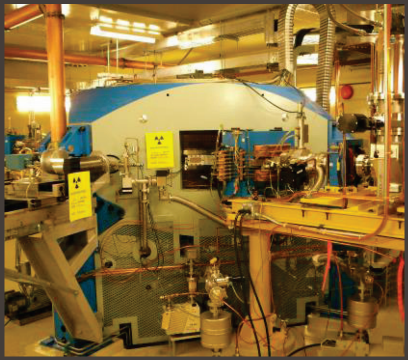

OPERATIONAL EXPERIENCE AT THE INTENSITY LIMIT IN COMPACT CYCLOTRONS

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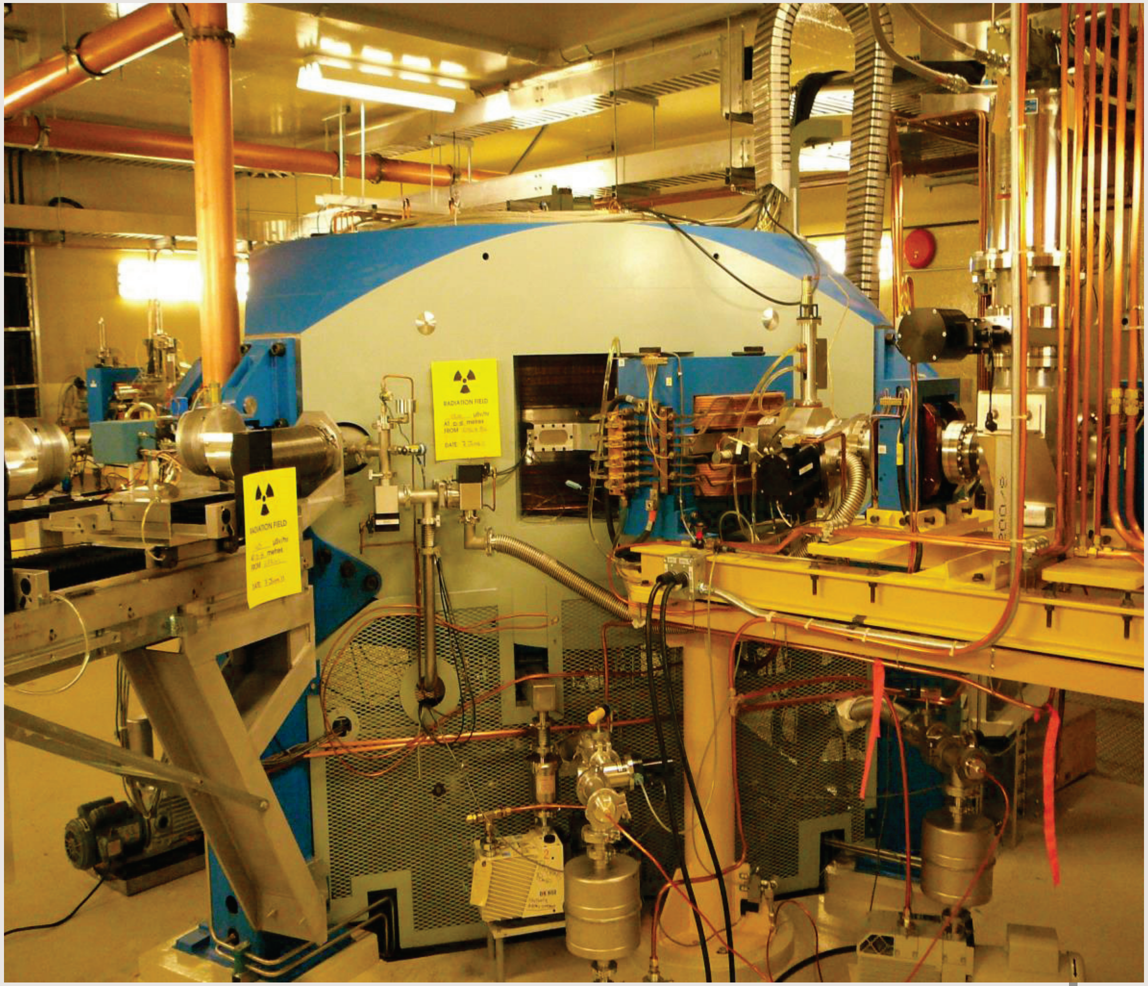
Introduction

- TR30s are compact, low energy, high current, dual beam, H- cyclotrons
- Originally designed and developed by TRIUMF and ACSI
- Extraction between 15MeV and 30MeV
- Used in medical isotope production



Introduction

TRIUMF experience with operating, maintaining and developing TR30, H- compact cyclotrons at:

- Total extracted beam levels of about 1mA
- 24hours, 365 days quasi continuous operation

Covering:

- 23 years of operation

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Introduction

- Cyclotrons subsystems:
  - Ion Source and Injection Line
  - Extraction Foils
  - RF Components
  - Diagnostics
  - Centre Region
- Maximum Extracted Single Beam
- Cyclotrons Availability

Introduction

- TR30-1 (in operation for more then 23 years) and
- TR30-2 (in operation for more then 10 years)

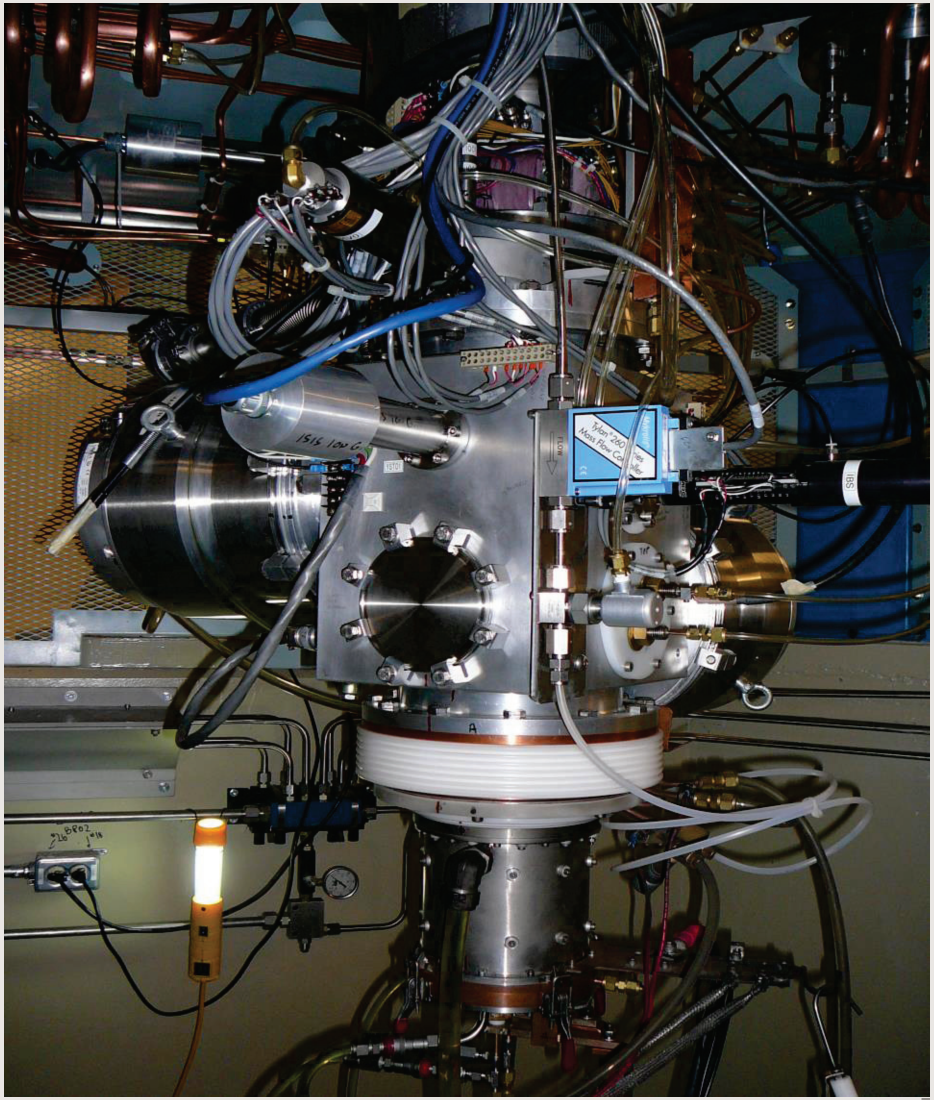
This experience helped us evaluate the long term performance of our cyclotrons and their present limits.

- Consider the machines output and performances in terms of charge delivered (mAh).

- Both beam intensity (mA) and uptime (hours) have to be considered concurrently

Ion Source and Injection Line

TR30-2 Ion Source and Injection Line



Ion Source and Injection Line

Filament lifetime

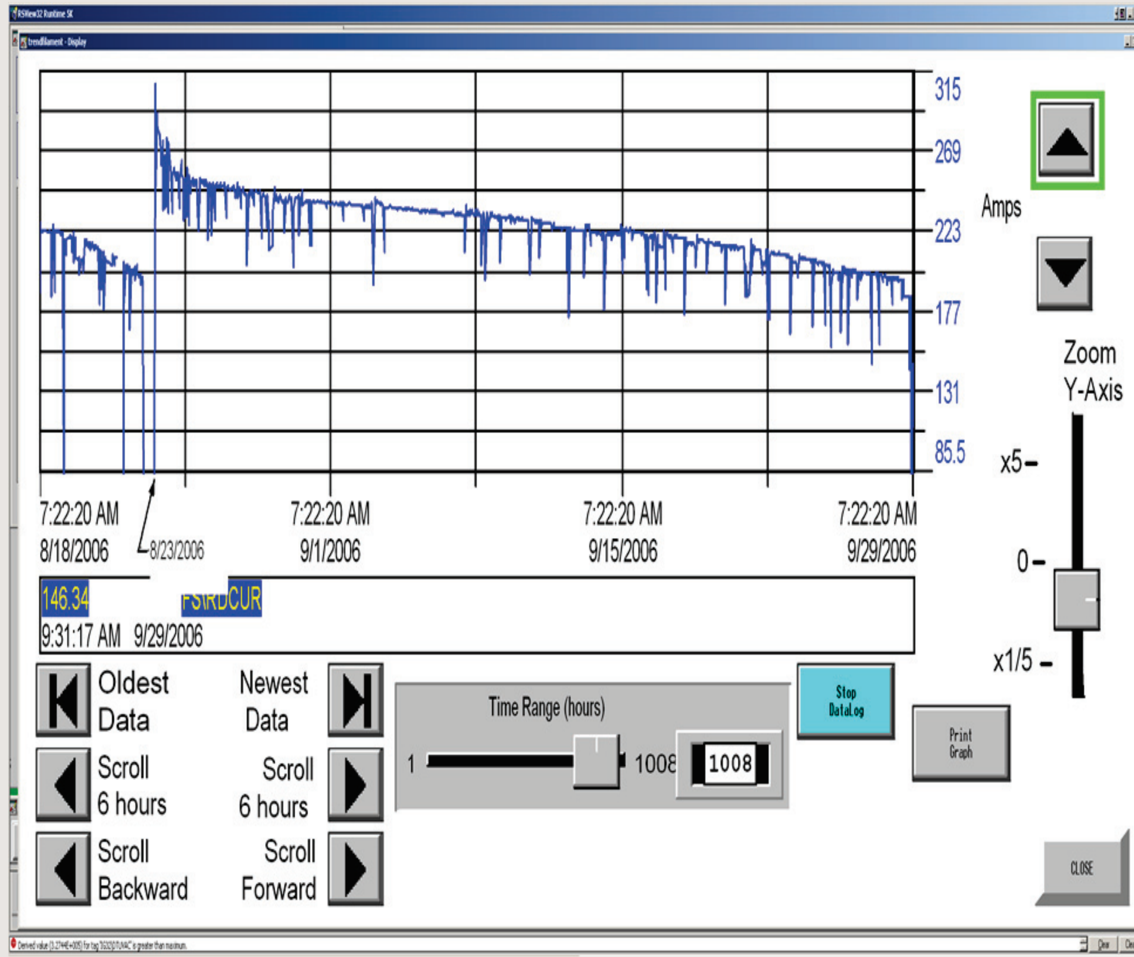
Ion Sources are running between 2 mA and 10 mA extracted beam

- 35 days lifetime
- 5 hours maintenance

  Affects only uptime, not beam amplitude before and after the change

Ion Source and Injection Line

TR30-1 filament current over 37 days of lifetime



Ion Source and Injection Line

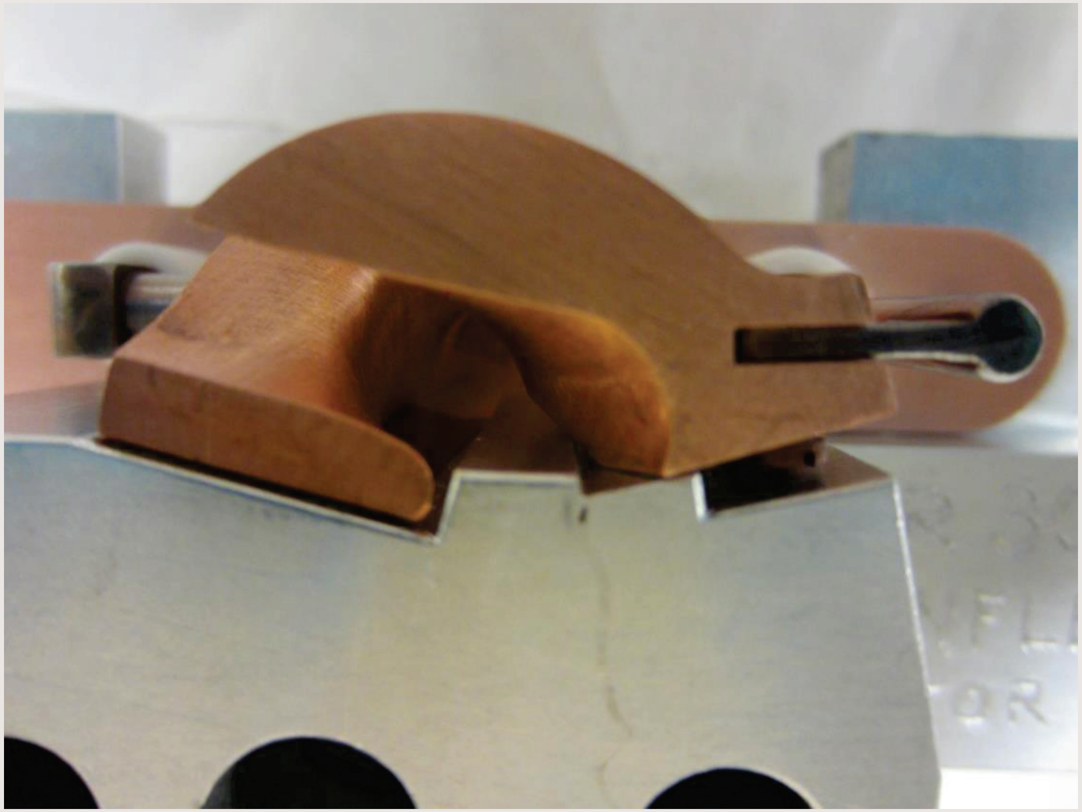
Inflector lifetime

- A failure rate of about once/year on both machines
- 4 days maintenance and recovery:
    - Cool-down
    - Replacement
    - Vacuum recovery
    - Inflector conditioning and tuning
    - Tank RF conditioning

Affects only uptime, not beam amplitude before and after the change

Ion Source and Injection Line

New inflector ready to be installed



Ion Source and Injection Line

TR30-2 beam eroded inflector

Ion Source and Injection Line

Buncher lifetime

- A failure rate of about once every 3 years on TR30-2 (less on TR30-1)
- Preceded by amplitude beam deterioration
- 2 days maintenance and beam recovery

Affects both beam amplitude and uptime

Ion Source and Injection Line

TR30-2 damaged buncher

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Ion Source and Injection Line

Ion Source components including extraction optics

- Gradual physical deterioration especially extraction optics, combined with:
- Nature of our operation

Affect both beam amplitude and uptime

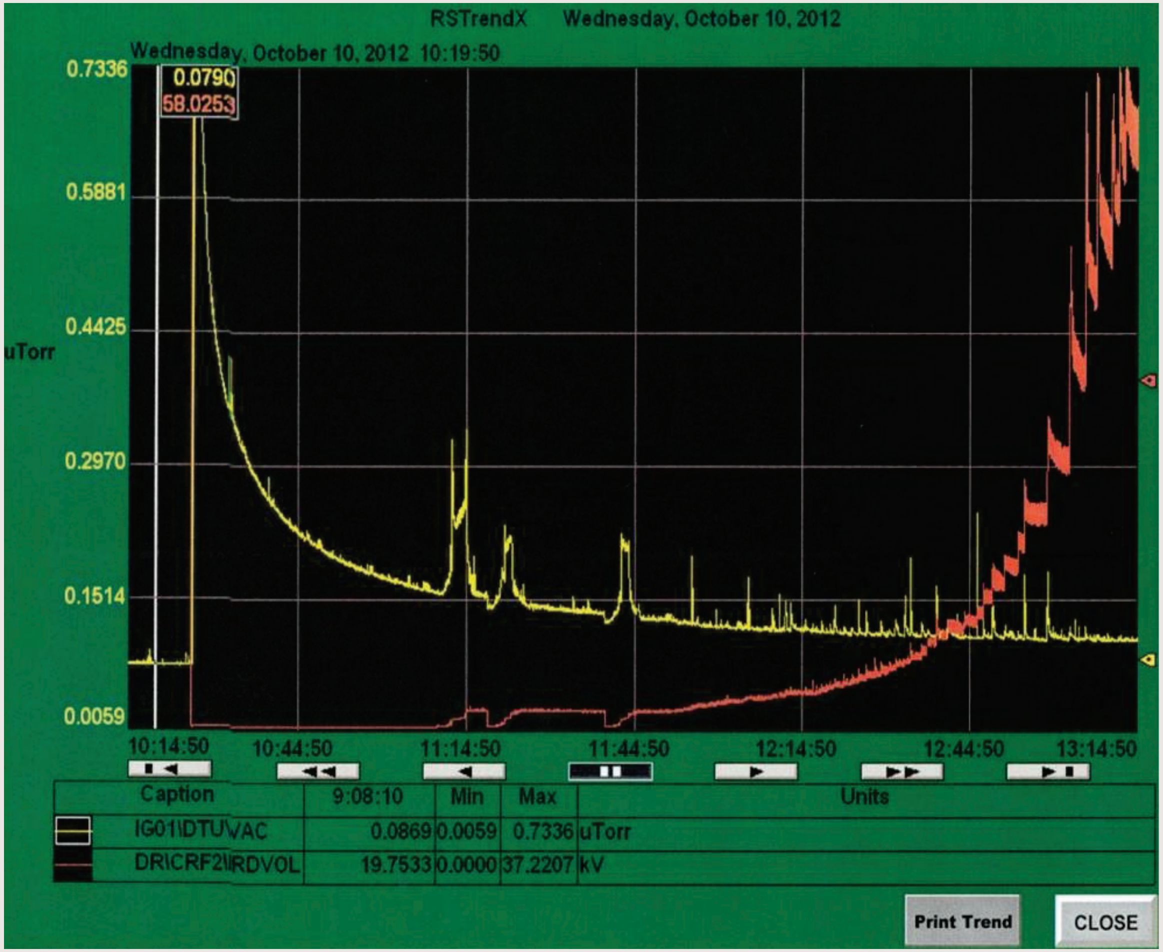
Extraction Foils

- There is typical beam deterioration during the lifetime of an individual foil due to its physical depreciation, which could be compensated by beam tuning and higher extracted beam
- New foil needs additional beam tuning, eventually a new carousel is necessary
- 5 hours to complete a carousel replacement
- Work is followed by tank RF conditioning

Affect both beam amplitude before and after the changes and uptime

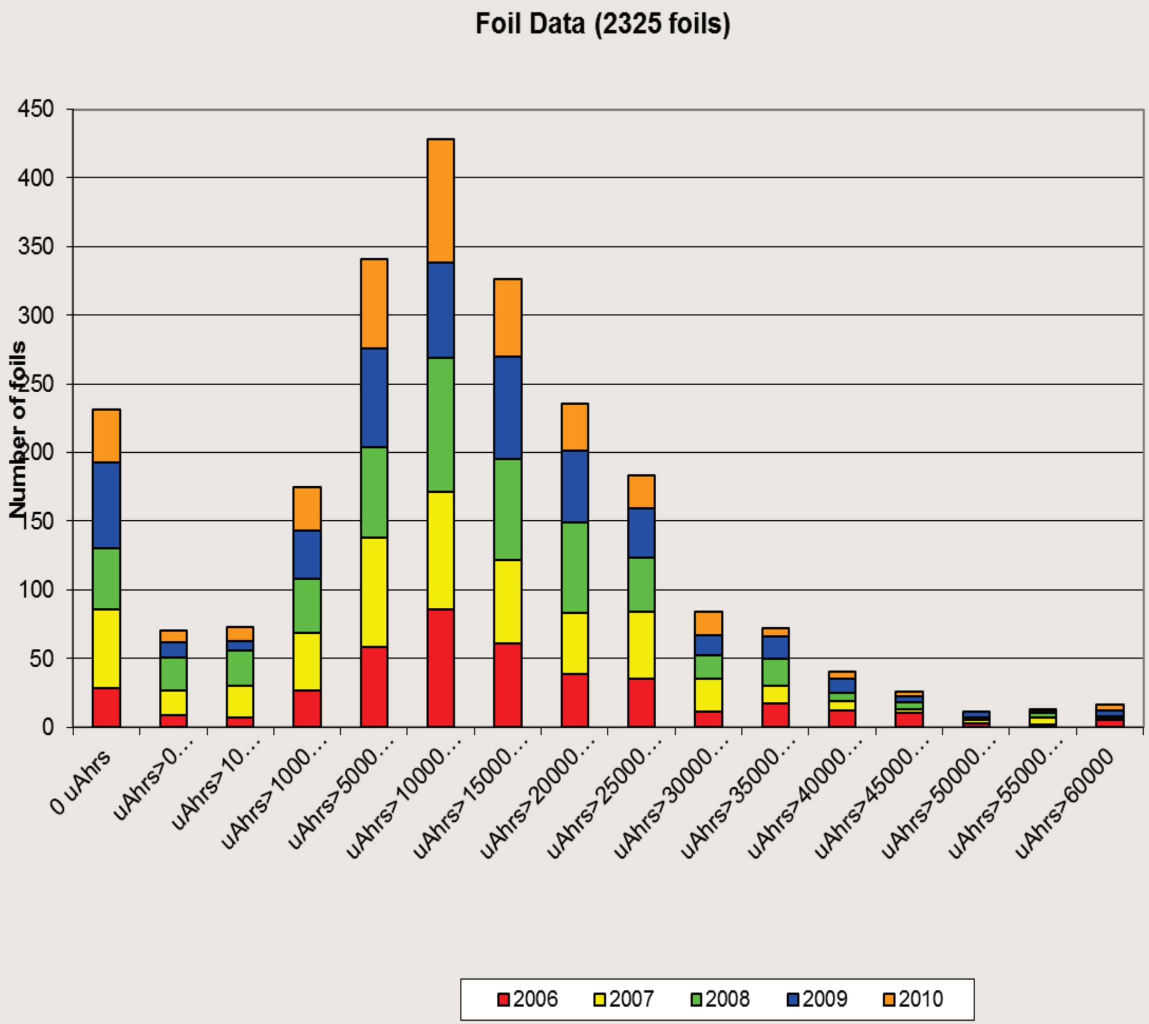
Extraction Foils

Tank pressure recovery after a carousel change (in yellow) and Dees voltage during RF conditioning



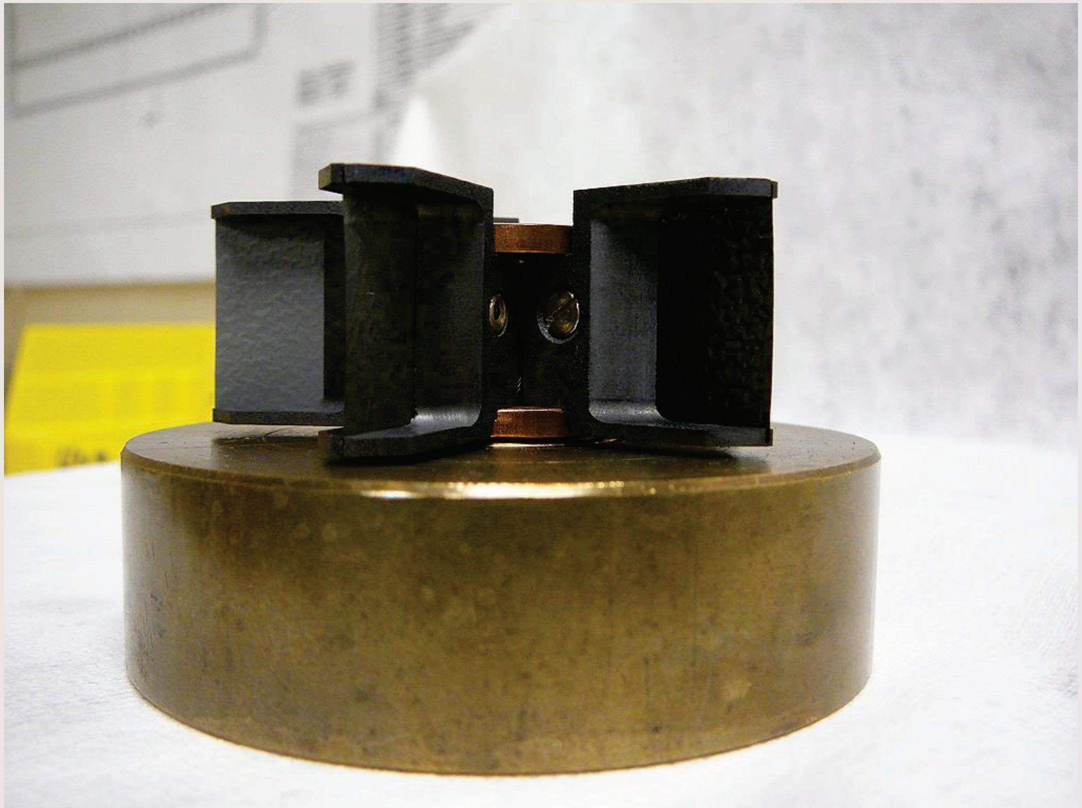
Extraction Foils

- 2325 foils over 5 years on all 4 beam lines (both cyclotrons)
- Average charge is about 15mAh
- No difference in average charge related to beam level
- Differences are related to beam instability on the foil scheduled or inadvertent



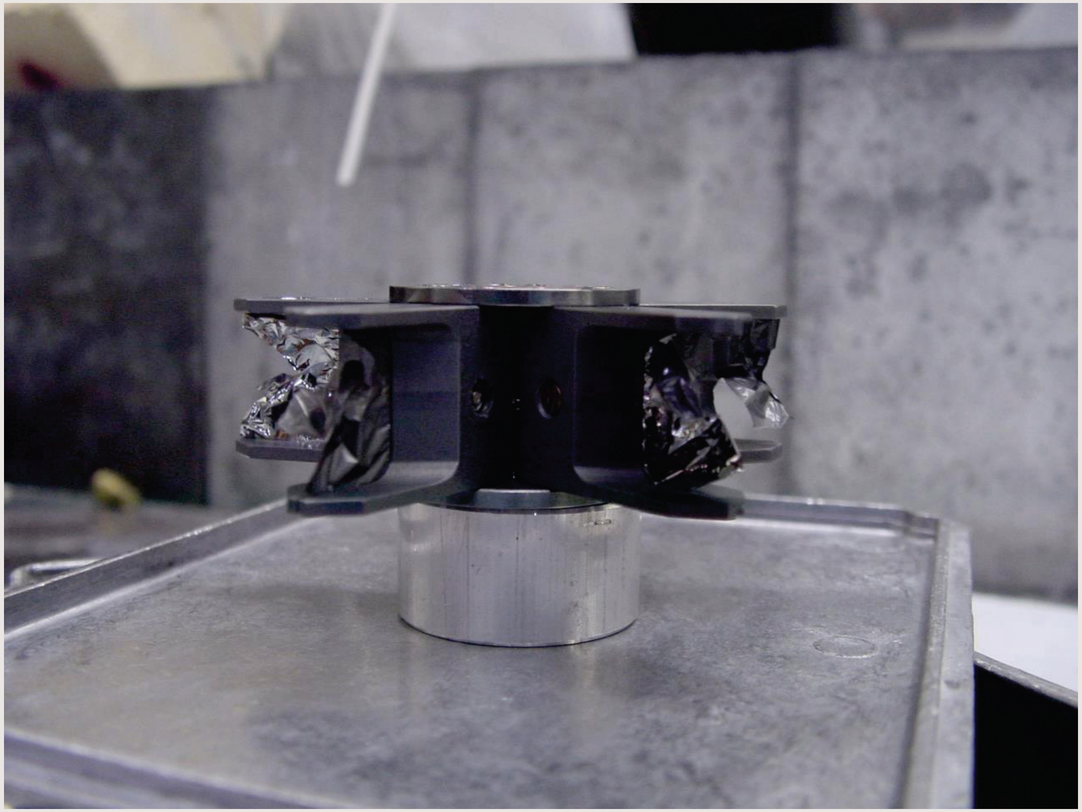
Extraction Foils

New extraction foils before installation



Extraction Foils

Used foils on extraction carousel



RF Components

Amplifier components

- RF tube
- High voltage capacitors
- RF drivers

Affect only uptime, not beam amplitude before and after the change

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RF Components

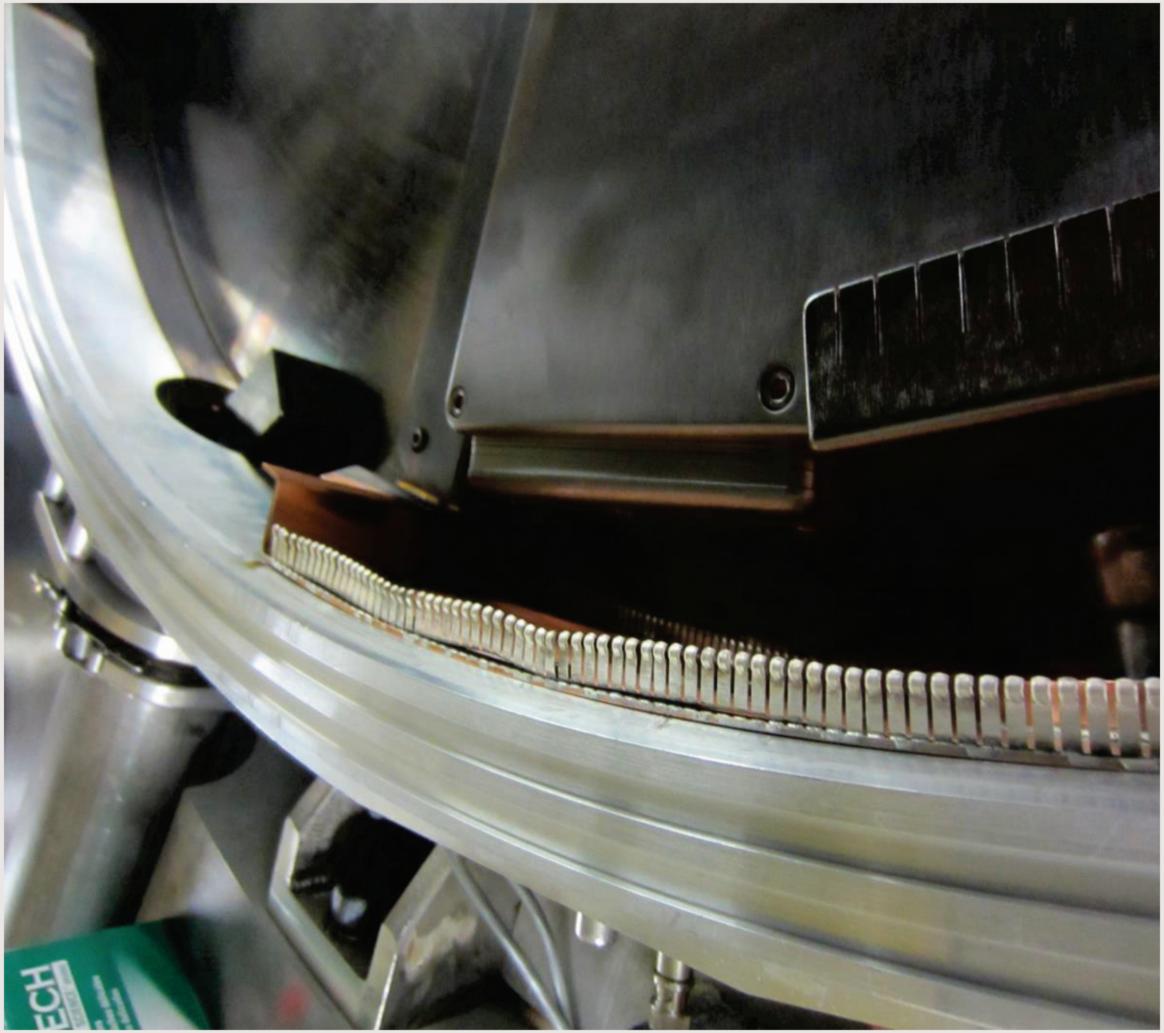
Components inside the tank

- Dees
- Couplers
- Liners

- We have experienced a peak in TR30-1 RF failures after 20 years of quasi continuous operation.
- Dees and RF liners developed water leaks and soldering fractures.

RF Components

TR30-1 liner with fractures in soldering



RF Components

TR30-1 Dee out for fixing a leak in a water cooling line

Dees were replaced with new ones in the following year

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RF Components

TR30-1 Dees repair:

- Radiation fields
- Contaminated parts

RF Components

RF Components inside the tank

- Maintenance and beam recovery take from 3 days to about a week or more:
  - Cool-down (high radiation fields and contaminated parts)
  - Complex work, alignment involved in a difficult space
  - Vacuum recovery
  - RF conditioning

  Affect both beam amplitude (limited beam due to RF instabilities before and after the repair) and uptime

Diagnostics

Most failures are occurring at the 1 MeV probe

- Fails an average of once every 16 months
- tank access is necessary
- Few days recovery

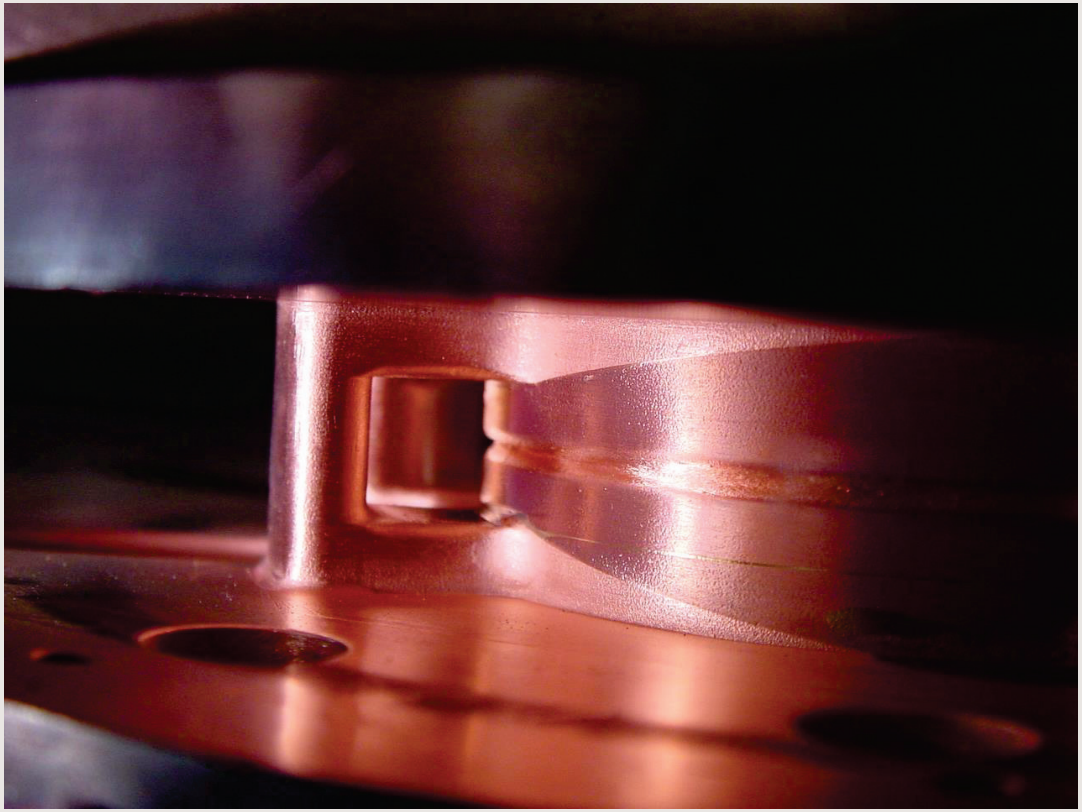
    Affects only uptime, not beam amplitude before and after the change

Centre Region

- Average accelerated current is limited by phase acceptance
- Space charge, both transverse and longitudinal are also limitations
- These limitations are becoming more evident when beams >1mA are accelerated
- About 10mA DC currents have to be produced by the Ion Source to accelerate >1 mA. We observe a overall transmission deterioration at these current levels
- Unaccepted beam ends on different parts of the Centre Region

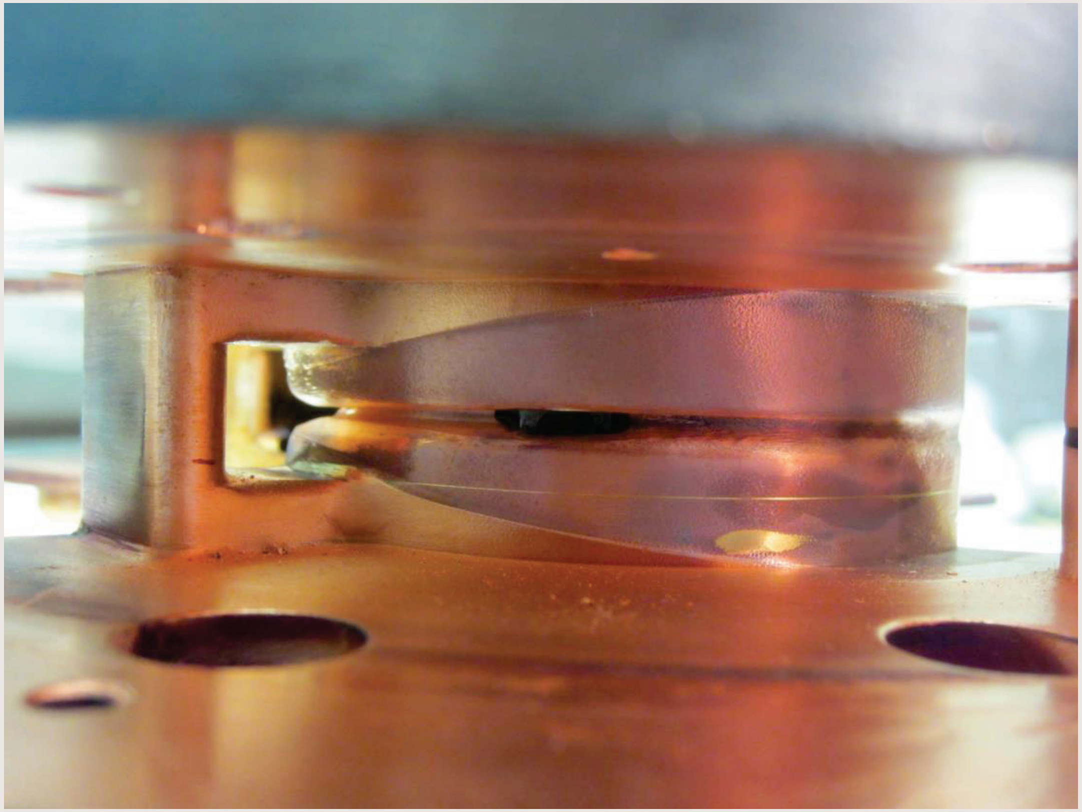
Centre Region

TR30-2 Centre Region post after 2 years of beam



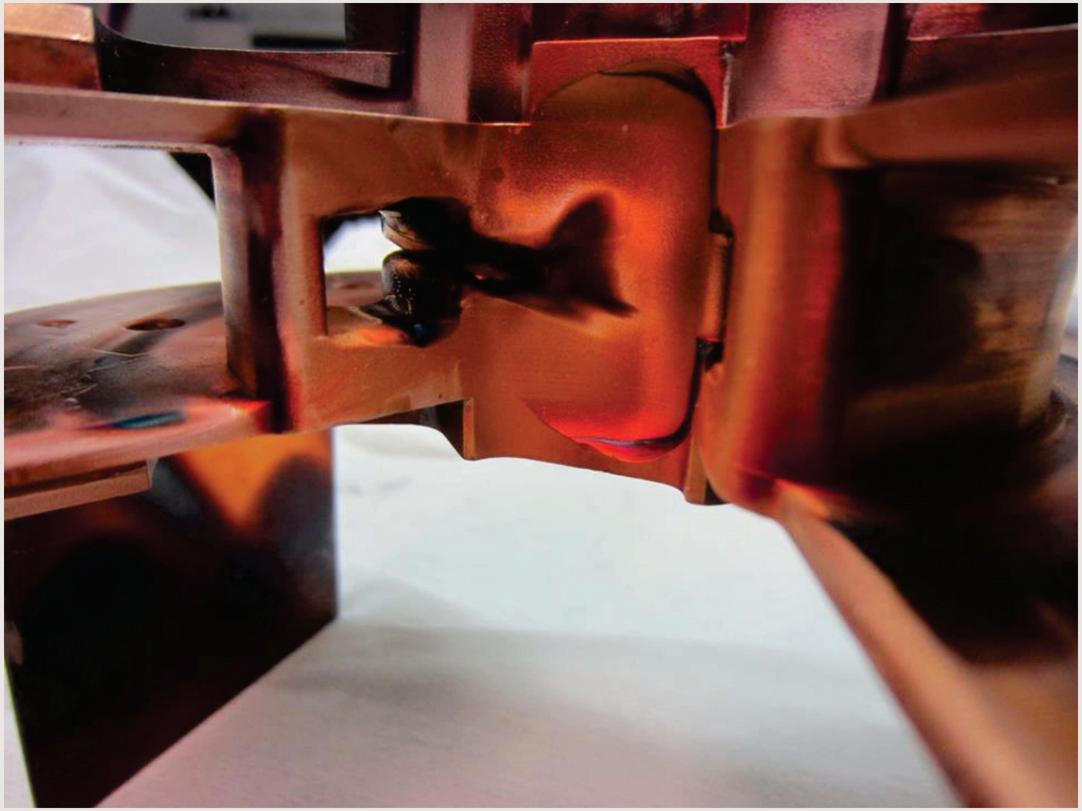
Centre Region

TR30-2 Centre Region after 10 years of beam



Centre Region

TR30-2 Centre Region deterioration



Centre Region

Dee tip - same machine

Centre Region

- Sputtering of metal surfaces is evident with its detrimental consequences in this area
- Beam stability, RF stability are affected
- Beam amplitude is eventually affected
- Misalignment during this process, and possible after maintenance due to conditions in the tank will further contribute to overall transmission deterioration
- Maintenance and beam recovery take about a week
  - Cool-down (high radiation fields and contaminated parts)
  - Complex work, alignment involved in a difficult space
  - Vacuum recovery
  - RF conditioning

Affects both beam amplitude before the repair and uptime

Extracted Beam

- Our usual maximum extracted beam amplitudes are up around 400μA to 500 μA (on each beam line)
- We experimented with increasing a single beam amplitude from 600 μA to 750 μA on target (this requires more then 900 μA total extracted).
- We were limited by heavy beam losses along the beam line in our existing configuration and target collimators. Example: the horizontal collimators currents doubled from 23 μA to 46 μA.

Cyclotrons Availability

- Availability is the ratio between the sum of beam running and standby hours to the total hours in a year
- Targets downtimes are specific to our application, excluding them would increase the averages to 75% and 80%
- Differences between the two cyclotrons are due to the higher target change frequency in TR30-1 and the Dees work done in 2010 and 2011

Year	TR03-1 [%]	TR30-2 [%]
2000	66	
2001	71	
2002	76	
2003	72	
2004	83	68
2005	91	76
2005	73	78
2007	69	70
2008	64	81
2009	64	75
2010	56	79
2011	55	78
2012	66	70
Average	70	75

Conclusions

- TR30s are generally reliable, compact, and high intensity cyclotrons
- Considering their performances in terms of charge (mAh), and when running close to the space charge limits in a 24/365 type of operation, we found practical limitations in both current amplitude and machines availability
- Some of these limits are possible to surmount with improvements in design, manufacturing and maintenance
- Some limits are inherent to this type of compact cyclotron and a different approach might be necessary to produce beams beyond 1.5 to 2 mA in long term applications

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Thank you!

Ion Source and Injection Line

Same inflector with its collimator seen from the injection line side