Welcome!

• to Birmingham

• to the University of Birmingham
Birmingham

- The 2nd largest city in the UK (city 1.1M, metropolitan region >3M)
- Not an old historic city: developed with the Industrial Revolution

Between 1775 and 1800 James Watt and Matthew Boulton made 450 steam engines in their Birmingham factory
Physics at the University of Birmingham

1940: Frisch + Peierls Memorandum: theoretically showed that a bomb could be made using a small amount of $^{235}\text{U}$

1940: Boot, Randall + Sayers developed the cavity magnetron
History of accelerators at Birmingham

60” Nuffield cyclotron (1948-1999) 10MeV p, 40MeV α

Construction started
1937: copy of Lawrence’s
60” cyclotron

Operated 51 years

Yoke etc still in place: can be visited this afternoon
History of accelerators at Birmingham

1 GeV Proton synchrotron
(1953-1967)

Mark Oliphant had idea for proton synchrotron

Birmingham machine overtaken during construction by Brookhaven Cosmotron
History of accelerators at Birmingham

Radial Ridge Cyclotron (1960-2002)
(axially injected polarised beams) 12MeV d, 24 MeV α, 33MeV \(^3\)He

Completely decommissioned after 2002: yoke now in Nuffield vault
History of accelerators at Birmingham

RDI 3MV Dynamitron (1970 - )

3MeV p on Li for BNCT
The MC40 cyclotron

is the third cyclotron to be operated at the University of Birmingham

In 2002-2004 transferred from Minneapolis to Birmingham
In 2005 we added a 12-way switching magnet (blue) [ex Vivitron]
One beam line ran into adjacent room (past Dynamitron accelerator) and was used for studying radiation effects (e.g. space electronics).
More recently, we were asked to provide high dose-rate damage studies (LHC ATLAS group and metallurgy) so extended a second beam-line into a specially shielded area.
High current irradiation cell:
ATLAS line on left,
Metallurgy chamber on right

Low current irradiation line:
Radiobiology, space applications upstream,
Nuclear physics scattering chamber downstream.
In 2009 Birmingham acquired most parts from the decommissioned Hammersmith MC40
Beams available  (hot filament ion source)

- p  11-39 MeV and 3-9 MeV (N=2)
- d  5.5-19.5 MeV
- α  11-40 MeV
- $^3$He  33-54 MeV and 13-27 MeV

Also 46 MeV $^{14}$N$^{4+}$ and 70 MeV $^{14}$N$^{5+}$ for nuclear physics
Cyclotron is used for

- Producing positron emitting nuclides for Engineering PET [NOT FDG]
- Producing $^{81}$Rb for $^{81m}$Kr generators
- Thin Layer Activation
- Other isotope production:
  - $^{69}$Ge for labelling oil
  - $^{62}$Zn supplied to St Thomas’ Hospital London
  - Various irradiations for NPL
- Radiation effects studies:
  - Radiobiology + dosimetry (proton imaging)
  - Space electronics etc
  - ATLAS components
  - Metallurgy of nuclear materials
- Nuclear physics (student projects)
Positron emission particle tracking (PEPT)

Label a single particle (grain of sand, etc) with positron-emitter (usually $^{18}$F from $^{3}$He on natural oxygen) and track it as it moves inside equipment.
Twin Screw Extrusion of Polymers

Modular camera installed on Modified Leistritz 27mm TSE

Screw Elements in FOV
Tracer particles for PEPT (continued)

Most are labelled with $^{18}\text{F}$ (half-life 110 min) produced by cyclotron irradiation of oxygen $[^{16}\text{O}(^{3}\text{He}, \text{p})^{18}\text{F}]$:

- “Large” (>1mm) particles of silica, alumina etc are directly activated – activity firmly fixed in bulk
- Smaller particles, and other materials (plastics etc) are indirectly labelled – produce $^{18}\text{F}$ in solution and then attach it to particle using appropriate surface chemistry (bridging ions, etc) - these tracer particles are generally OK except in aqueous environments, when the activity rapidly leaches off again

For aqueous environments, we have developed other radioisotope labels. For example, $^{66}\text{Ga}$ (9 hours) produced by proton irradiation of Zn, followed by cation exchange separation.
$^{81}\text{Rb}$ (4.6 h)
Parent of $^{81\text{m}}\text{Kr}$ (gas), which decays (13s) to g.s. emitting 190 keV gamma

(Parent/daughter generator)

$^{81\text{m}}\text{Kr}$ used for imaging lung function using gamma camera
^81^Rb production

Using the technique developed at MRC Cyclotron Unit (Hammersmith):

- Irradiate target containing $^82$Kr gas (6 bar pressure) with 29 MeV protons (30µA)
- $^81$Rb is produced and deposits on walls of target
- At end of irradiation, recover $^82$Kr gas cryostatically
- Then elute $^81$Rb from target: 3 x 40ml transferred to dispensing room.
- Finally evacuate target ready for reuse.

Currently making approx 60 generators per week – fairly stable

Entire procedure is controlled by Beckhoff PLC.
Same PLC has gradually been extended to control cyclotron interlocks etc

$^81$Rb Production statistics

Started $^81$Rb production in March 2006
5 evenings per week, 50 weeks per year

To end of March 2014, attempted production on 1994 days, of which 1933 were successful (97% success rate)

Have produced over 27k generators
Thin Layer Activation

For measuring wear on components (especially automotive parts, for R&D): irradiate surface with beam from accelerator to create long-lived radionuclide in well-defined surface layer (typically ~ 50µm deep). Subsequently monitor surface removal by detecting gamma-rays either from remaining layer or from wear debris.

Steel:
- $^{56}\text{Fe}(p,n)^{56}\text{Co}$ (77 days, 0.85 MeV and 1.24 MeV gammas)
- $^{56}\text{Fe}(d,n)^{57}\text{Co}$ (270 days, 0.122 MeV gammas)
- Might activate different surfaces with each for simultaneous studies

Aluminium
- Best probably $^{27}\text{Al}(^3\text{He}, 2\alpha)^{22}\text{Na}$ (2.7 years, 0.511 MeV and 1.27 MeV gammas)

Diamond-like carbon (DLC) coatings
- $^{12}\text{C}(^3\text{He}, 2\alpha)^7\text{Be}$ (53 days, 0.47 MeV gamma)
ATLAS radiation hardness testing

Samples in cold box (fed with liquid nitrogen) scanned through 27 MeV proton beam
Cyclotron is used for

- Producing positron emitting nuclides for Engineering PET [NOT FDG]
- Producing $^{81}$Rb for $^{81m}$Kr generators
- Thin Layer Activation
- Other isotope production:
  - $^{69}$Ge for labelling oil
  - $^{62}$Zn supplied to St Thomas’ Hospital London
  - Various irradiations for NPL
- Radiation effects studies:
  - Radiobiology + dosimetry (proton imaging)
  - Space electronics etc
  - ATLAS components
  - Metallurgy of nuclear materials
- Nuclear physics (student projects)