Positron emitters produced from naturally occurring targets

T. W. Leadbeater, A. Buffler, T. Hutton, M. van Heerden

(University of Cape Town, South Africa)

Context

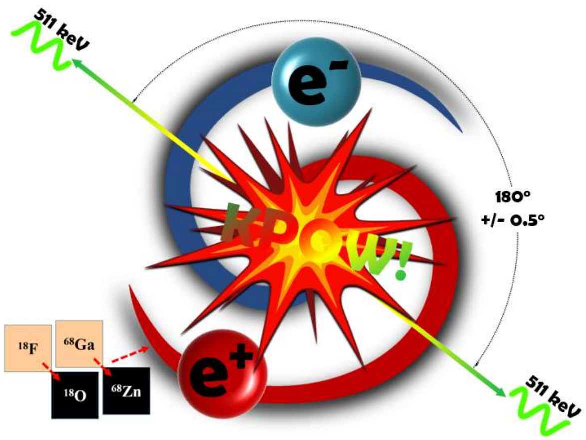
Source(s) of radioisotopes
Short lived
High specific activity
Chemical control

\+

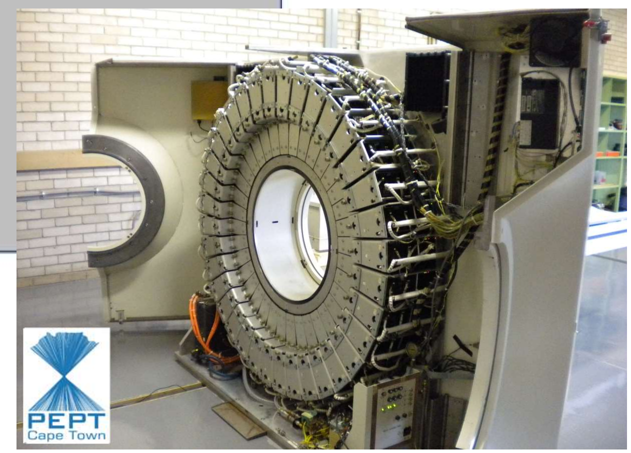
Materials of interest
Activation
Radiochemistry
"vector molecules"

\+

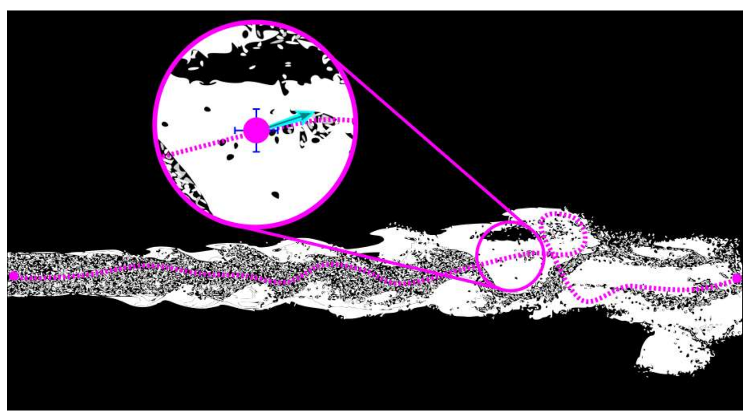
Detection of emissions
Instrumentation
Position sensitivity
Positron camera

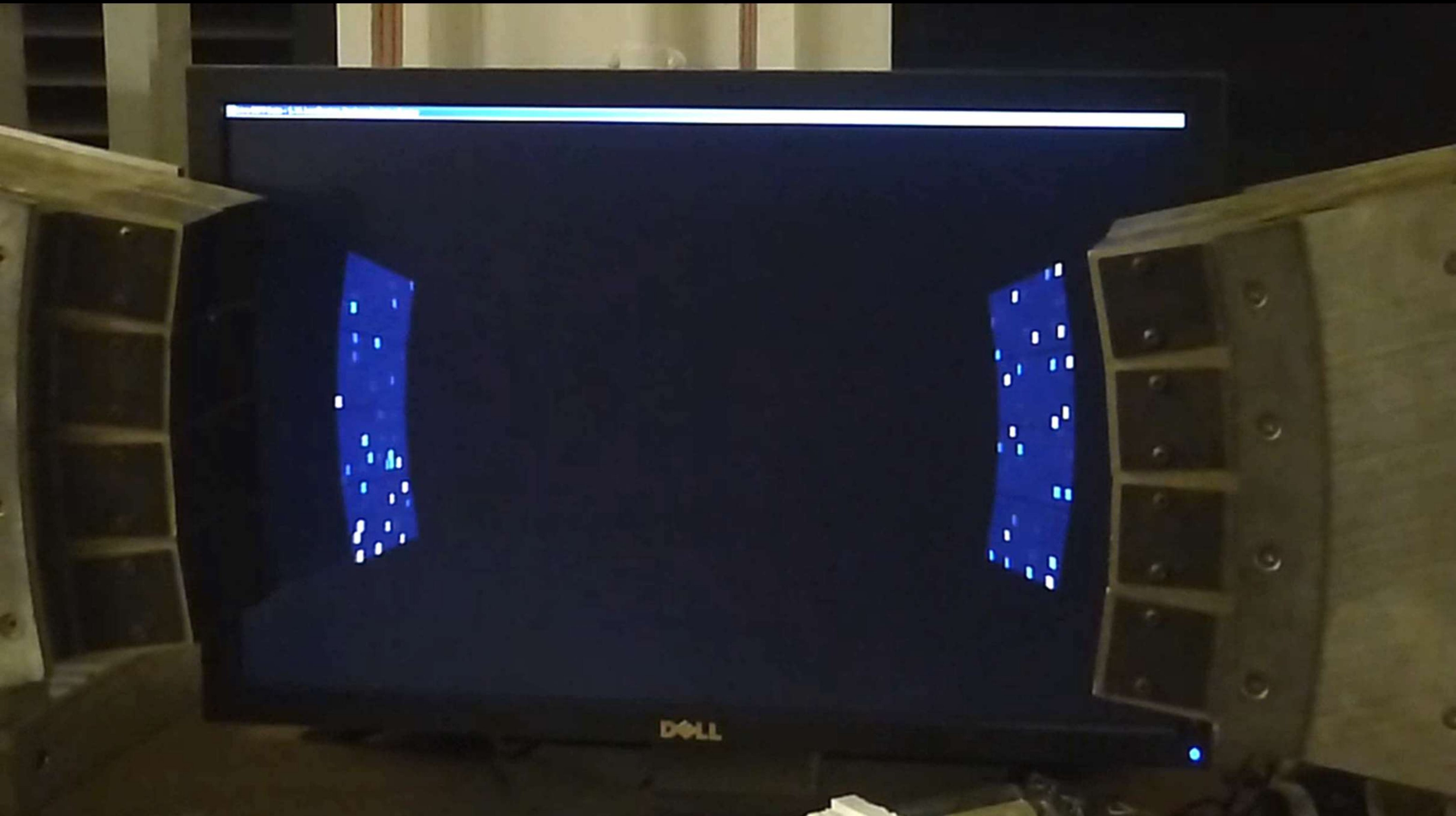


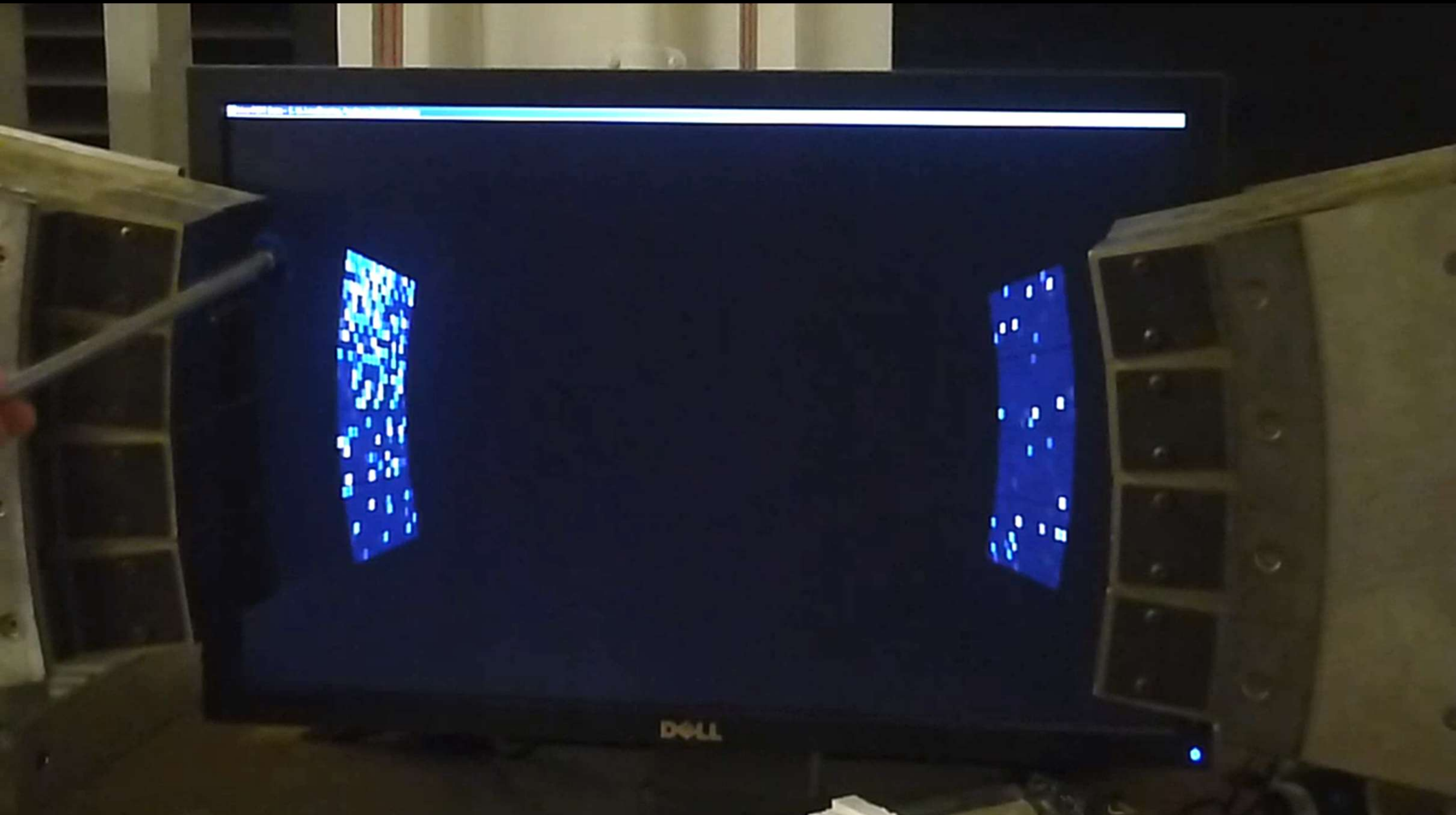
Novel experimental techniques
SPECT / PET / PEPT
Structure / function
Integral / Differential / Simulation

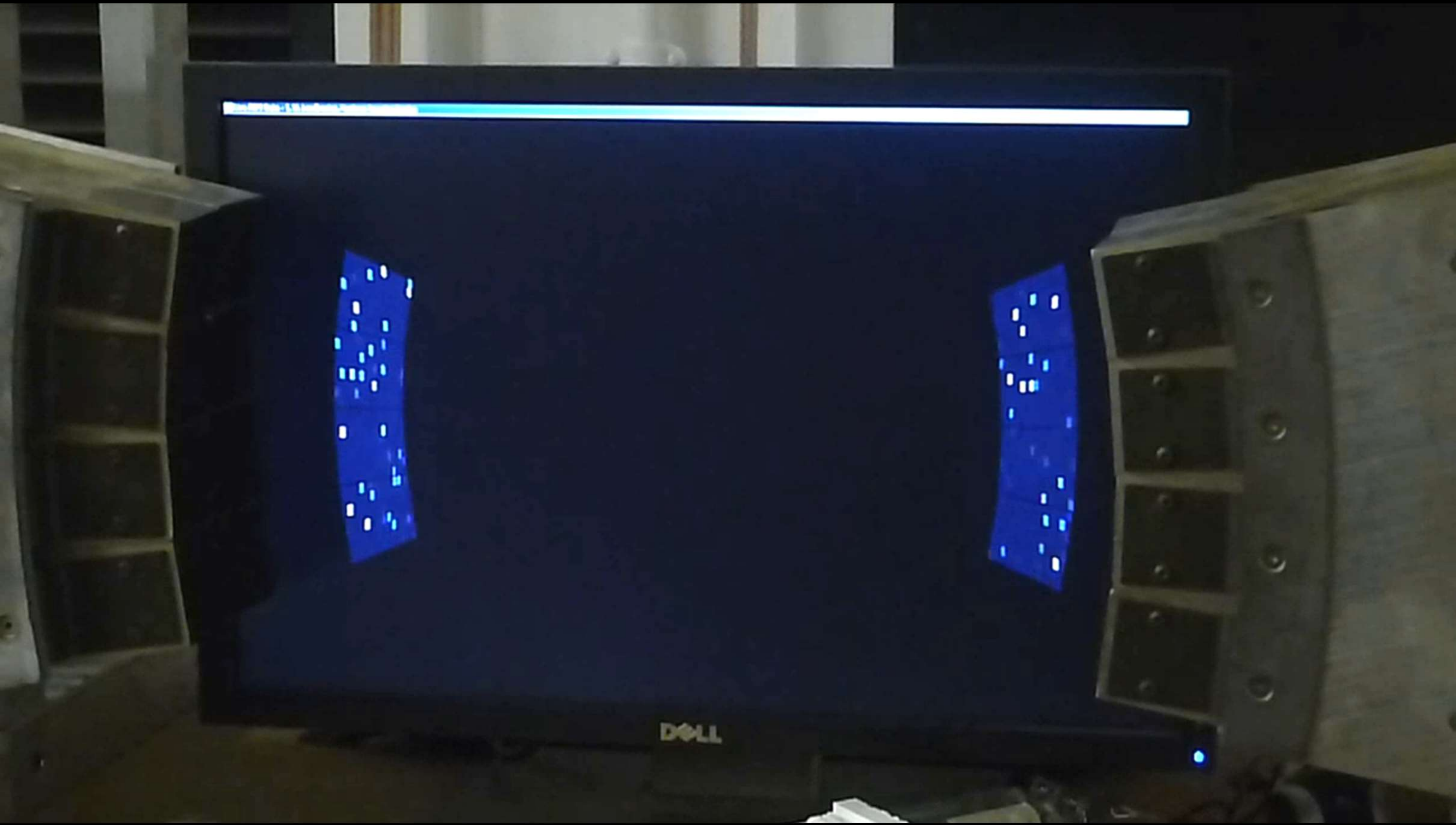


Applications
Real world flows
Engineering systems
Fundamental flows
Benchmarking




DELL

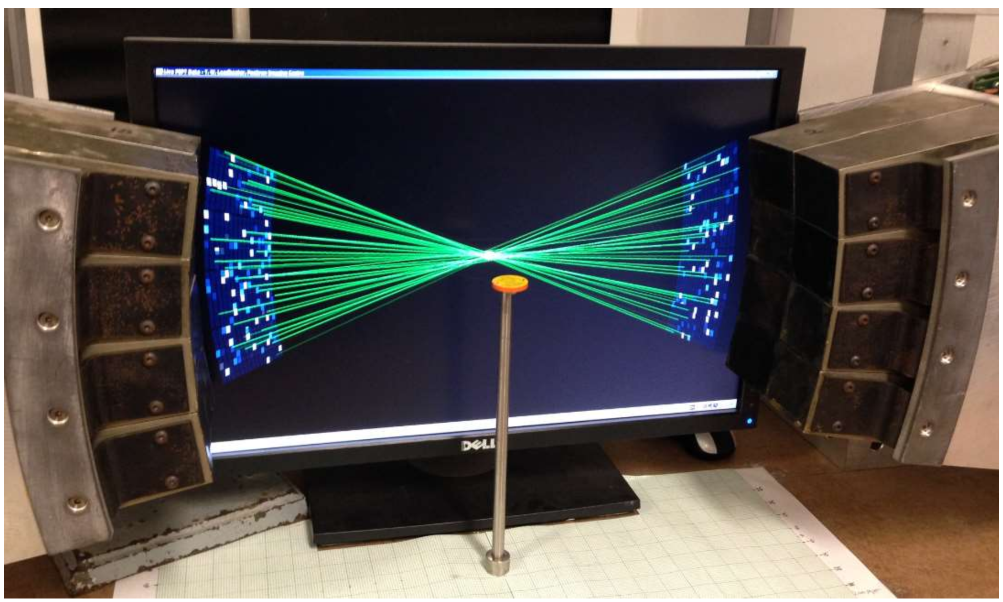




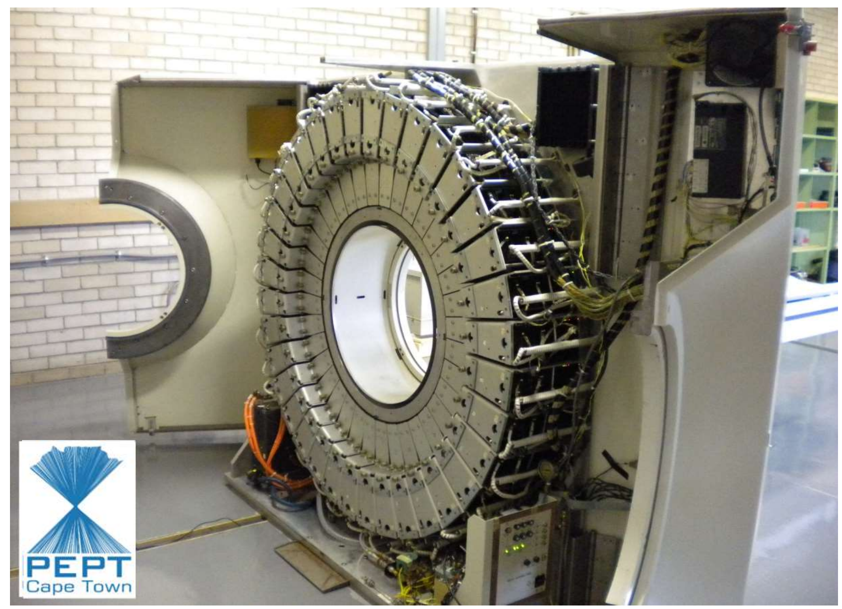
BGO Positron Cameras (UCT & iThemba LABS)

Millimetre scale segmented scintillators (@ 511 keV):
65% intrinsic efficiency, 30% energy resolution, 10 ns resolving time
Many parallel coincidence channels ($2\tau < 12$ ns), prompt + delayed
MHz data acquisition rates (singles, prompts, delayeds)
Applications, training & education, hardware development, …

@ UCT
1024 Crystals (expandable)



@ iThemba LABS
27648 Crystals (fixed)



Particles, Fluids & Mixed Phase Flows

- 3 dimensional tracer imaging
- Non-intrusive
- Opaque and dense systems
- Particle and liquid tracers
- High speed (kHz – MHz acquisition)
- Particle speeds up to 10 m/s
- Locations accurate to 0.5mm in 3D
- Well understood uncertainty budget

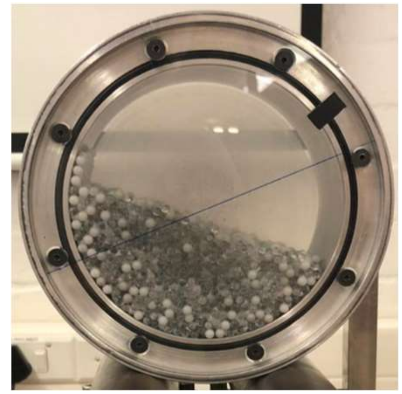
Fundamental flow studies

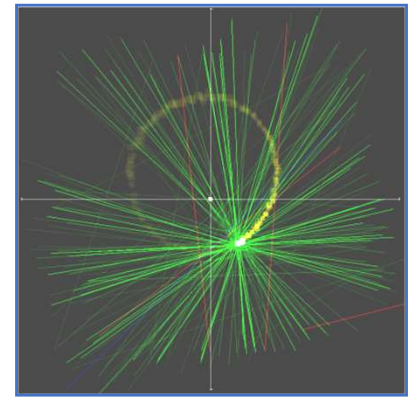
- development of transport models
- validation & benchmarking

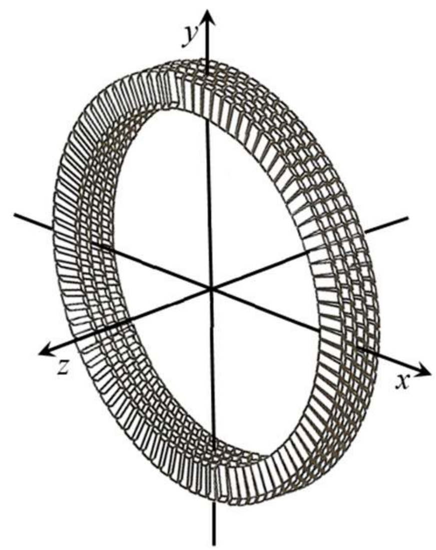
System-specific studies

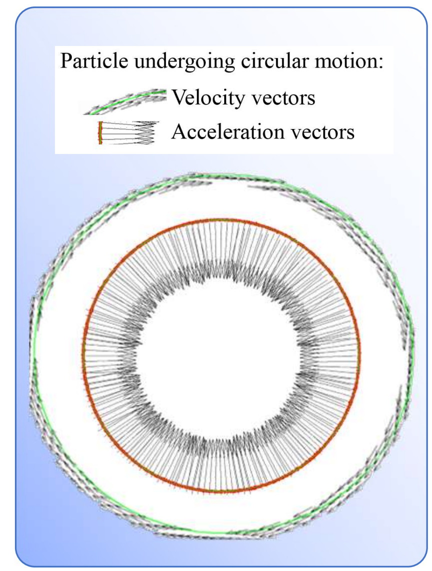
- system optimization and design
- multiphase systems, granulation,
- flotation cells…

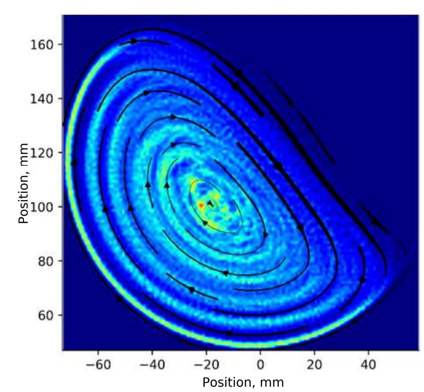
Knowledge driven design strategy

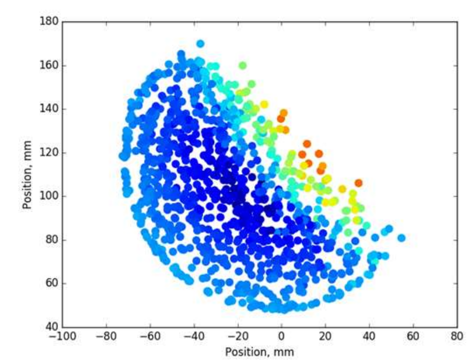


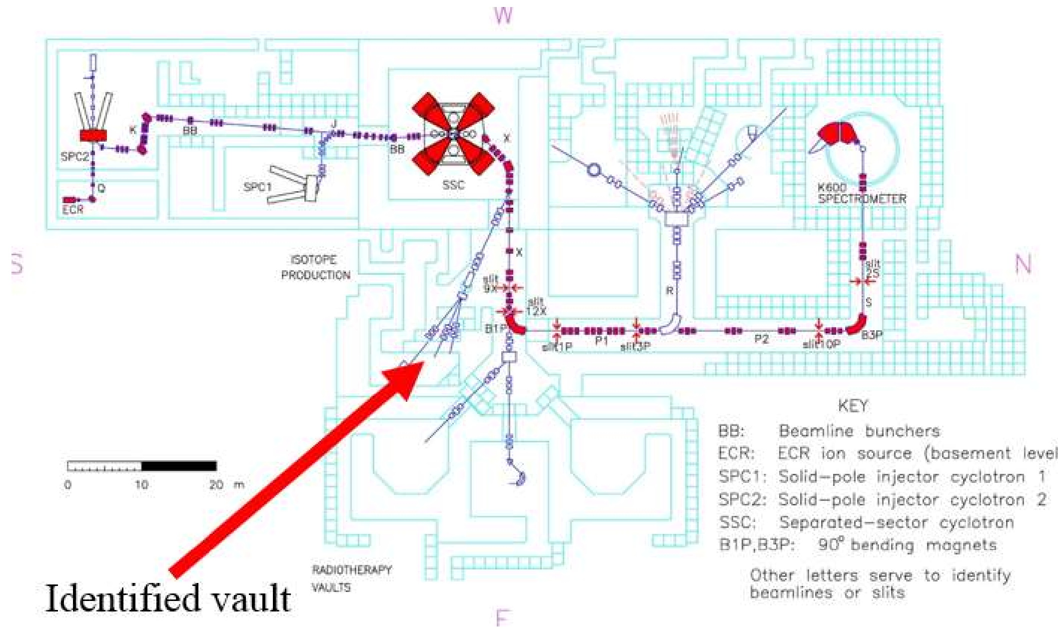








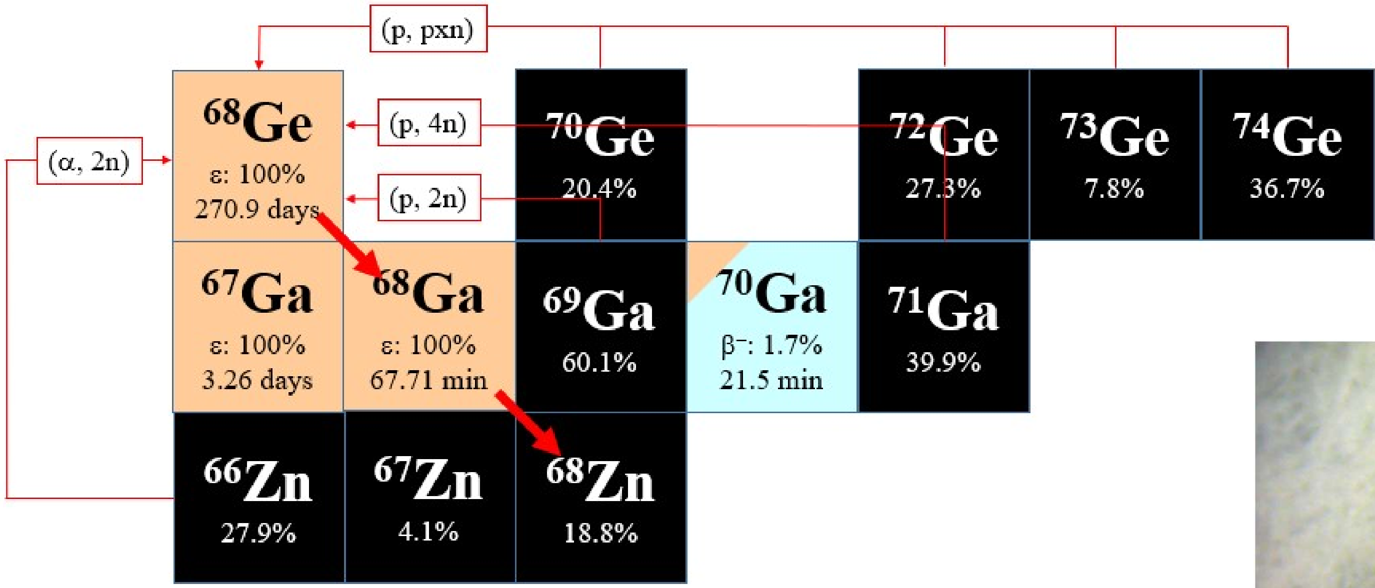




iThemba LABS accelerator infrastructure:

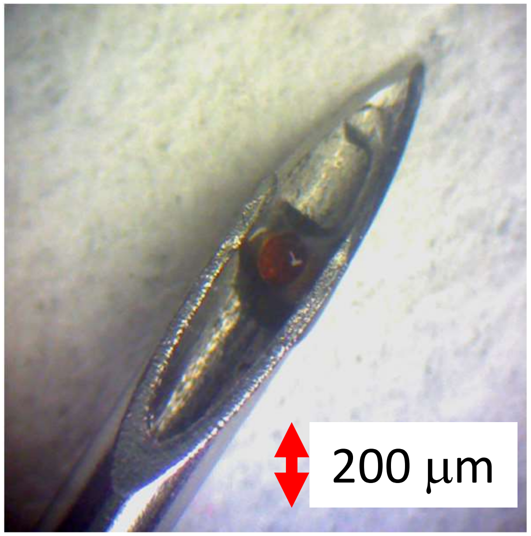
- Ion sources: PIG, ECR, proton & light ions, polarized proton…
- Solid pole injector cyclotron SPC1 ($k = 8$) & SPC2 ($k = 11$)
- $k = 200$ Separated Sector Cyclotron (SSC)
- 11 MeV PET cyclotron (^{18}F production)
- 70 MeV Cyclone cyclotron (new) (^{68}Ge production)

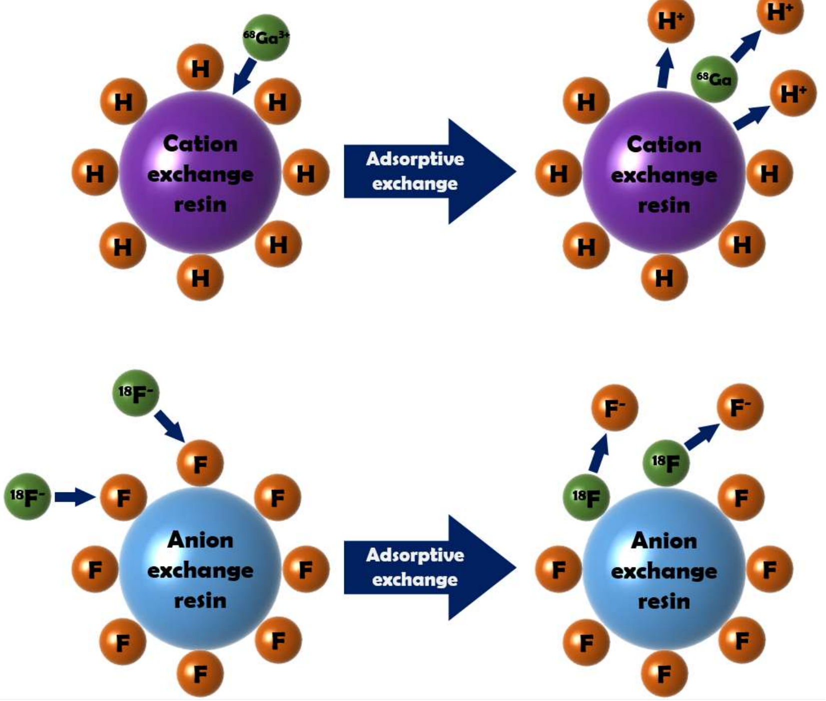
Radiochemical analogues: $^{68}Ge/^{68}Ga$



$^{nat}Ga(p, xn)^{68}Ge$

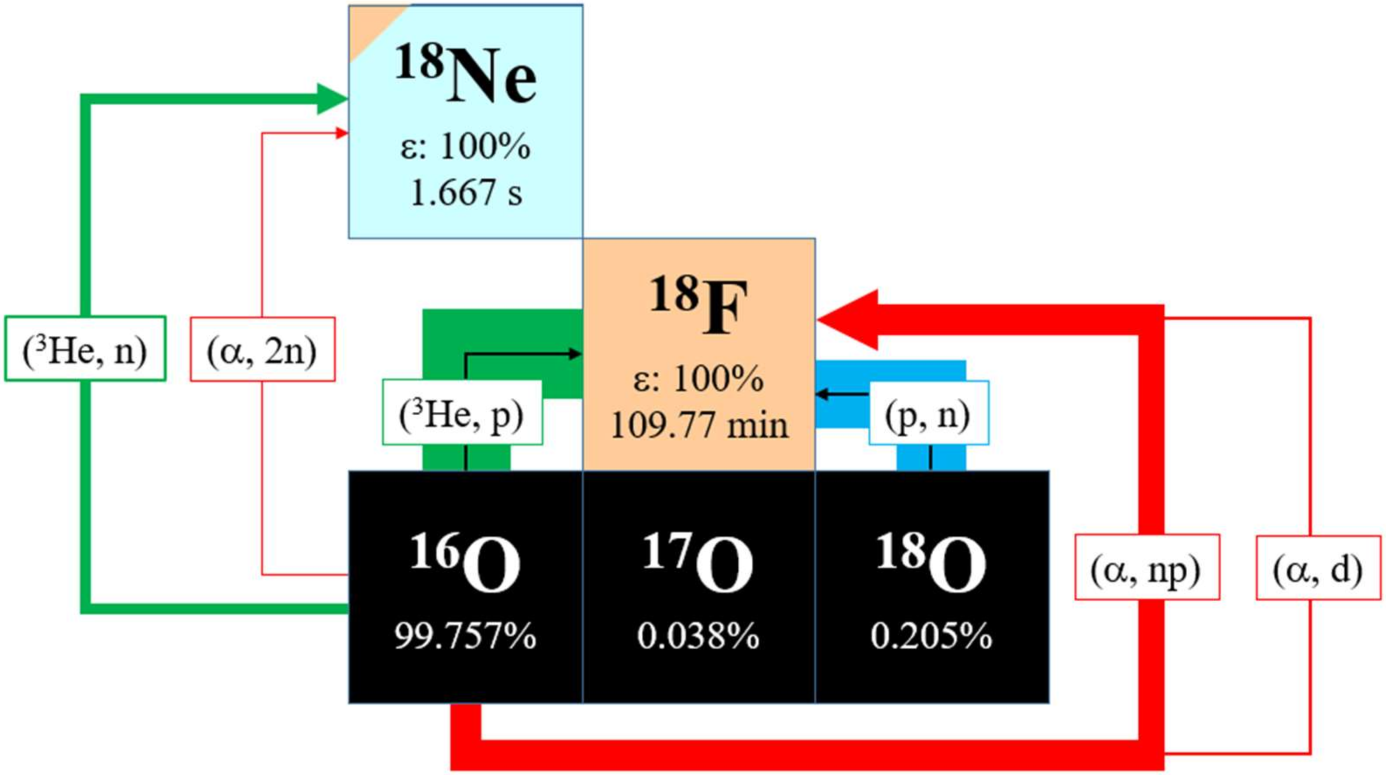
@ 66 MeV





- Phase representative analogue,
- or selected from bulk
- Size range 50 μm – 10’s mm
- Aggressive environments (high temperature, pressure)

^{18}F: Latin *fluor*, meaning “a flowing”



Typically **natural** materials required:

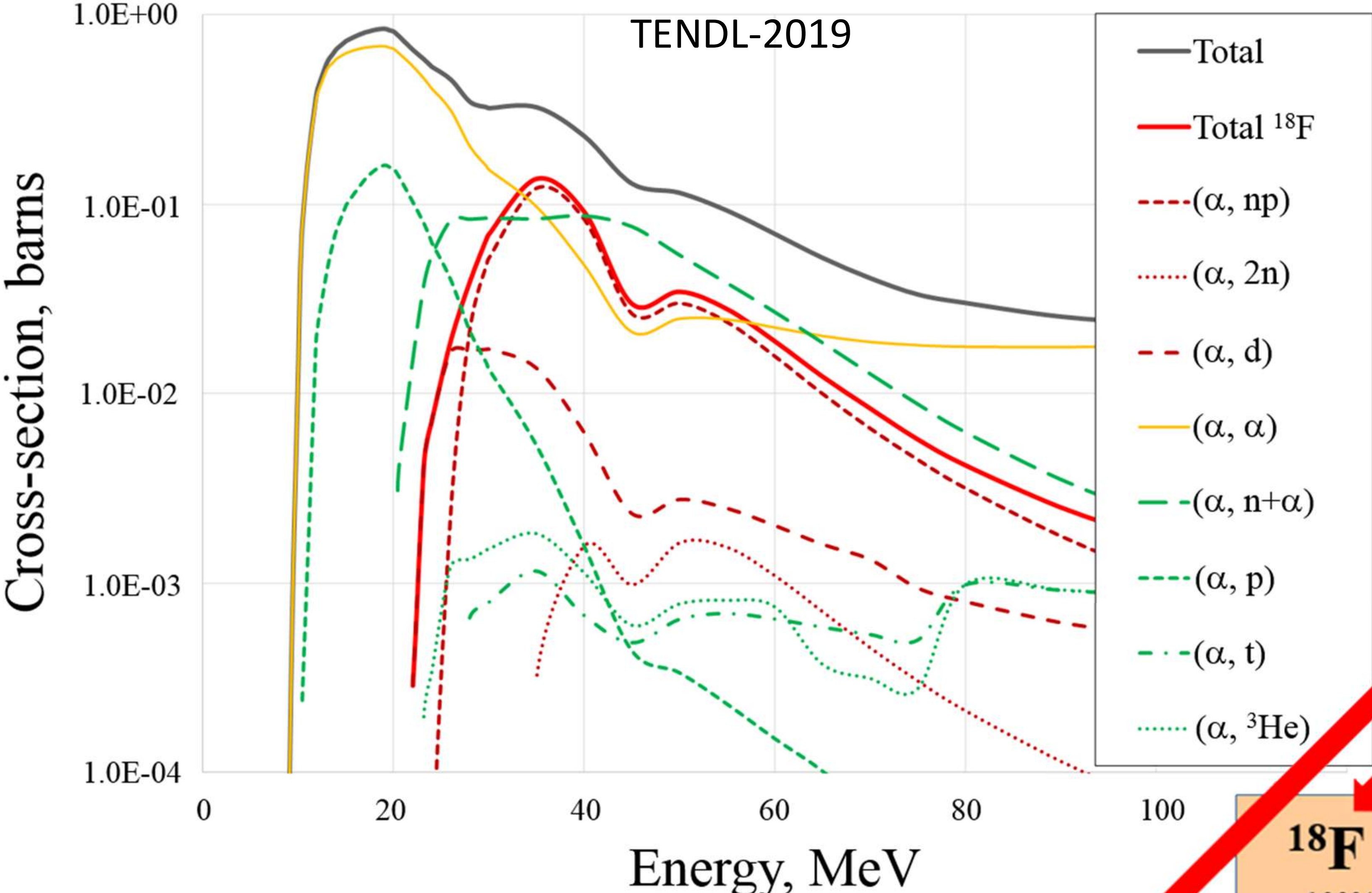
- Water (H_2O) (radiochemistry),
- Glass/silica (SiO_2),
- Mullite ($3Al_2O_3{\bullet}2SiO_2$),
- Magnetite (Fe_3O_4),
- Chromite ($FeCr_2O_4$)

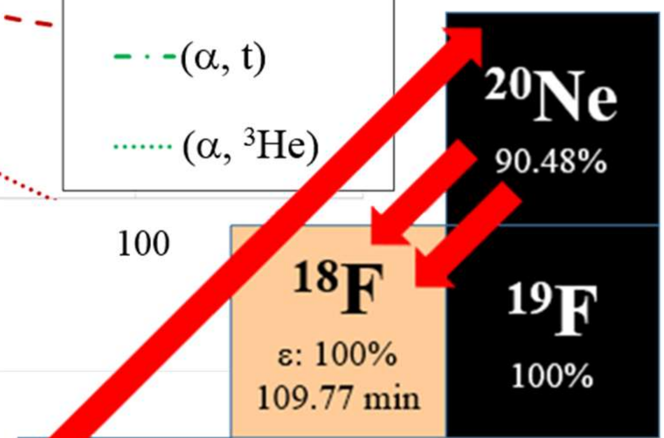
UNIVERSITY OF BIRMINGHAM

$^{16}O(^{3}He, p)^{18}F$

$^{16}O(^{3}He, n)^{18}Ne \rightarrow {}^{18}F$

“Novel” reactions: $^{16}O(\alpha, x)^{18}F$





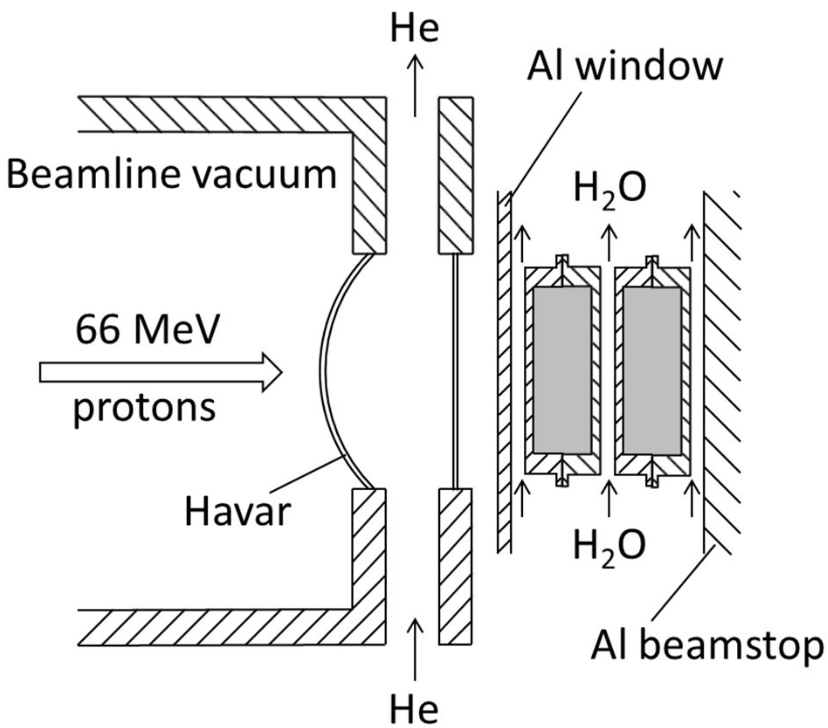
$^{16}O(\alpha, np)^{18}F$
$^{16}O(\alpha, d)^{18}F$
$^{16}O(\alpha, 2n)^{18}Ne \rightarrow {}^{18}F$

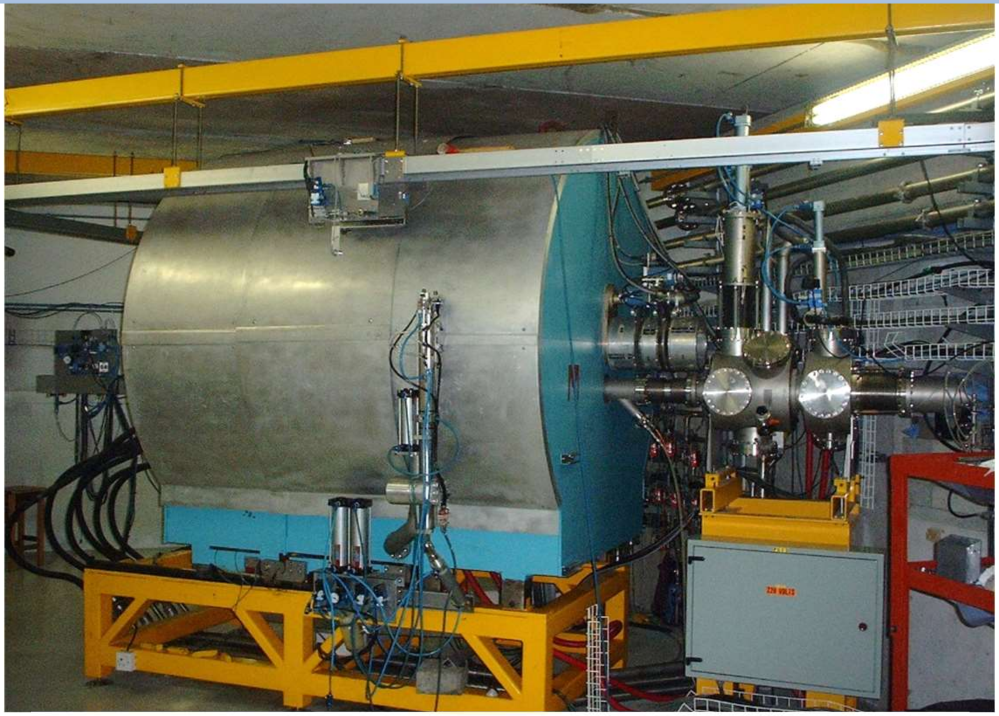
Activation @ iThemba LABS

Radionuclides currently produced with 66 MeV protons from SSC

^{22}Na, ^{68}Ge, ^{82}Sr, ^{123}I

Target Station 1: The Elephant
Horizontal-beam target station





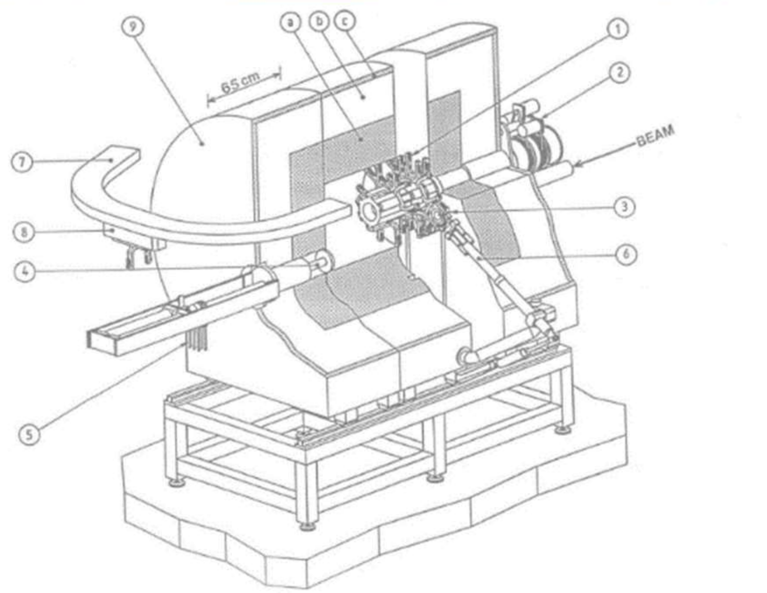
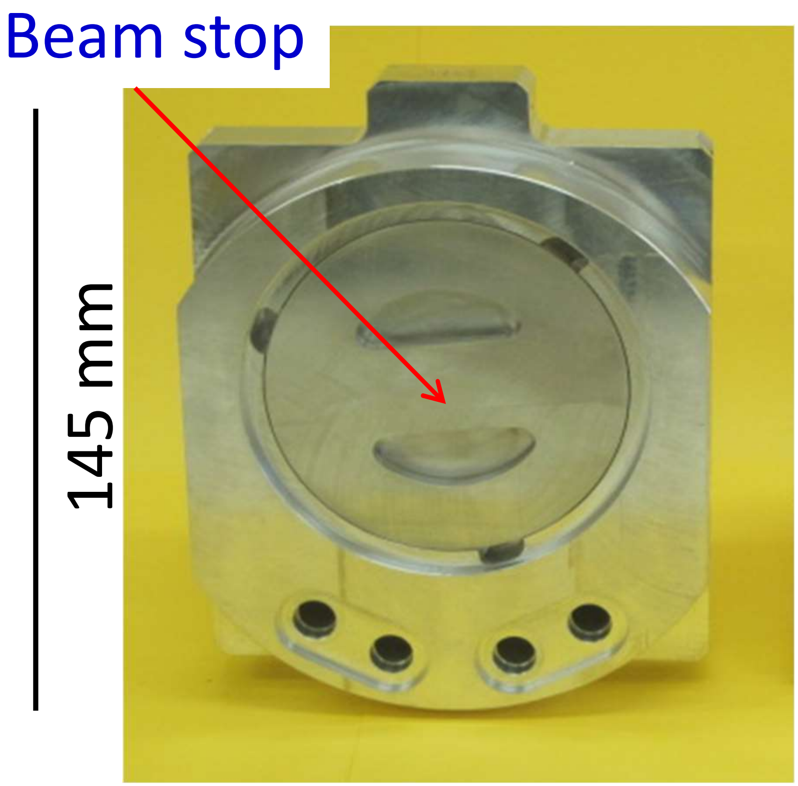


Fig.1 Perspective view of the target station, showing the rotary target magazines (1) and their motor drives (2), target in load/unload position (3), target pusher arm (4) with cooling water lines (5), target transfer robot arm (6), electric-rail target transport system (7) with trolley (8) and neutron attenuation shield (9), composed of iron (a), paraffin wax containing 2.5% boron-carbide (b) and lead (c). Also see photo in Fig. 2.

Target Holder

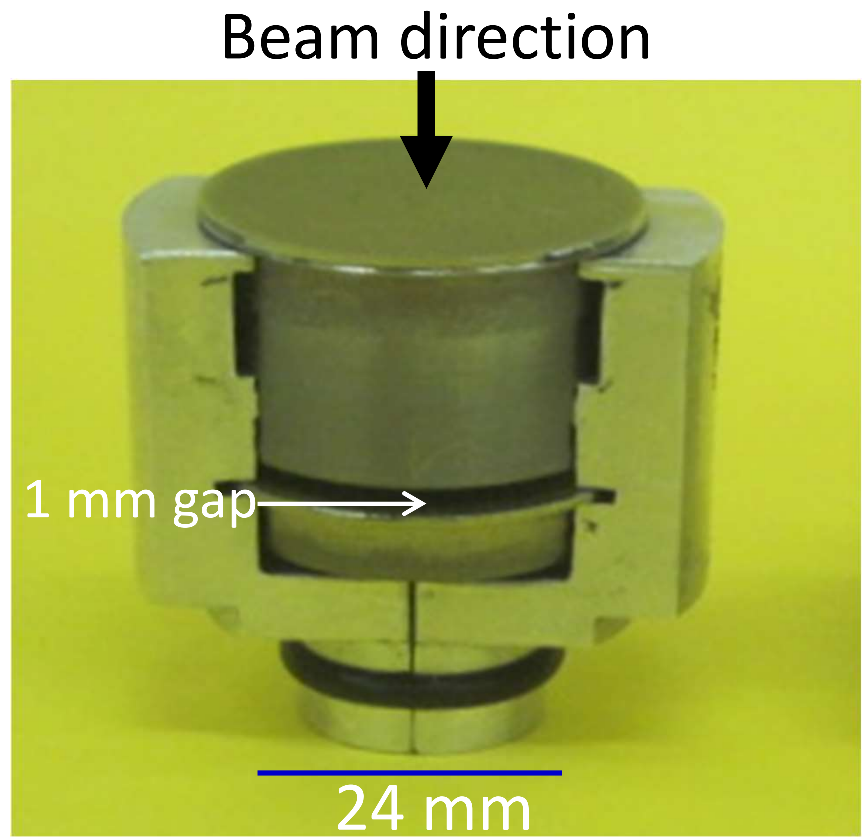
Water cooling, volume flow rate: 30 liter/min per port. Pressure: 10 bar.

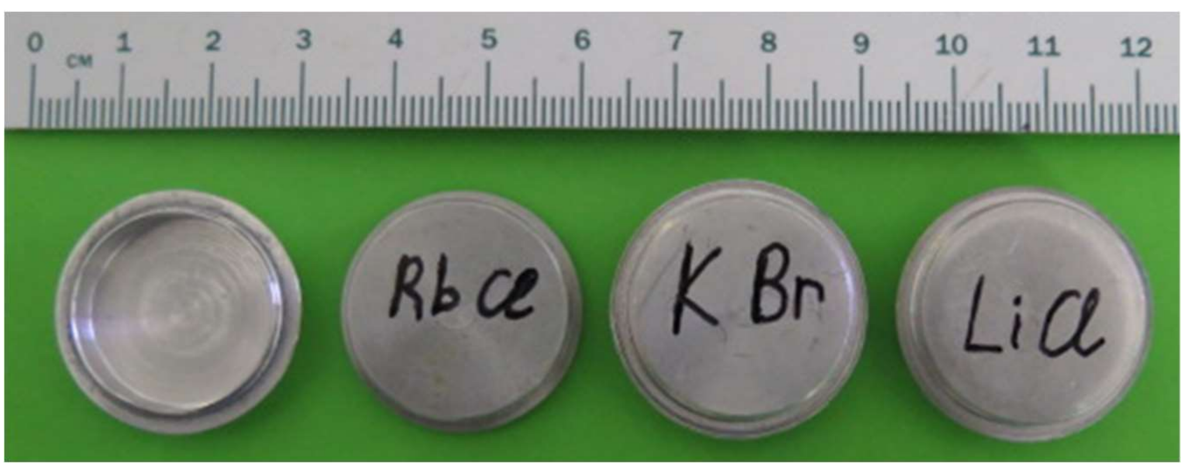


Encapsulation:

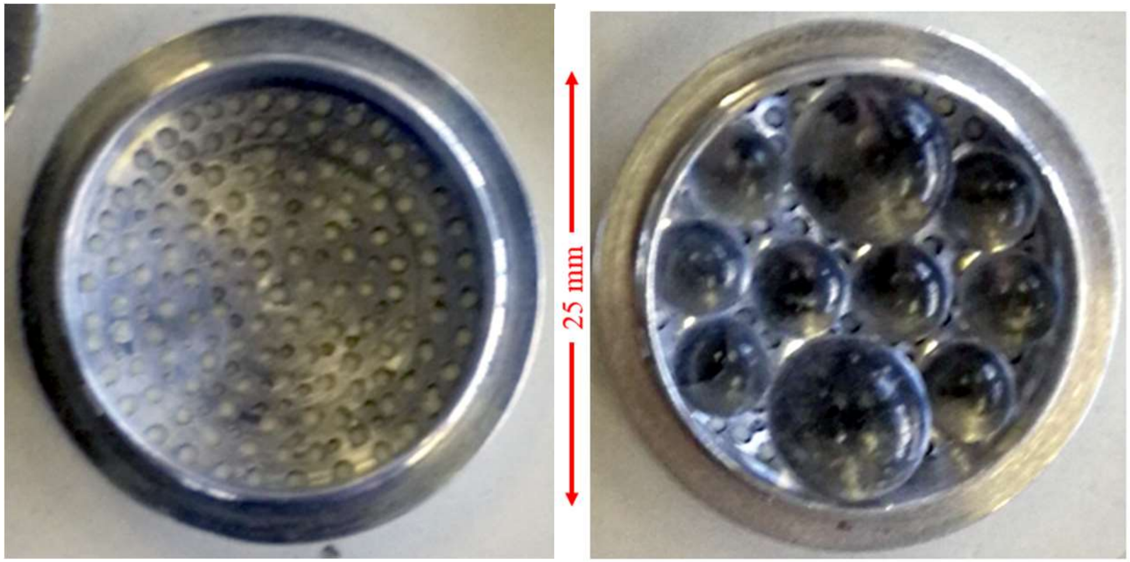
Stainless steel (316) for Rb, Niobium for Ga.

Cold indentation welding forms sealed target unit

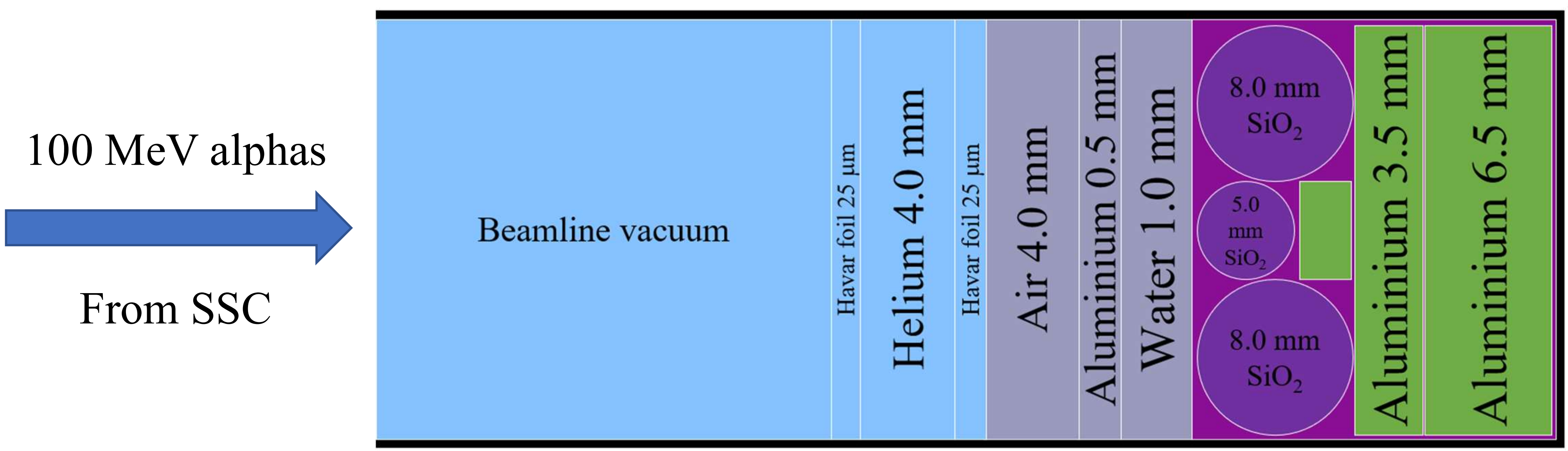




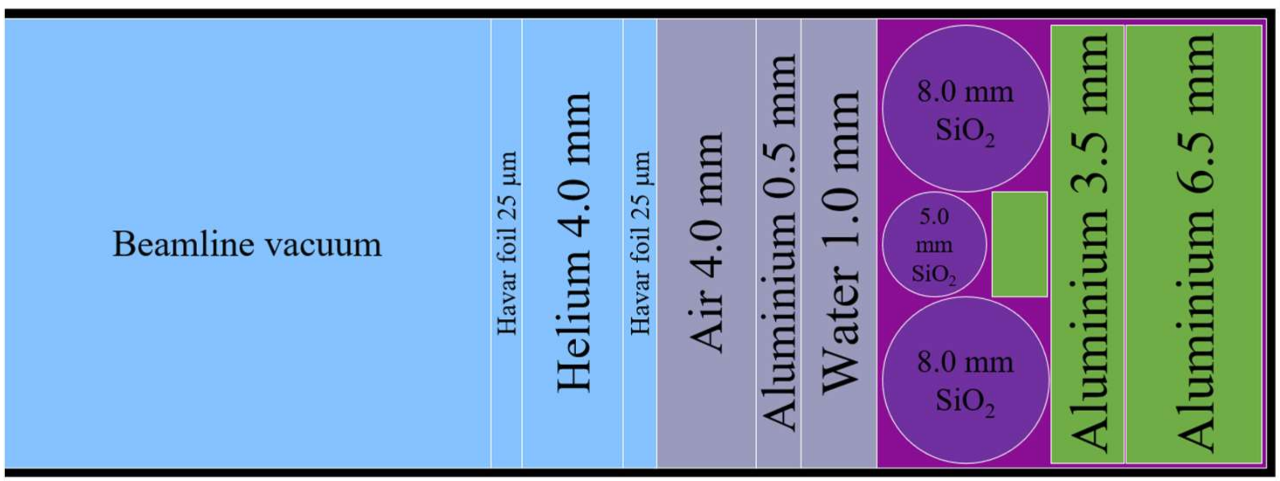
SiO_2 Targets: This Work

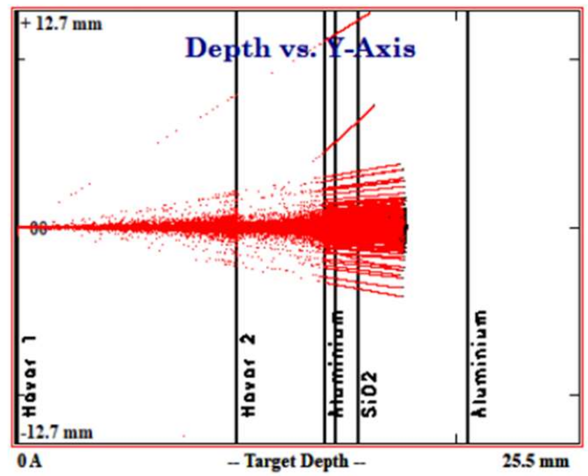


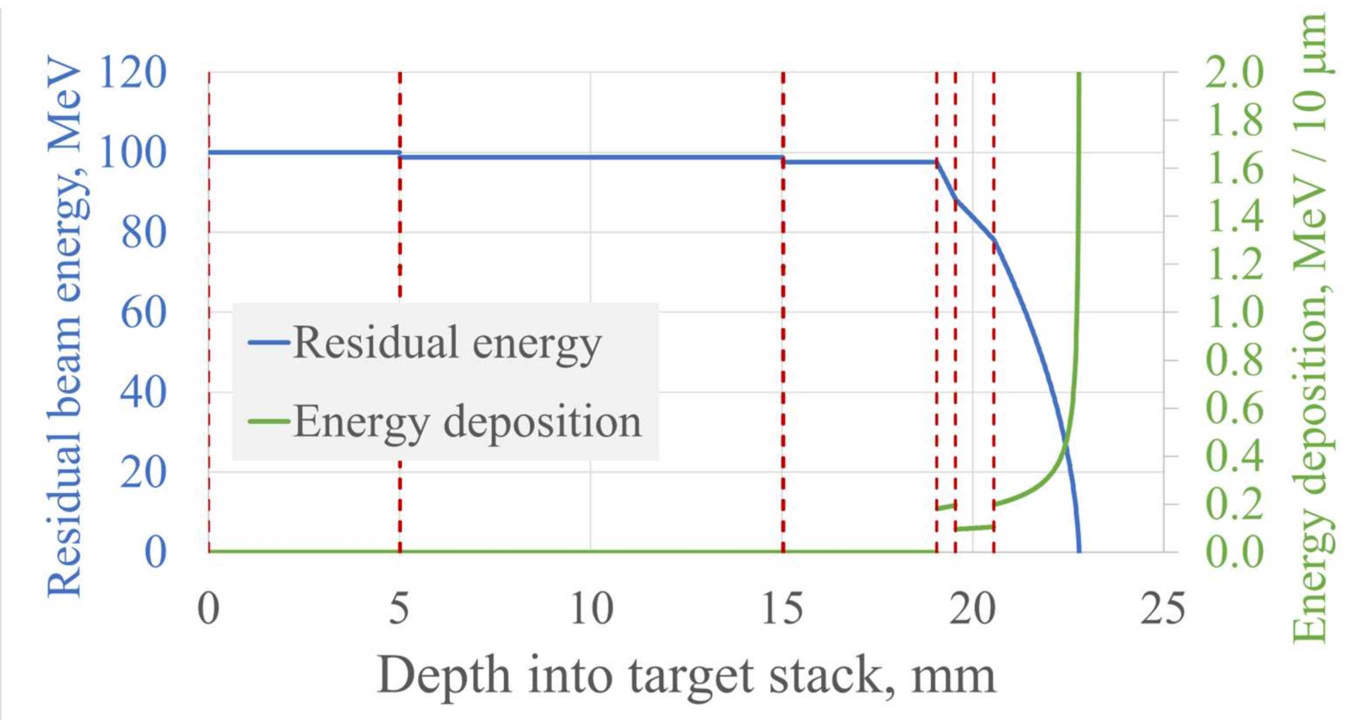
5 – 10 mm diameter SiO_2 (glass) spheres

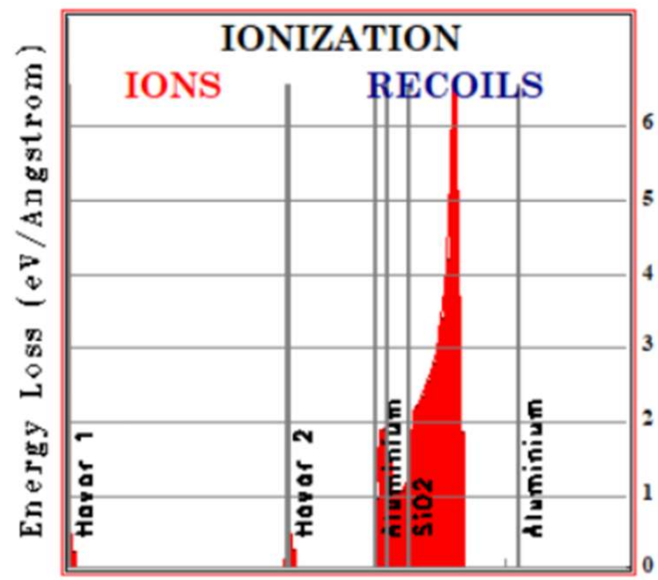


Modelling: Target stack

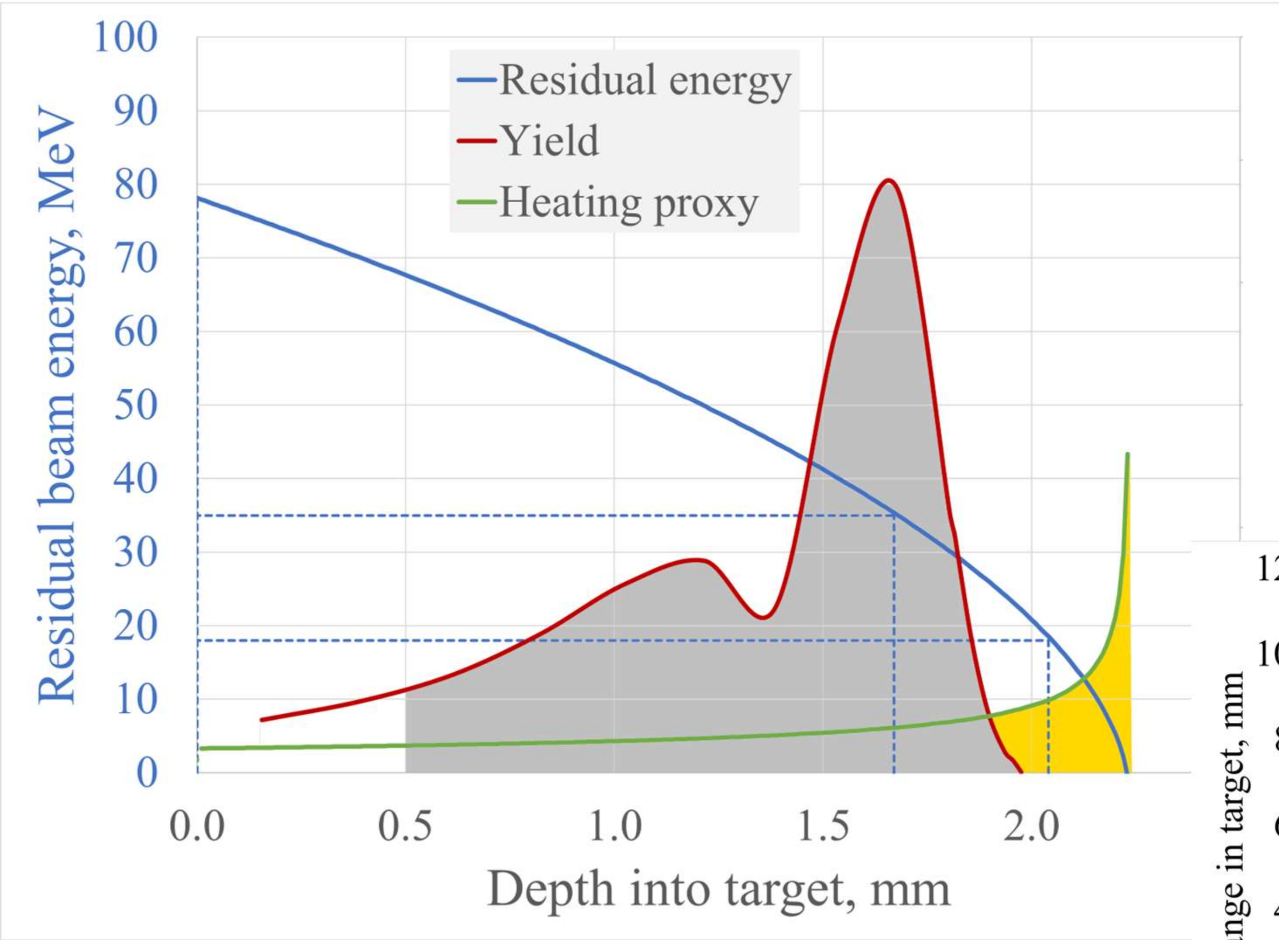


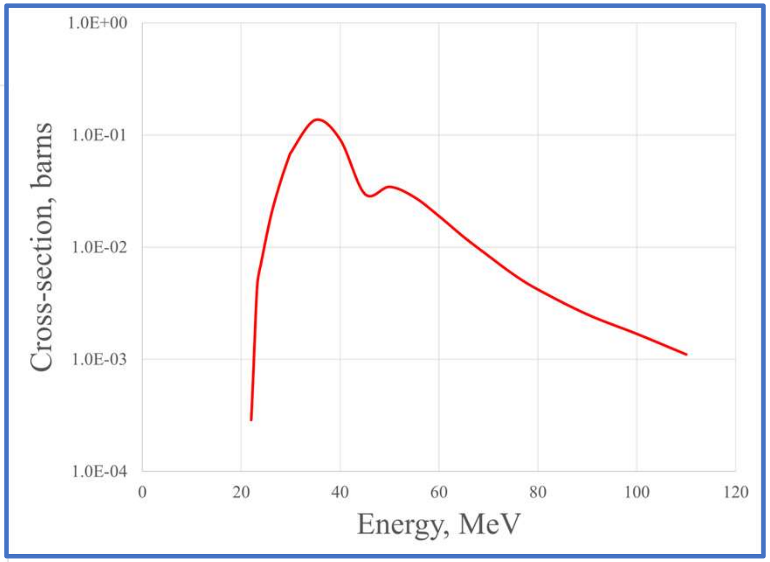


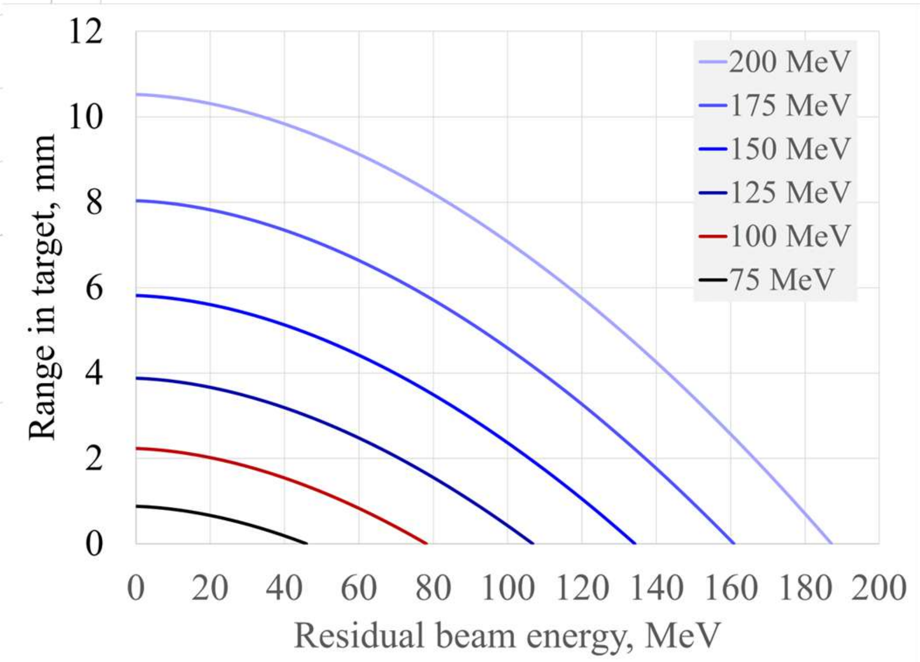




Modelling: Energy, Yield & Range



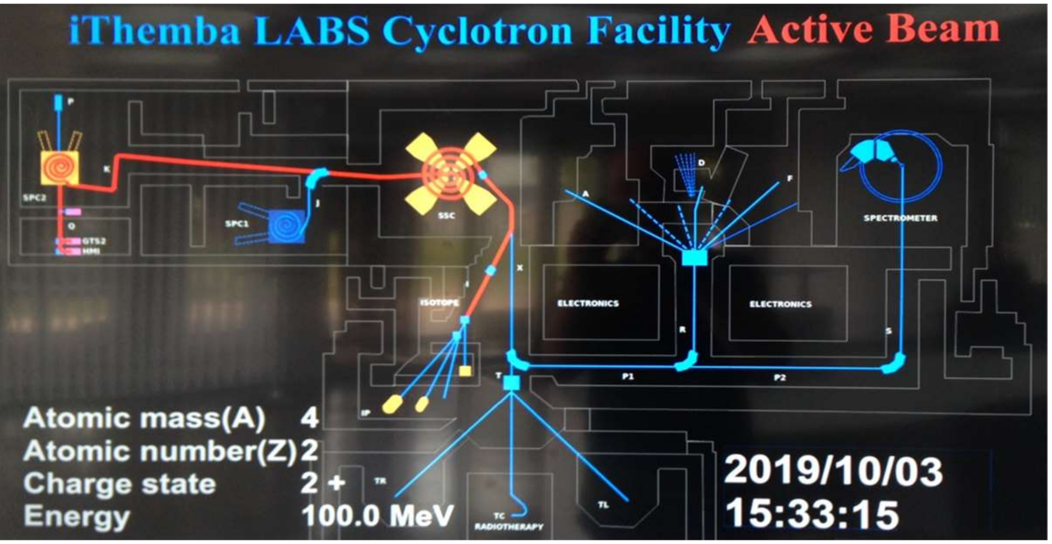


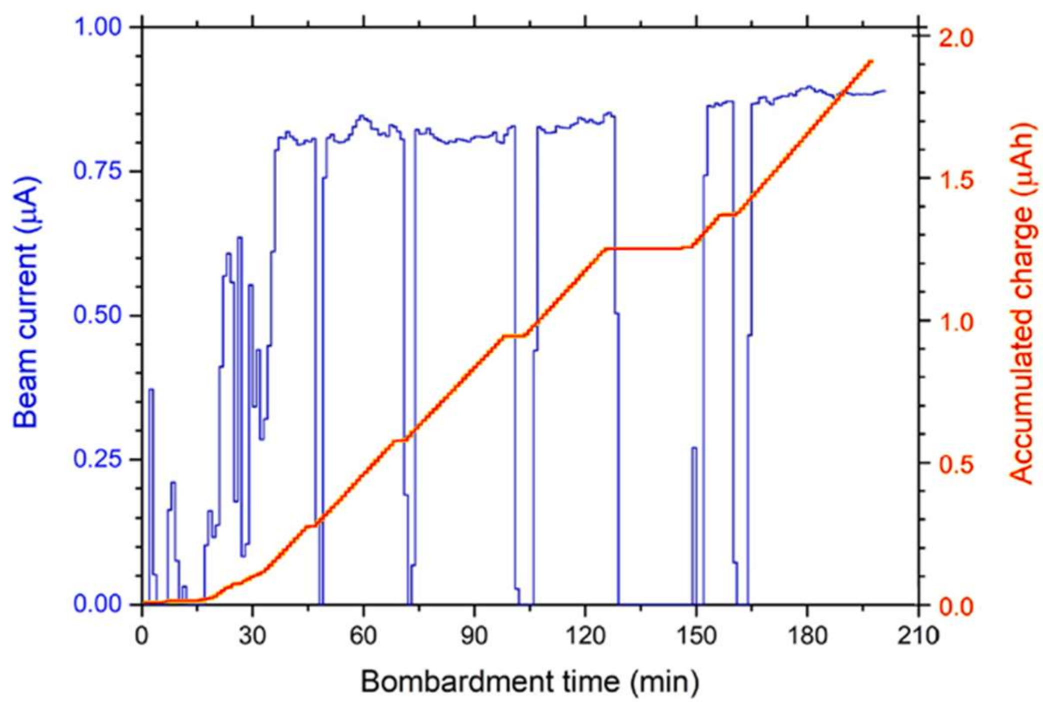


Optimised by matching beam energy to target thickness (machine settings & degraders)

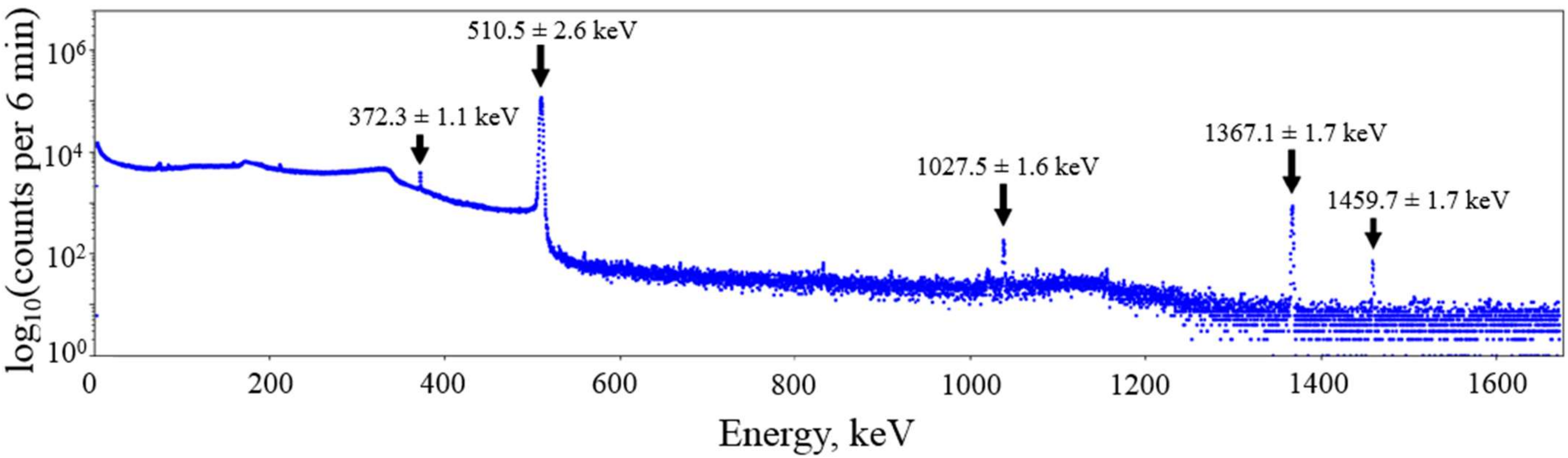
NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

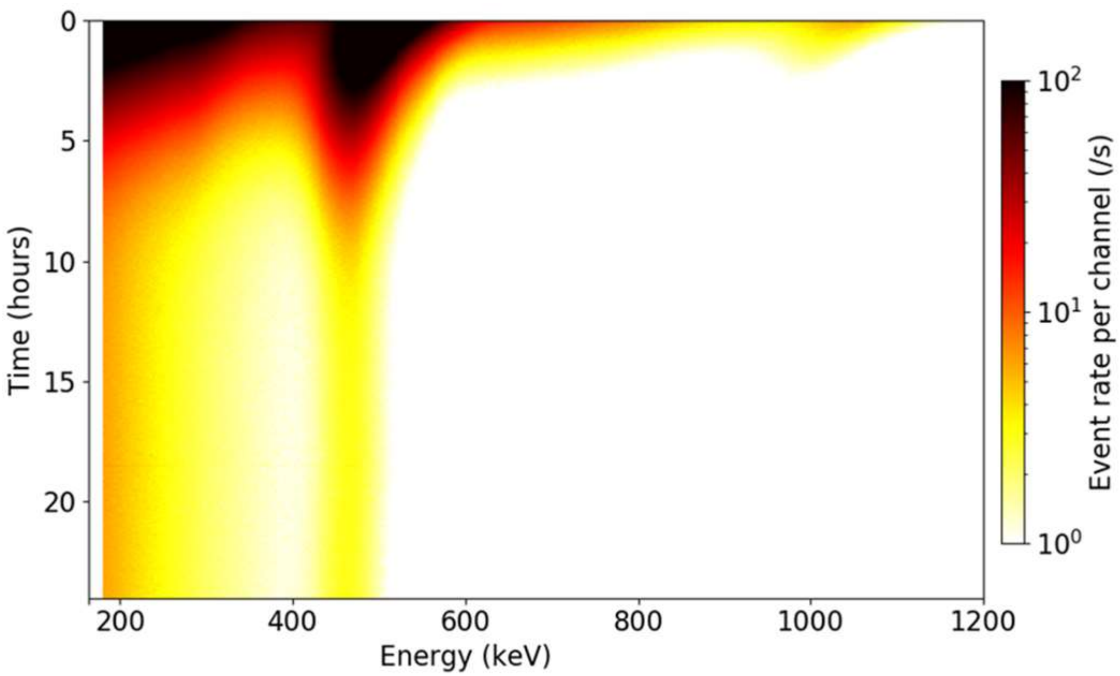
Activation

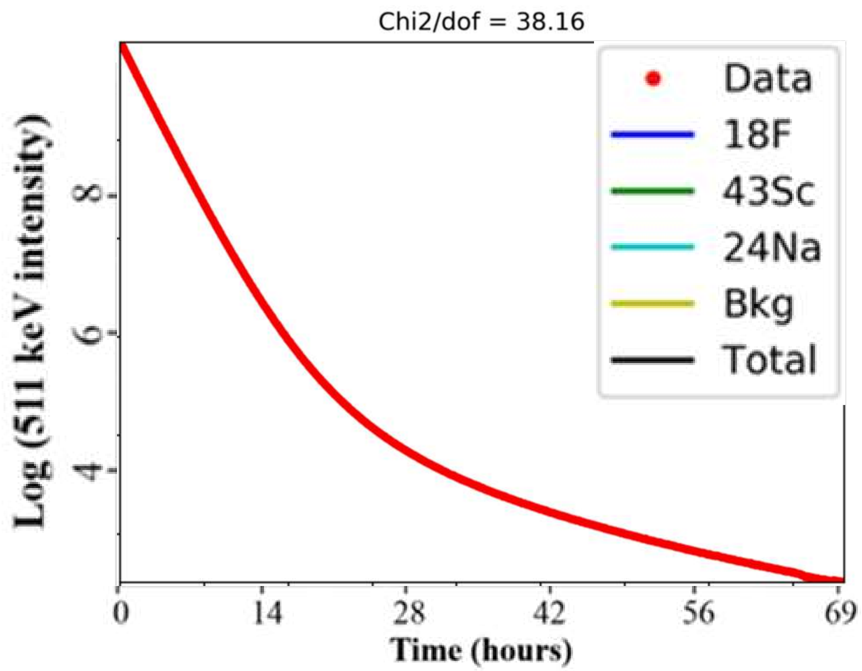




Activation Product Characterisation







Proof-of-Concept & Reproducibility

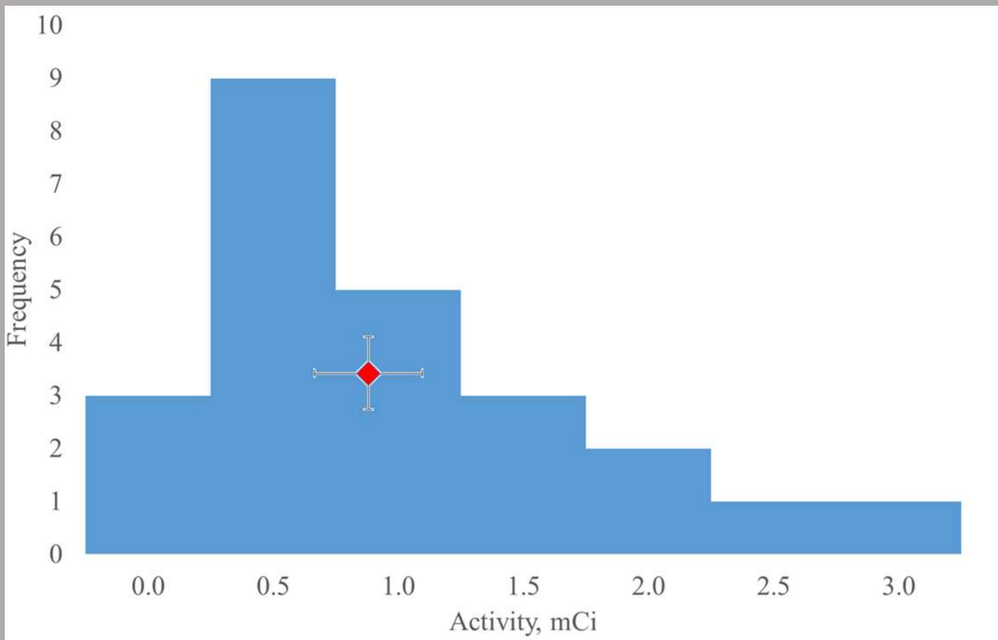
Compound	Chemical Composition [%]
SiO_2	61-67
Na_2O	10-18
CaO	5-10
Al_2O_3	3-8
B_2O_3	1-5
MgO	0.5-3

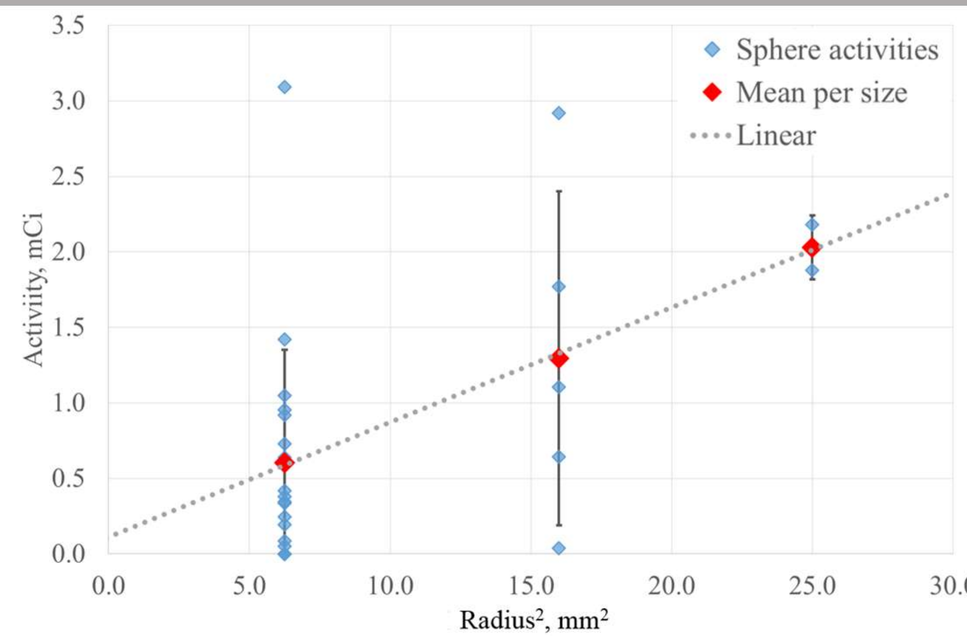
Identified products (EOB):

^{18}F (β^+ 1.8 hours) ~95%

^{43}Sc (β^+ 3.9 hours) < 5%

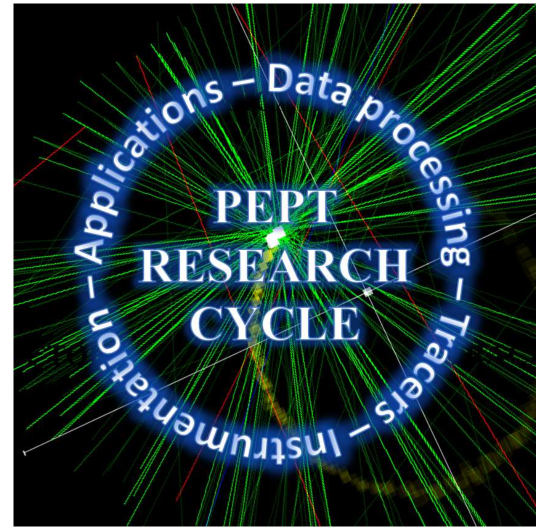
^{24}Na (β^- 14.9 hours) < 5%



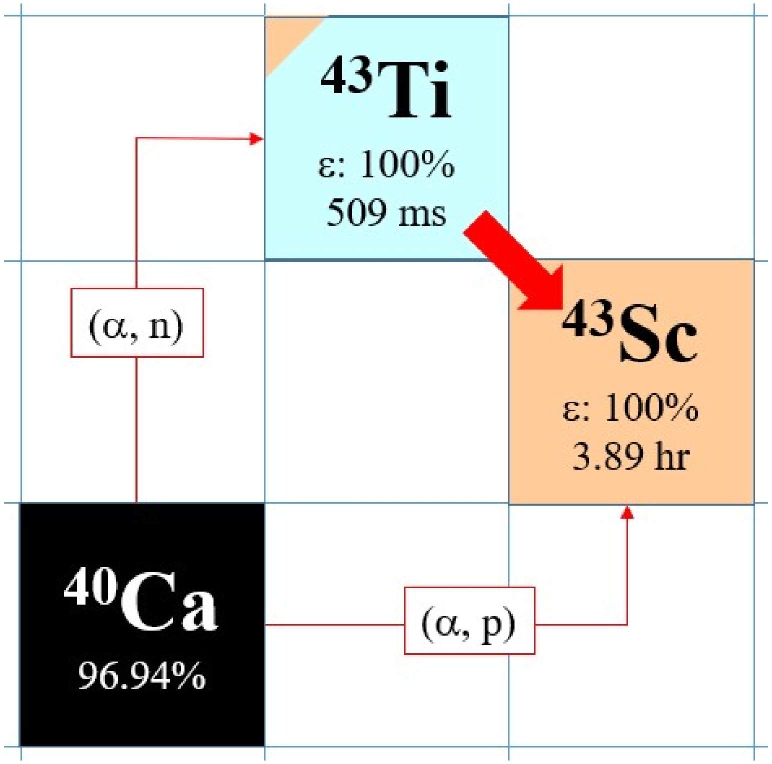


Conclusions

- Positron Emission Particle Tracking (PEPT) measures tracer particle trajectories to study flow dynamics.
- The $^{16}O(\alpha, x)^{18}F$ reaction channels were investigated, using a 100 MeV, 800 nA, alpha particle beam on SiO_2 targets.
- Beam & target modelling used to optimise energy: maximising activation product yield, minimising heating.
- Contaminants characterised by half-life measurements and spectral analysis. Yield products were ^{18}F, ^{24}Na and ^{43}Sc, with ^{18}F being the significantly dominant component.
- This reaction mechanism is therefore a reasonable candidate to compliment existing tracer particle production techniques at PEPT Cape Town.

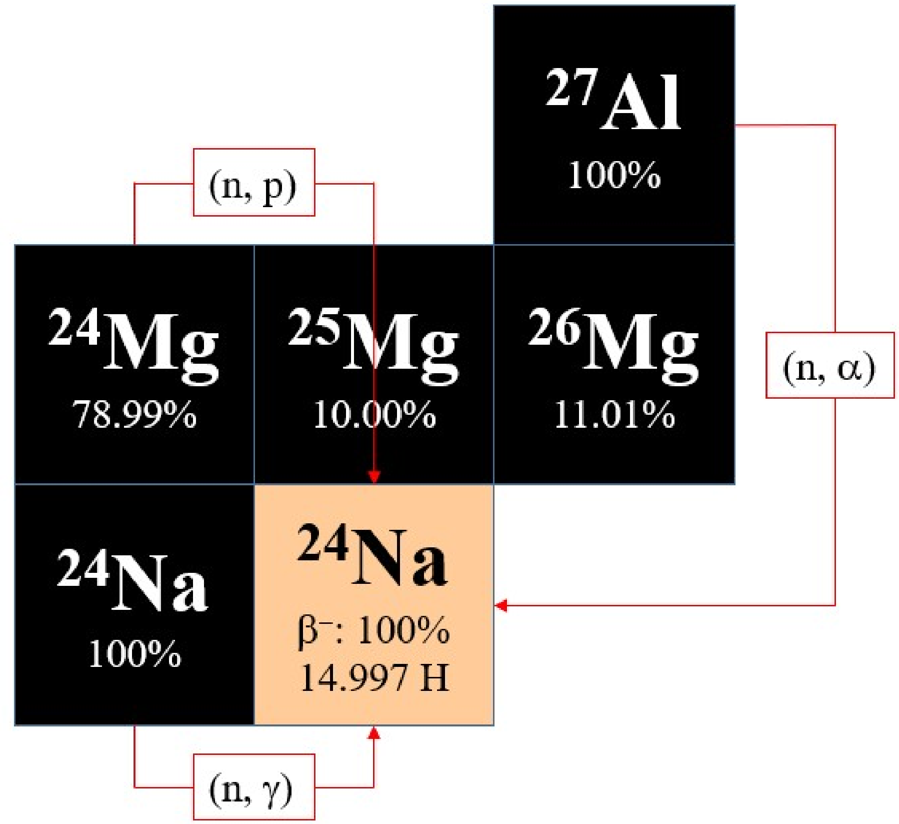


^{43}Sc and ^{24}Na



Gamma and X-ray radiation:

	Energy (keV)	Intensity (%)
	220.4 S	9E-4 % 3
	372.9 3	22.5 %
Annihil.	511.0	176.2 % 16
	593.3 7	0.0021 % 7
	1337.9 7	0.00180 % 23
	1558.3 6	0.0084 % 6
	1930.7 6	0.0151 % 9



Gamma and X-ray radiation:

Energy (keV)	Intensity (%)
996.6 10	0.00210 % 20
1368.626 5	99.9936 % 15
2754.007 11	99.855 % 5
2871.0 10	2.5E-4 % 4
3866.22 15	0.074 % 3
4238.9 10	8.4E-4 % 10