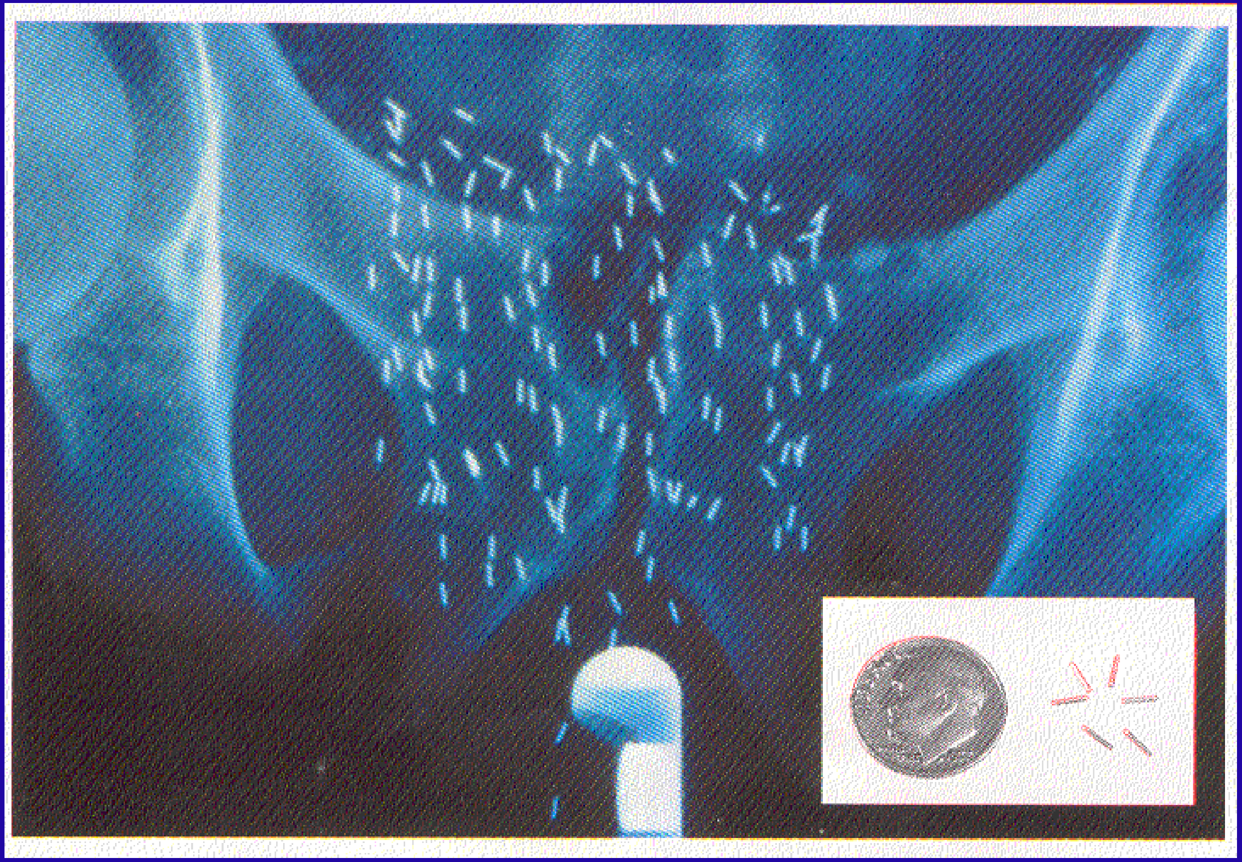
Radioisotope production expands from imaging to therapy : larges doses require high current, powerful accelerators

Cyclotrons for Brachytherapy



IBA

Prostate Brachytherapy



Radioisotopes for cancer therapy : application to the prostate cancer

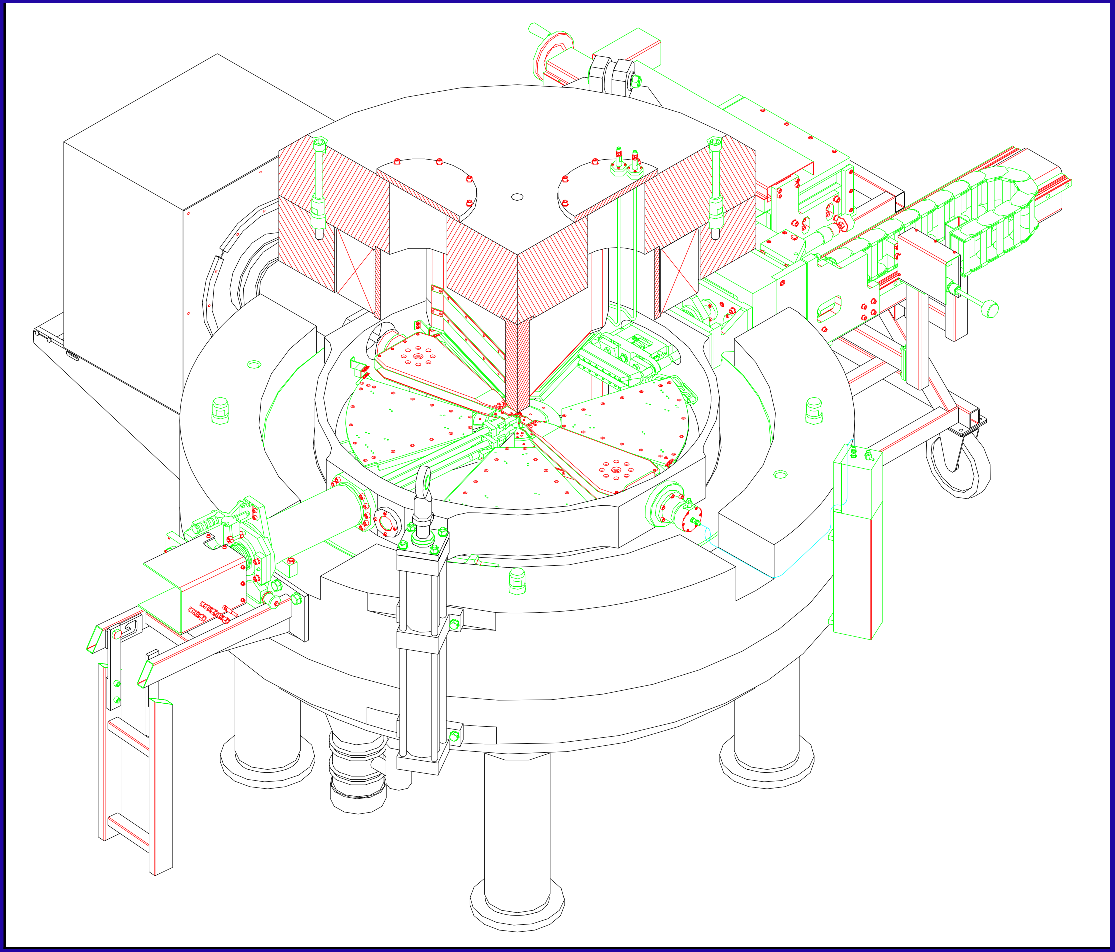
Radio nuclide characteristics : Pd-103 vs. I-125

	Pd-103	I-125
Half-life (days)	16.97	60
Energy (keV)	20-23	27-35
Half-value-layer (mm.lead)	0.008	0.025
Biologic dose equivalent (Gy)	115	160
Initial dose rate (cGy/hr)	20-24	6-10

Cyclotrons for Brachytherapy

- In 2001, 5 million seeds were sold, representing 62,000 treatments
- The market of seeds for prostate cancer brachytherapy was $165 M, of which around 40% for Pd 103
- The dose to be used per patient are much larger, of longer lived isotopes
- Low yield and high productivity require multi-milliampere cyclotrons
- At Theragenics, IBA has installed 14 cyclotrons, with 2 mA beam current each (28 mA total beam current). A smaller number of higher current cyclotrons would be preferable

The CYCLONE 18+



The 2 mA Cyclone 18+

30 kW of beam with 100 kW of electrical power

80% of the RF power is beam acceleration

The CYCLONE 18+

- ^{103}Pd is produced by a (p,n) reaction on ^{103}Rh, requiring 12 to 18 MeV protons
- The use of an internal target avoids the issue of extracting 2 mA of beam
- The target is placed at grazing incidence in respect to the beam, causing a fraction of the beam to scatter away from the target
- Pure aluminum pole shields are used to limit the magnet activation

IBA

The Self-extraction Cyclotron

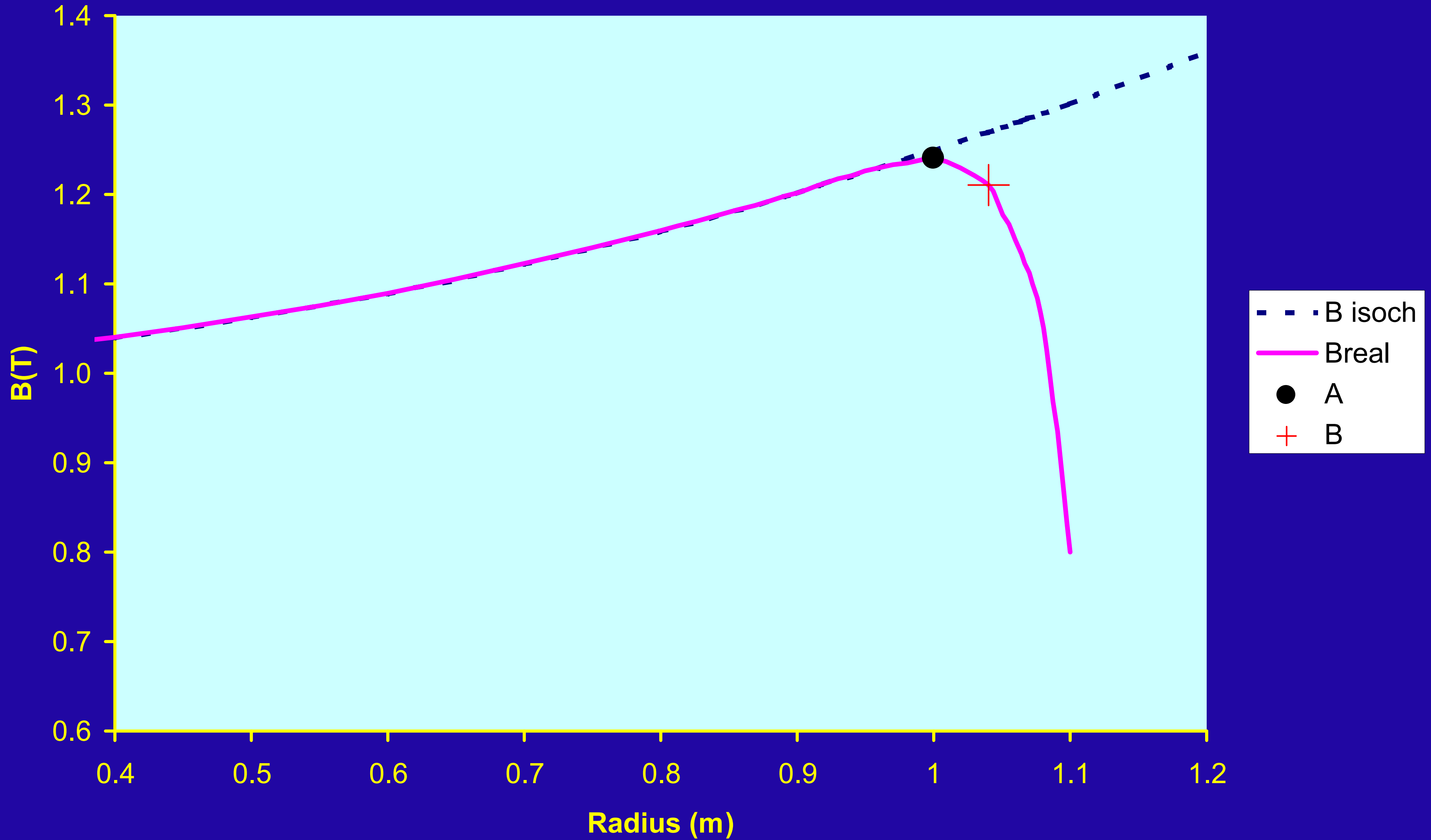
- Larger proton beam currents are needed at low energy for the production of radioisotopes such as Pd 103
- The beam size on internal targets in cyclotrons is limited. Heat removal from the target surface becomes an untractable problem
- Cyclotrons with internal targets become too radioactive for hands-on maintenance
- Cyclotrons with extracted beams of 2 mA and more are needed for this application
- In classical isochronous cyclotrons, extracting the beam with ES deflectors, the heating of the deflector septum is the limit
- H- cyclotrons, with axial beam injection and extraction by charge exchange are limited around 1.5 mA by space charge effects in the very low energy injection line (30 kV)

The Self-Extraction Cyclotron (1)

- In 1995, IBA proposed a new method to extract positive ions from a cyclotron without using an electrostatic deflector
- In an isochronous cyclotron, the departure from the ideal radial field leads to a phase lag of the accelerated particle. The acceleration stops when the phase lag reaches 90°, defining the limit of acceleration (A)
- The radius where the field index R/B.dB/dR= -1 corresponds to the point where the ions are able to drift freely out of the magnet: this is what we call the point of self-extraction (B)
- The task of the ESD is to bring the beam from A to B
- When the magnet gap becomes very small (<10 times the radius gain/turn at extraction), B is encountered before A

$\Rightarrow$ self-extraction

The Self-Extraction Cyclotron



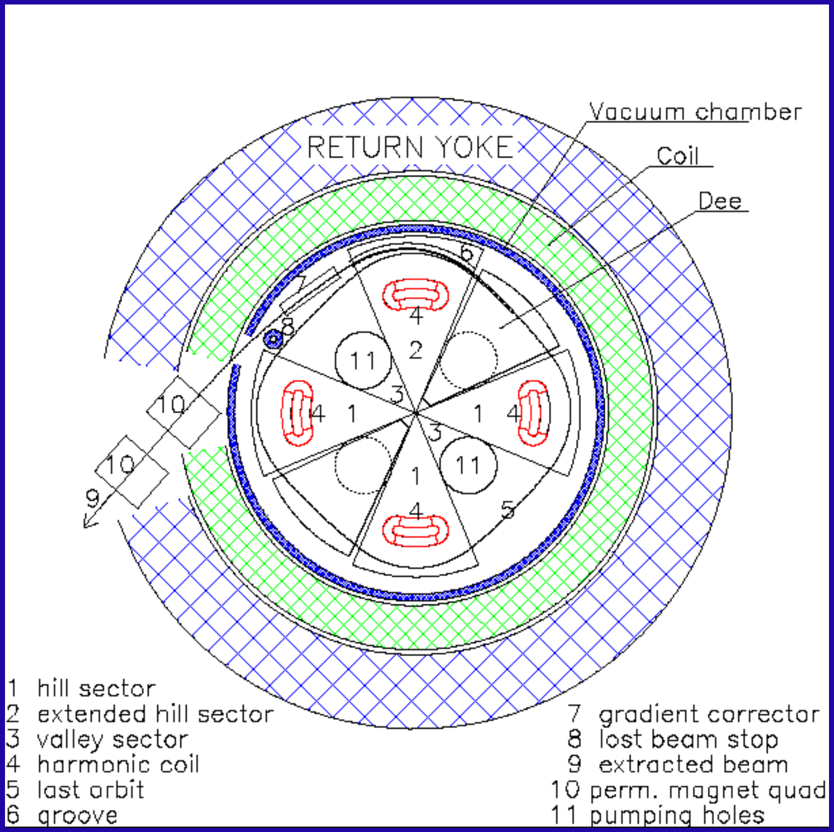
The Self-Extraction Cyclotron (2)

- The key to this rapid transition is the use of a small vertical pole gap of quasi-elliptical shape near the extraction radius
- Self-extraction concept experimentally verified with the 230 MeV cyclotron, in good agreement with simulation predictions
- In 1998, IBA started the design and construction of a cyclotron to demonstrate the self-extraction of very high intensity proton beams
- Energy of 14 MeV selected for production of ^{103}Pd
- The new method requires a large radius gain per turn, easier to achieve in a low energy cyclotron
- The RF is sized to be able to accelerate 140 kW of beam (10 mA!)

Self-extraction vs. Single-Turn Extraction

- It is important to stress the difference of the proposed method with the existing method of extraction of high intensity beams with ESD, as in PSI injector cyclotron
  - Single turn extraction, good turn separation
  - small emittance and RF phase width
  - high charge density $\Rightarrow$ strong longitudinal space charge effects
- Self-Extraction Cyclotron: uncritical industrial machine
  - Multi-turn extraction
  - Large emittance and RF phase width
  - lower charge density $\Rightarrow$ little space charge effects

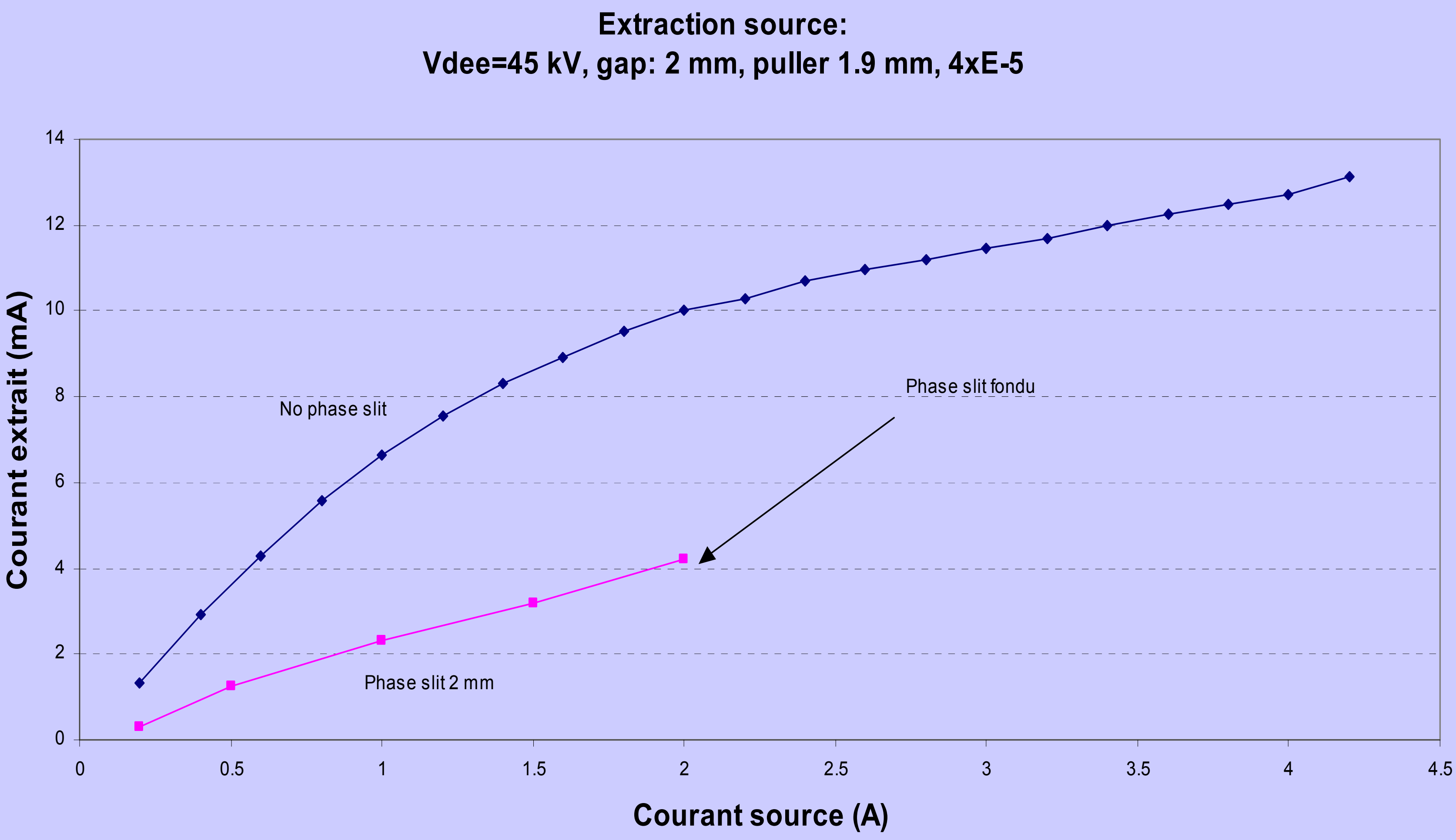
Realization of the extraction



- The extraction path is a groove machined in a pole having an extended length
- Separation of turns created by harmonic coils close to extraction radius
- A 10-20 mm radial gain at extraction is produced, to push the beam across the self-extraction limit into the extraction path
- Measured extraction efficiency > 80% at low currents, > 70% at 2 mA
- Lost beam collected on a high power, low activation beam catcher. This catcher is used as secondary production target

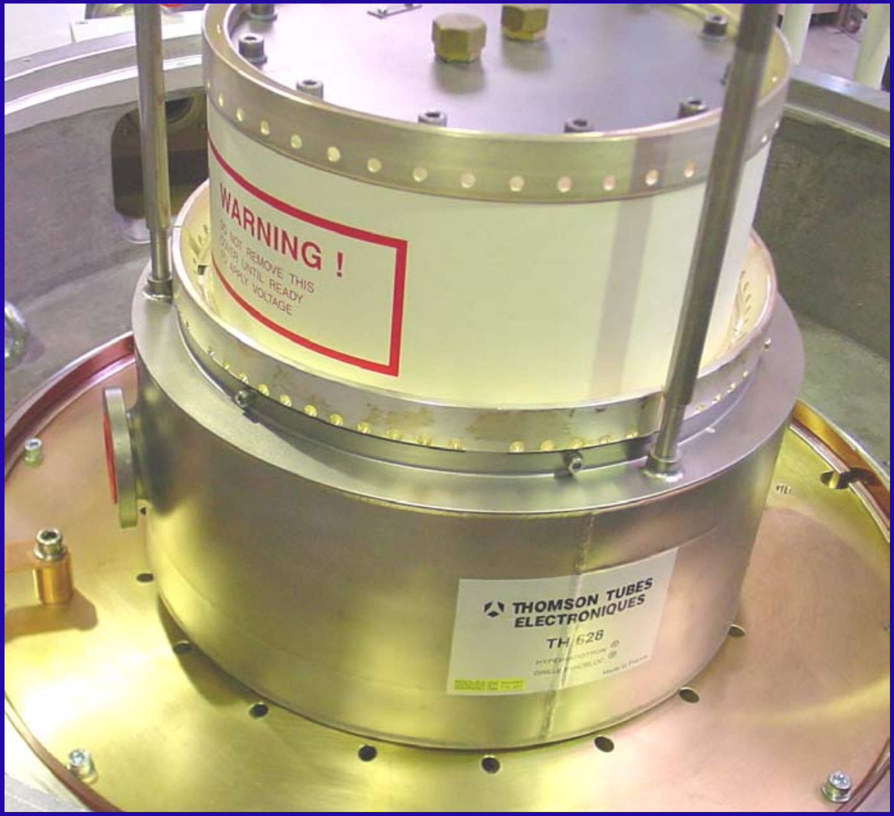
Median Plane View

Source Current vs Arc Current



Diacrode grid tube amplifiers

- Electron grid tubes (tetrodes) are still the preferred solution for high average powers at frequencies < 250 MHz
- In tetrodes, the amplifiers circuits (input, output, G1G2) are generally quarter-wave resonators with the voltage node in the tetrode
- At higher frequencies, and with large tubes, the current node is almost located at the tube connector
- The maximum power achievable at high frequencies is therefore generally limited by the current carrying capacity of the grids and of the tube connector
- The Diacrode is the equivalent of a tetrode where the connections could be made at both ends of the electrodes, in half-wave resonators.

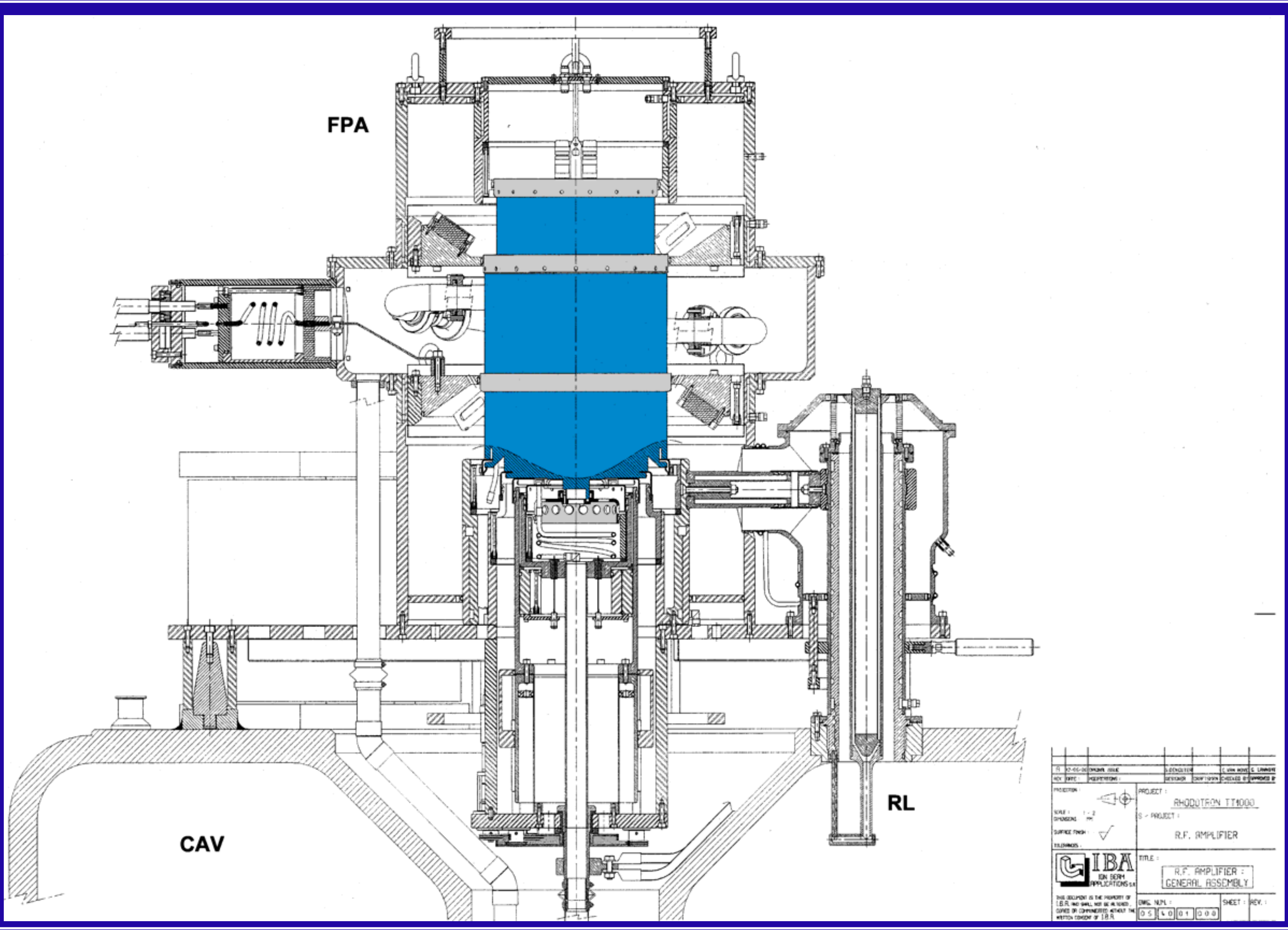


1MW CW RF Amplifier

- Thomson TH628 Diacrode®
- 1.5MW CW RF Power Capability @ 107.5MHz
- High Efficiency 17.5kV/80A anode PSU regulated by IGBTs

IBA

1MW CW RF Amplifier

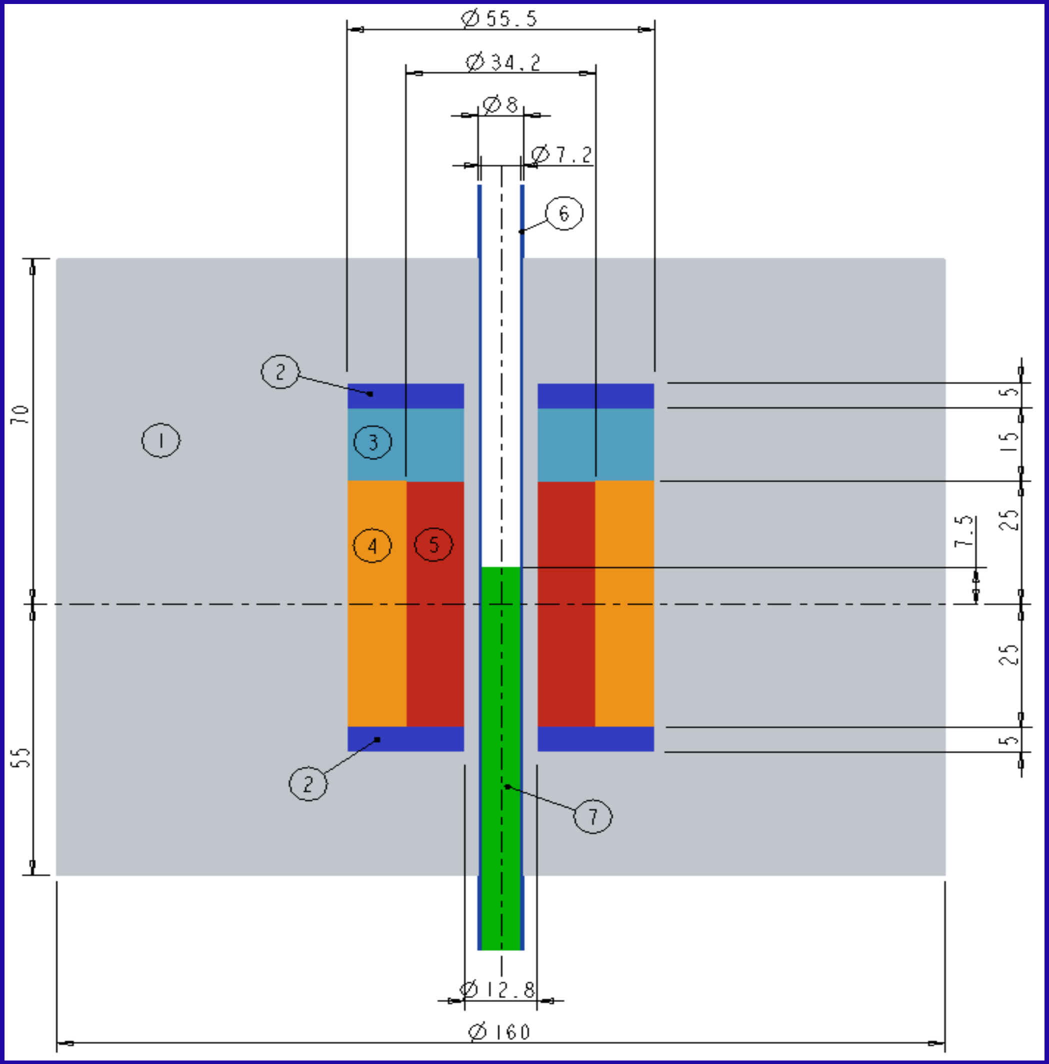


The TT1000 Rhodotron

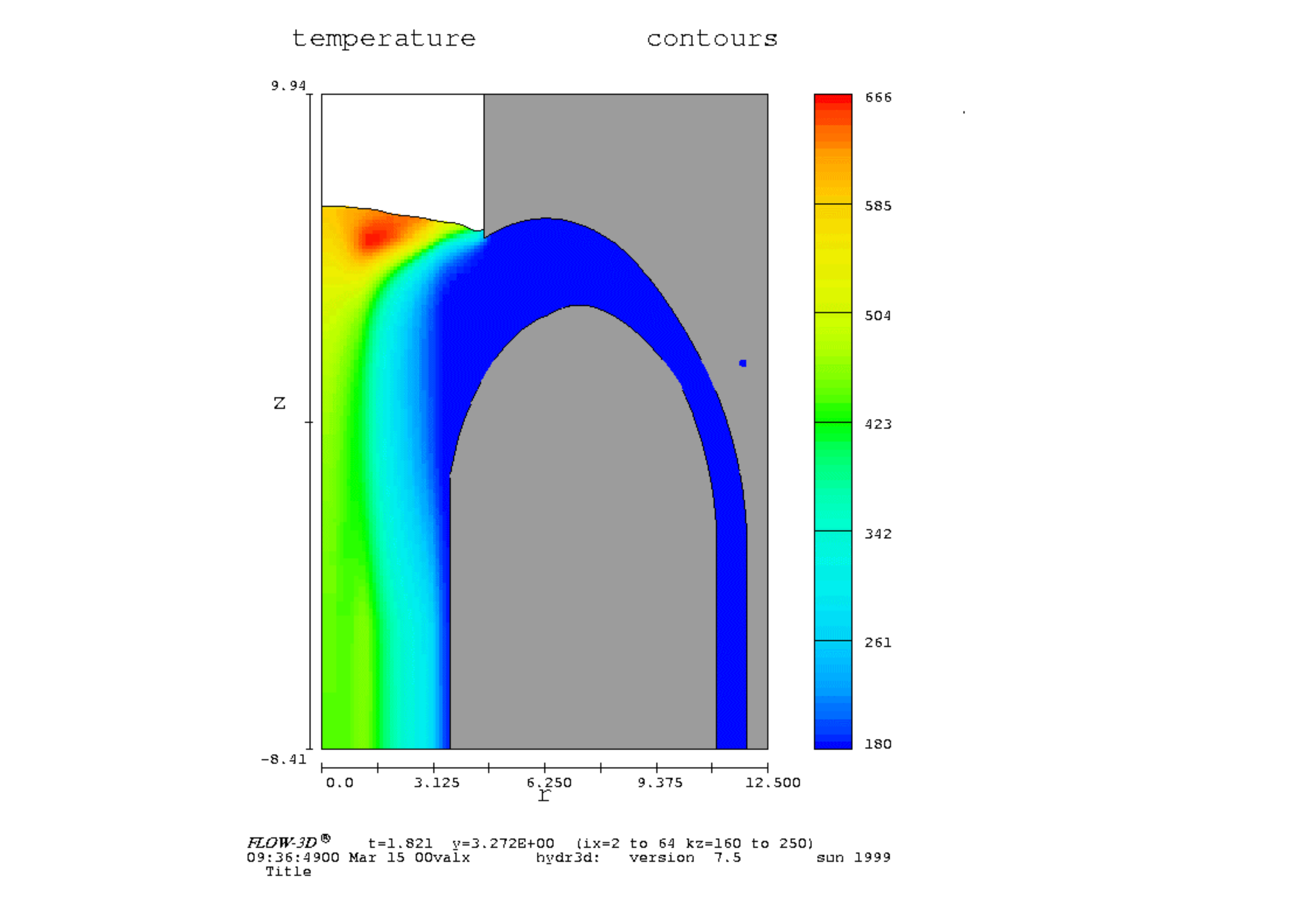
Very high power cyclotrons for energy applications

- The transmutation of long lived nuclear waste, or safer and cleaner nuclear energy production could be made in sub critical nuclear reactors driven by a powerful proton beam
- In Belgium, the MYRRHA project associates the CEN-SCK and IBA
- The goal of MYRRHA is to make a multi-purpose fast, high flux, 25 MW sub critical reactor driven by 1.75 MW proton beam.
- The spallation neutron source uses a special, windowless design
- To reach the high neutron fluxes needed, the specifications of the proton accelerator are 350 MeV and 5 mA

Axial view of the R-Z geometrical model of MYRRHA ADS



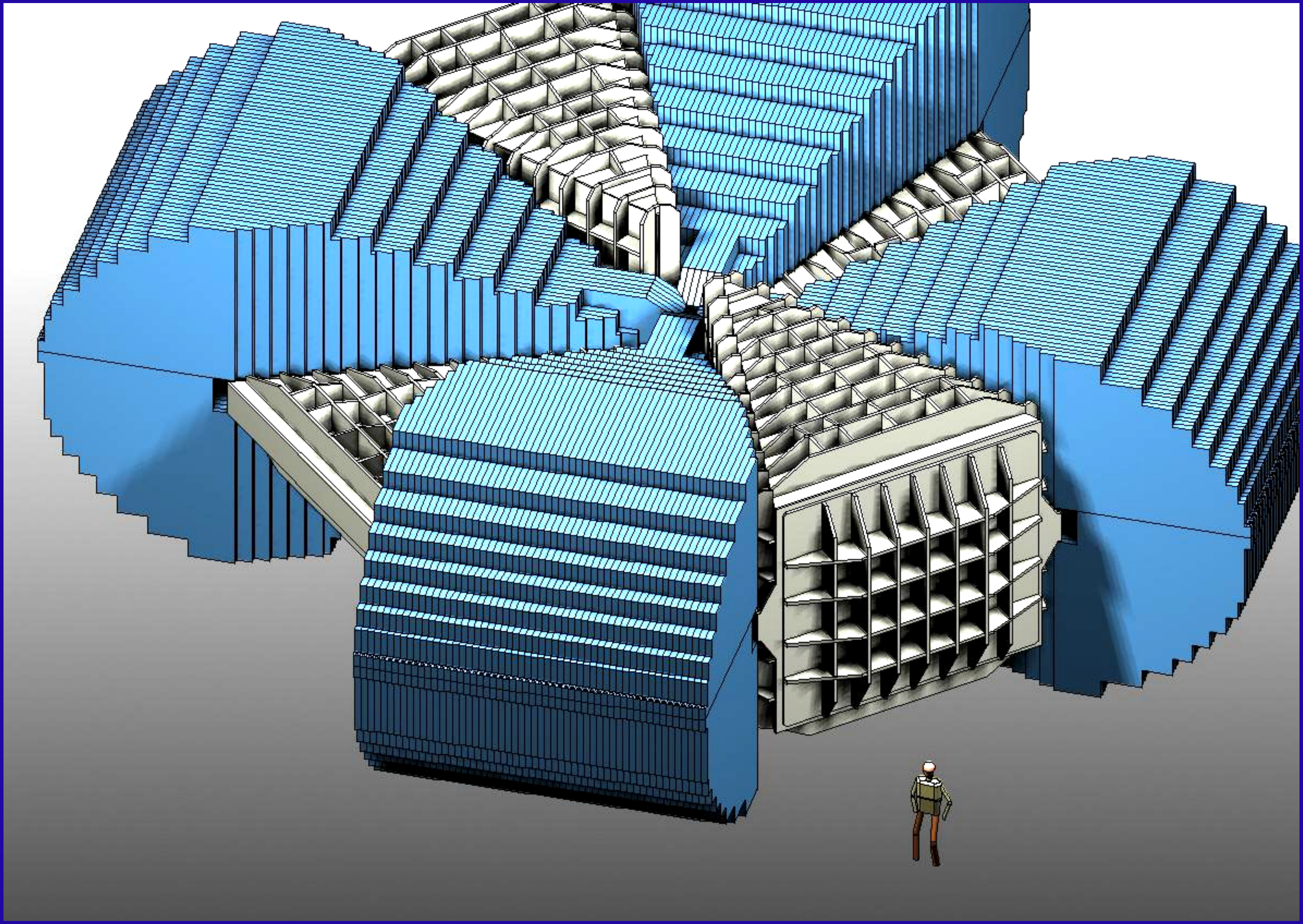
MYRRHA windowless spallation target



Design of cyclotrons for ADS

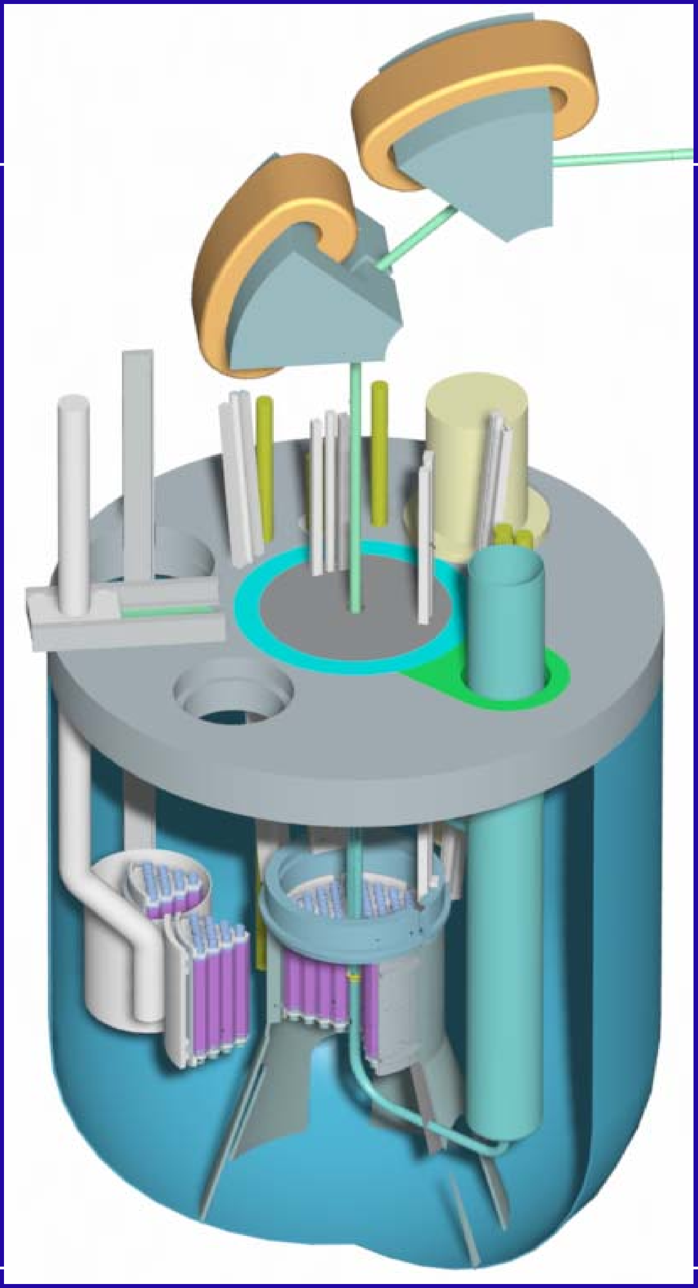
- The first IBA design for MYRRHA was based on a chain of two cyclotrons, as in the PSI designs
- But a special requirement of accelerators for subcritical reactors is the need to minimize the number of short beam interruptions
- The experience of existing cyclotrons shows that the ES devices at injection and extraction are responsible for the largest number of short trips > A cyclotron chain is therefore not a good idea!
- The concept of a single, very large cyclotron accelerating 2.5 mA of HH+ molecules at 700 MeV was developped. Extraction by stripping yields 5 mA of 350 MeV protons.
- The resistive design, illustrated hereafter is very large and expensive. A SC alternative is under design.

View of the resistive MYRRHA cyclotron

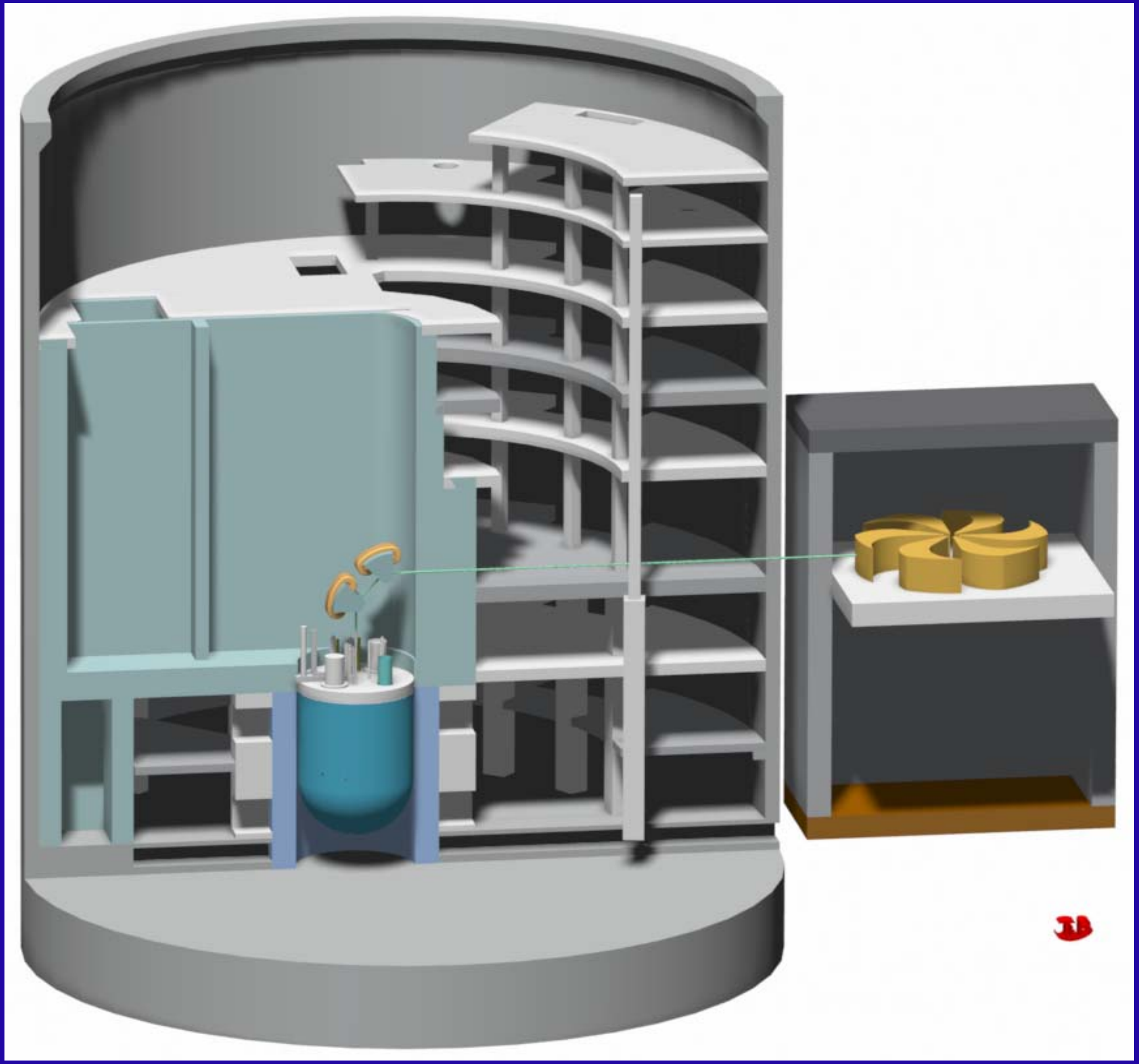


IBA

MYRRHA core



MYRRHA Building



IBA

IBA