



**iThemba
LABS**
Laboratory for Accelerator
Based Sciences



DEPARTMENT OF
PHYSICS
UNIVERSITY OF CAPE TOWN

M e A S U R e

Metrological and Applied Sciences University Research Unit

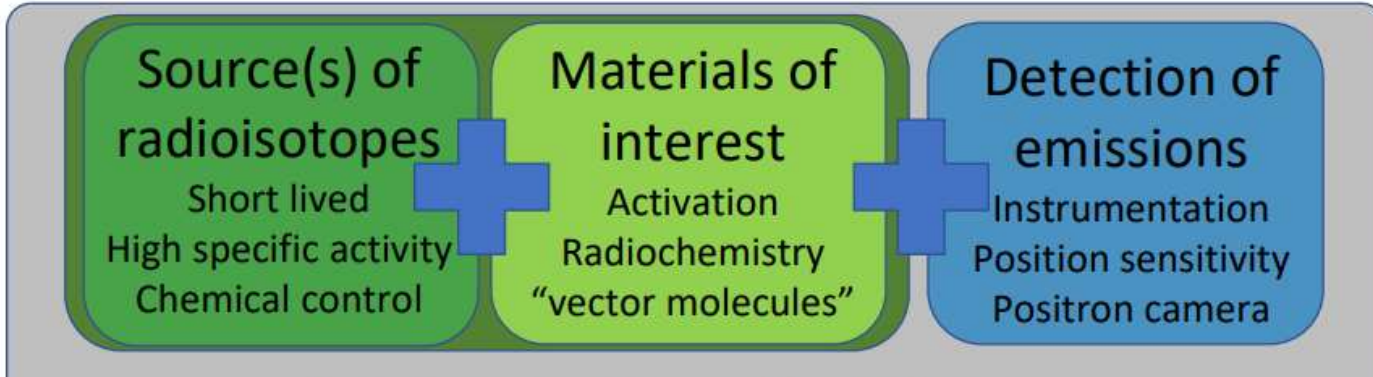
Targetry for the in-beam activation of tracer particles for Positron Emission Particle Tracking

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30th Conference of the
International Nuclear Target
Development Society INTDS 2022

Context

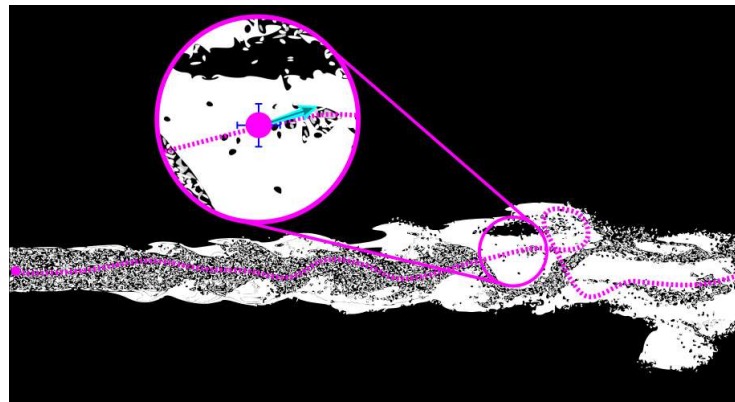
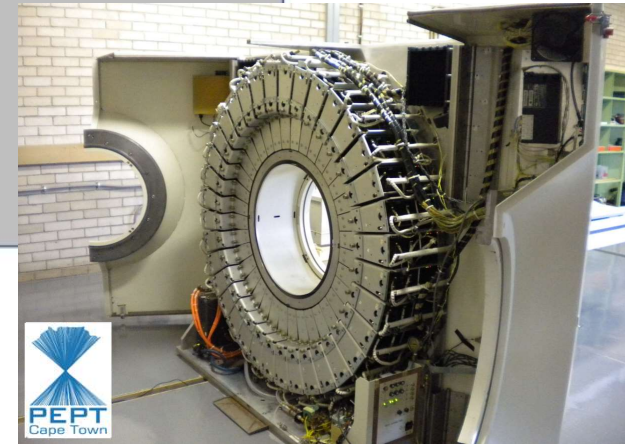
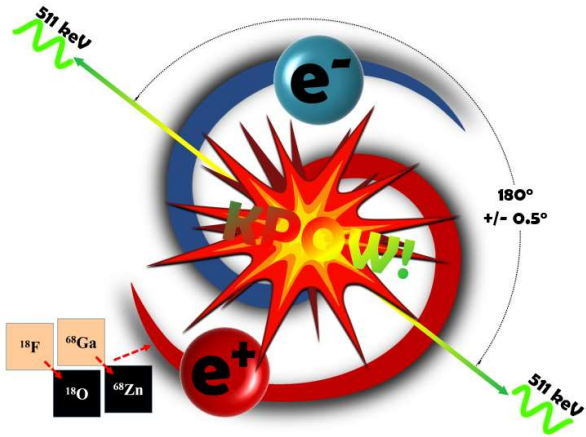


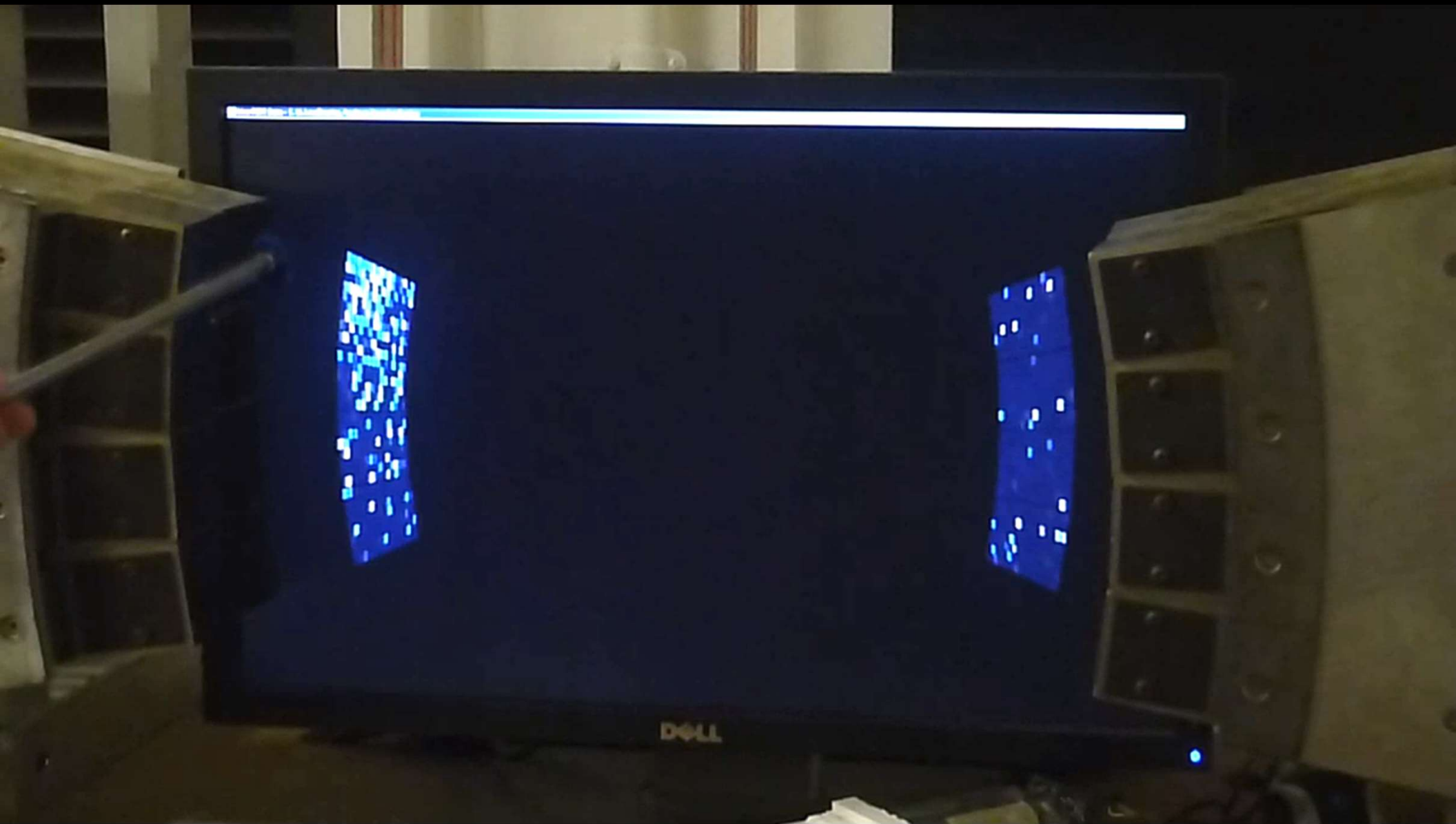
Novel experimental techniques

SPECT / PET / PEPT
Structure / function
Integral / Differential / Simulation

Applications

Real world flows
Engineering systems
Fundamental flows
Benchmarking



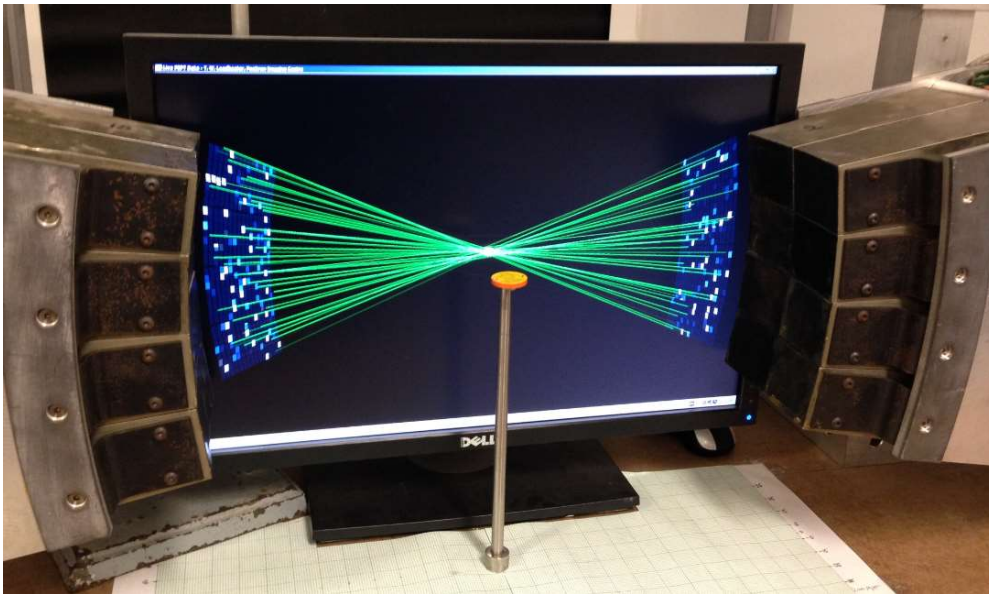


BGO Positron Cameras (UCT & iThemba LABS)

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, delayed)
Applications, training & education, hardware development, ...

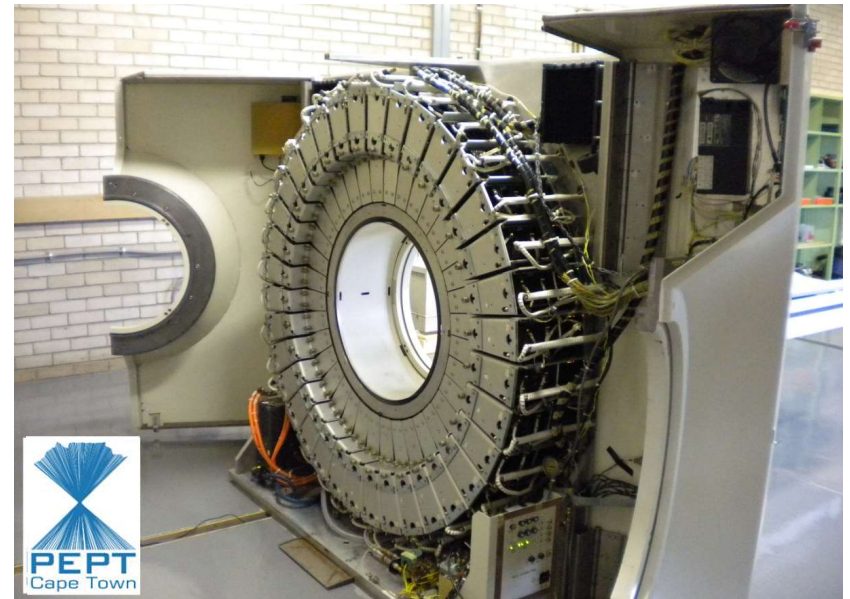
@ UCT

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

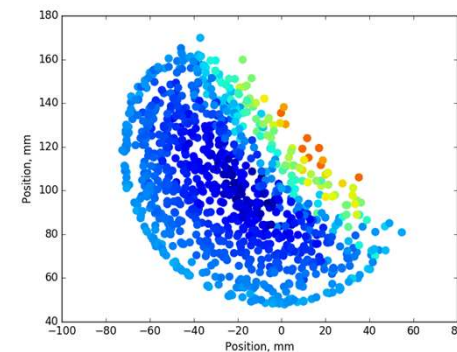
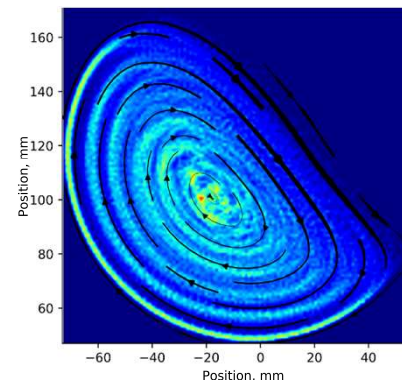
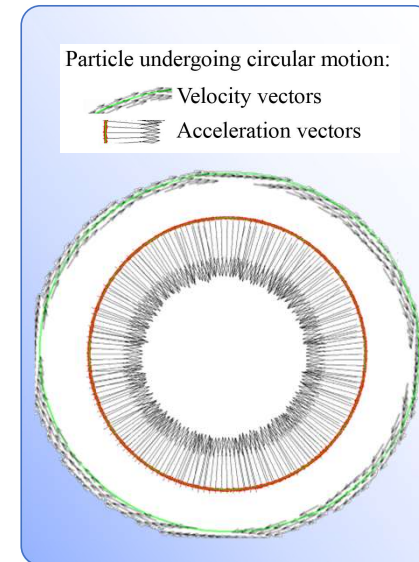
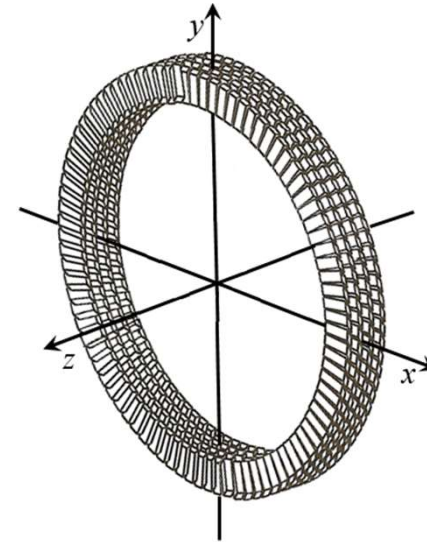
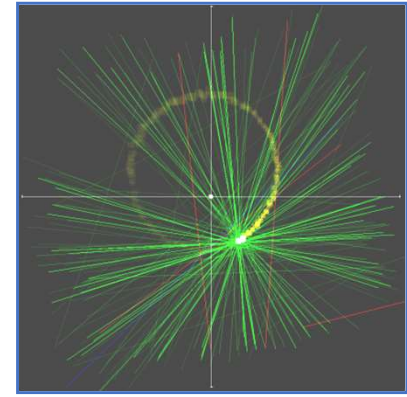
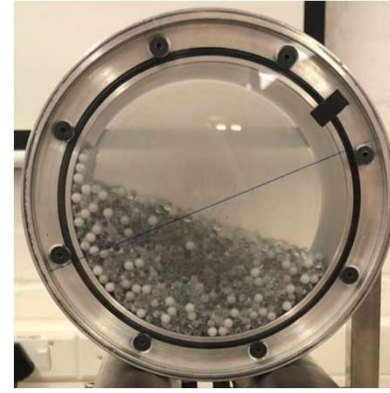
Fundamental flow studies

- development of transport models
- validation & benchmarking

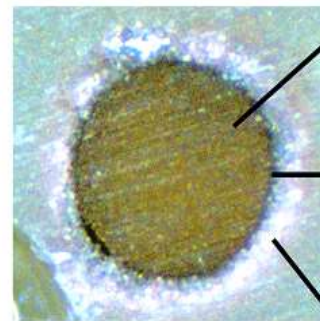
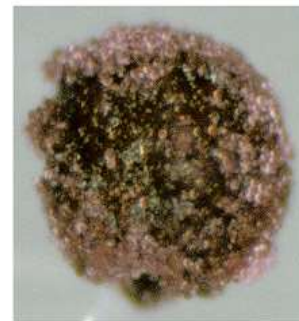
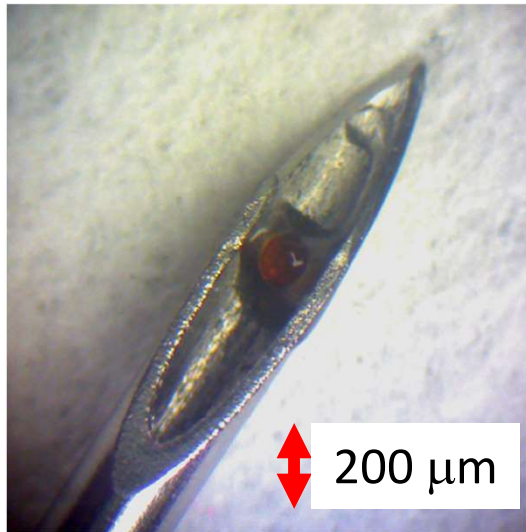
System-specific studies

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

Knowledge driven design strategy



Controlled Physical Characteristics: Tracers



Core:

Purolight[®] NRW 100

Adhesive layer:

Epoxy resin with nickel powder

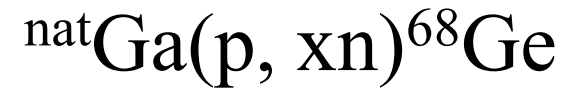
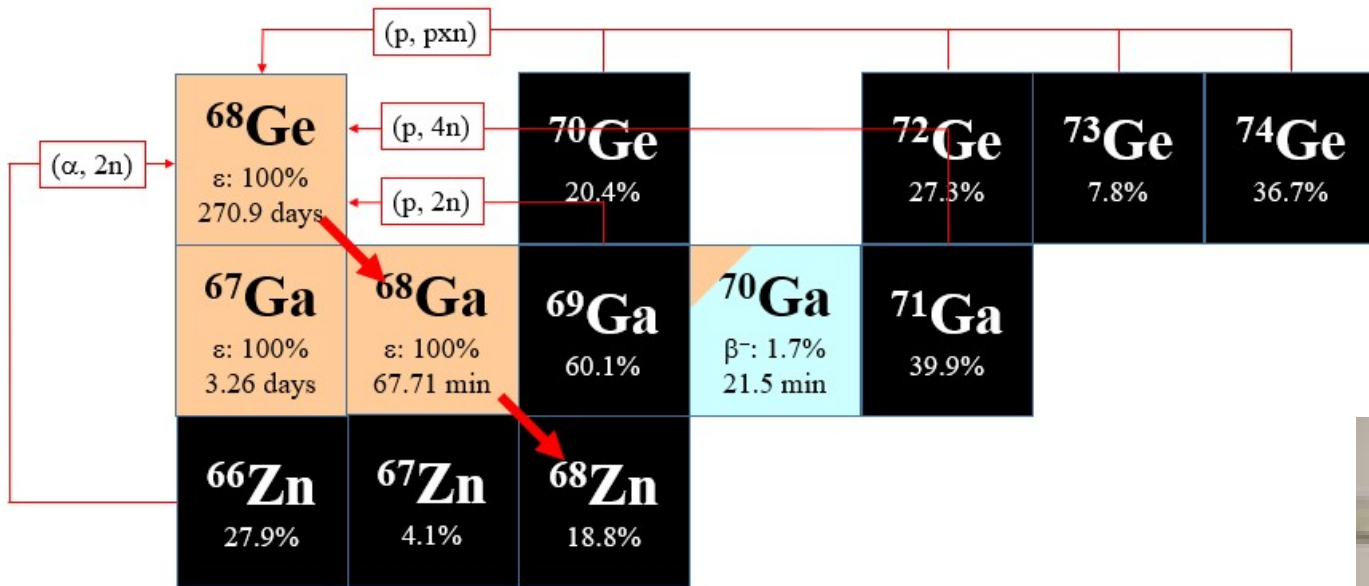
Coating layer:

PMMA powder

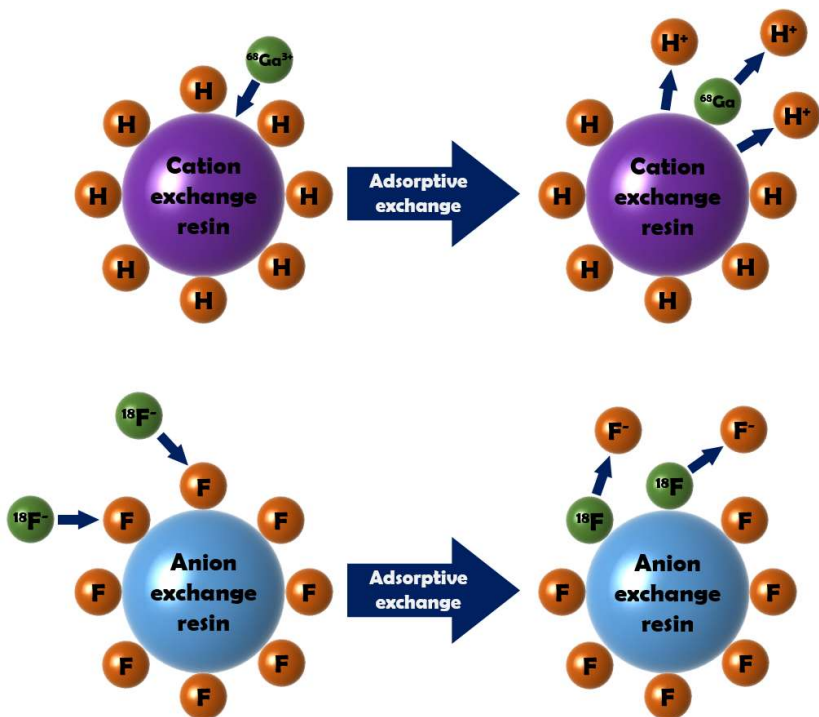
500 μm

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

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

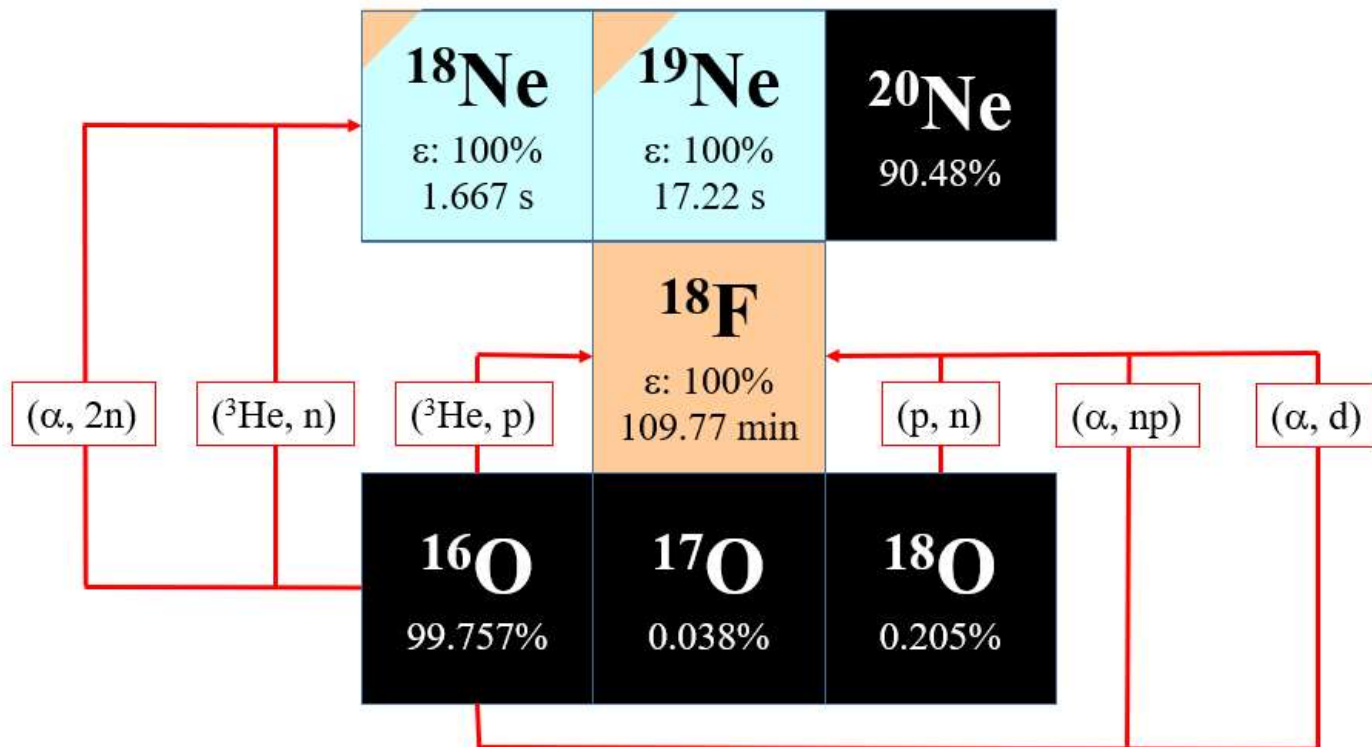


@ 66 MeV



SnO_2 based column

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

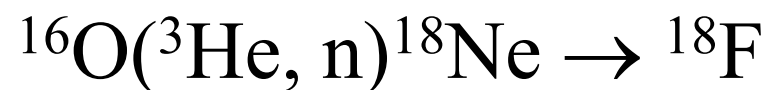


Typically **natural** materials required:

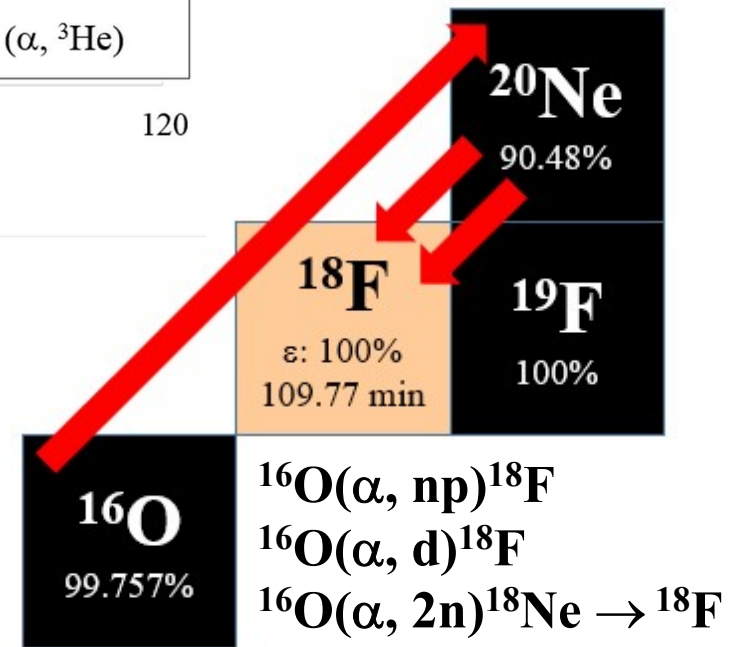
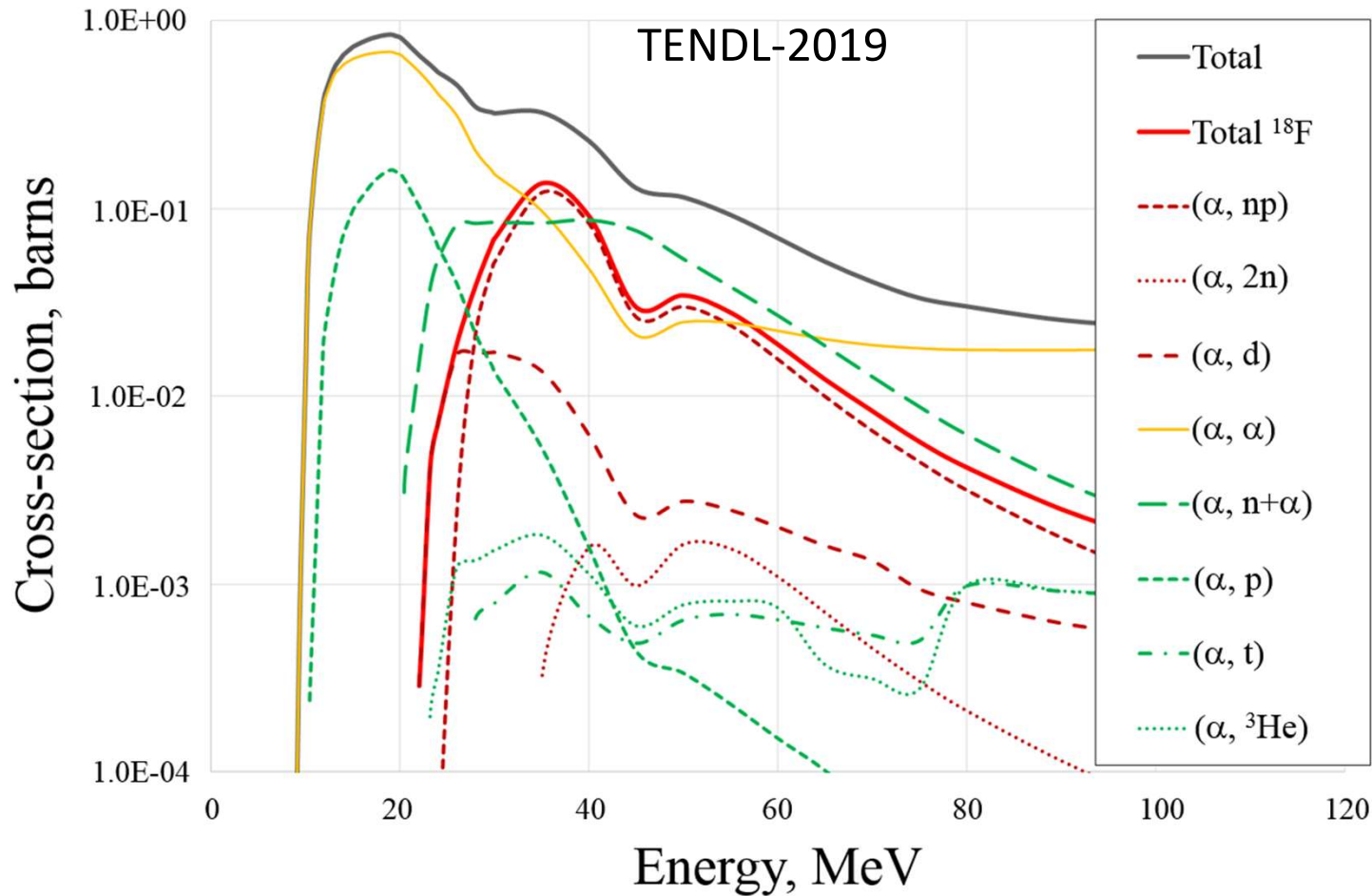
- Water (H_2O) (**radiochemistry**),
- Glass/silica (SiO_2),
- Mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$),
- Magnetite (Fe_3O_4),
- Chromite (FeCr_2O_4)



UNIVERSITY OF
BIRMINGHAM



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



Commercial Activation @ iThemba LABS

Radionuclides currently produced with 66 MeV protons from SSC



Target Station 1: The Elephant
Horizontal-beam target station

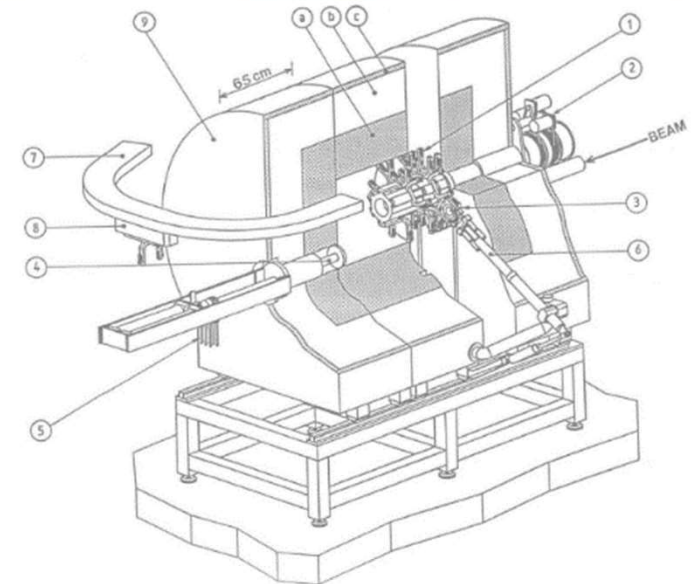
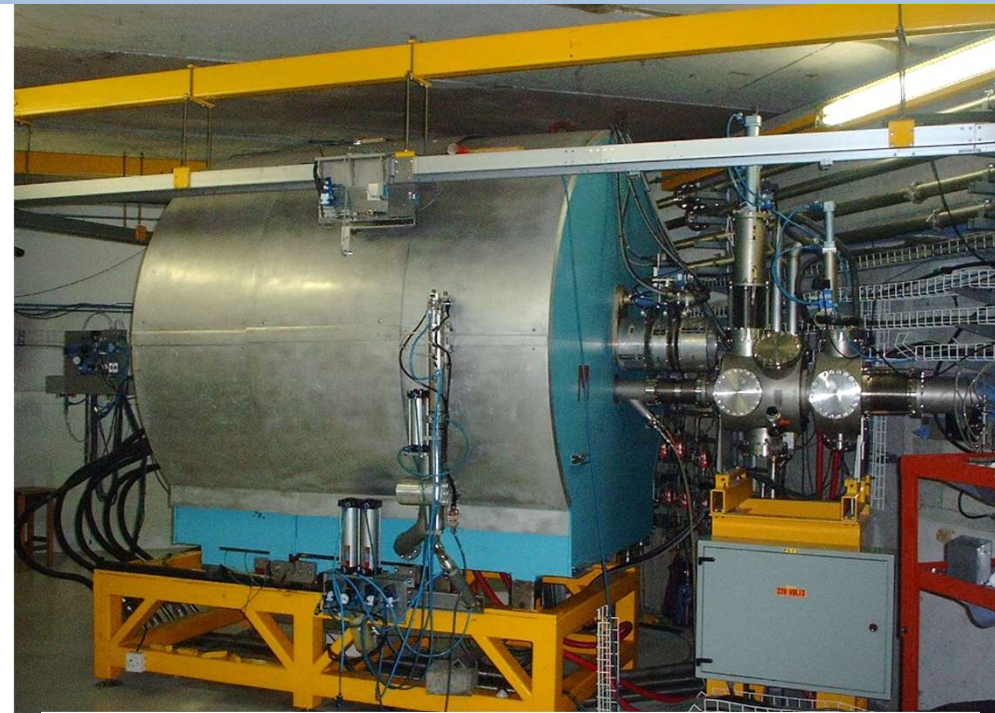
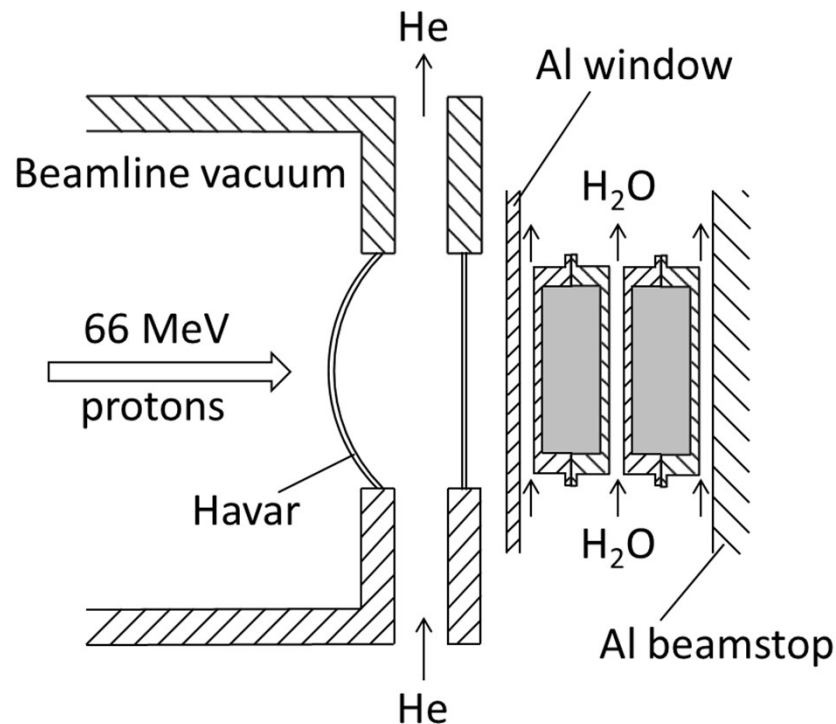


Fig.1 Perspective view of the target station, showing the rotary target magazines (1) and their motor drives (2), target in load/unload position (3), target pusher arm (4) with cooling water lines (5), target transfer robot arm (6), electric-rail target transport system (7) with trolley (8) and neutron 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.

Beam stop

145 mm

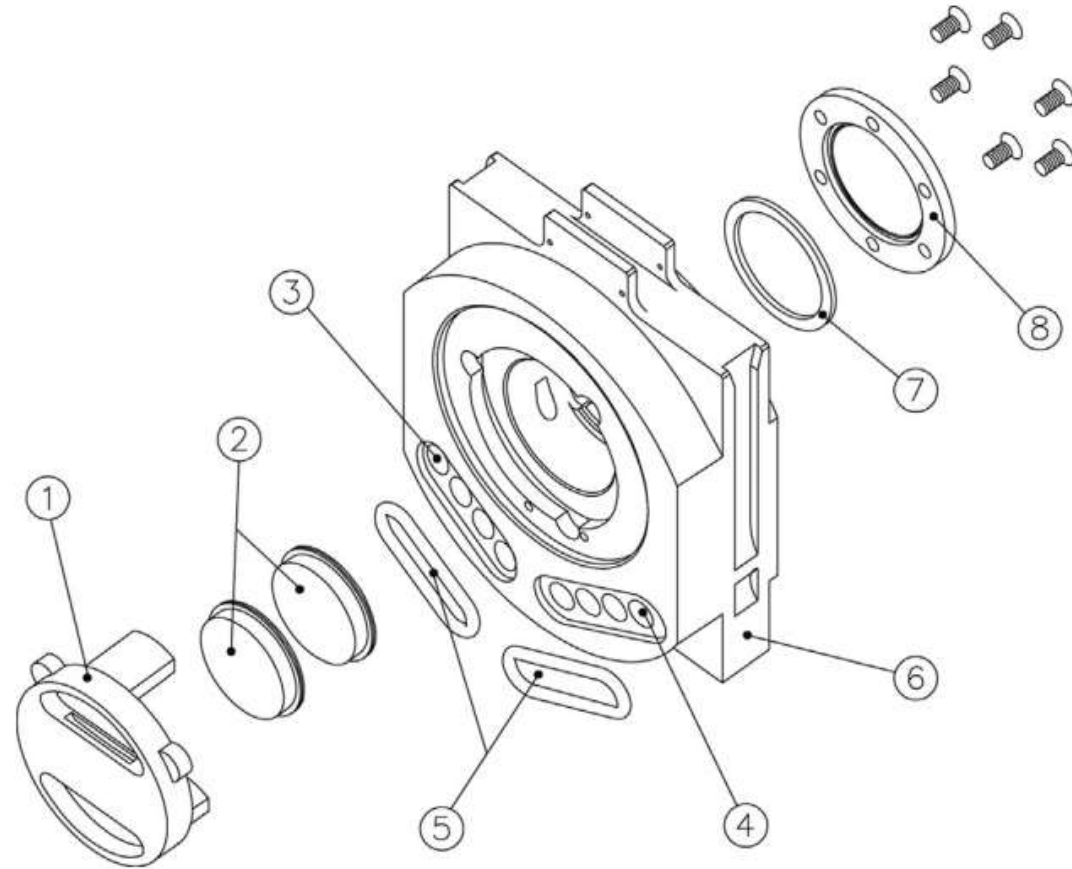


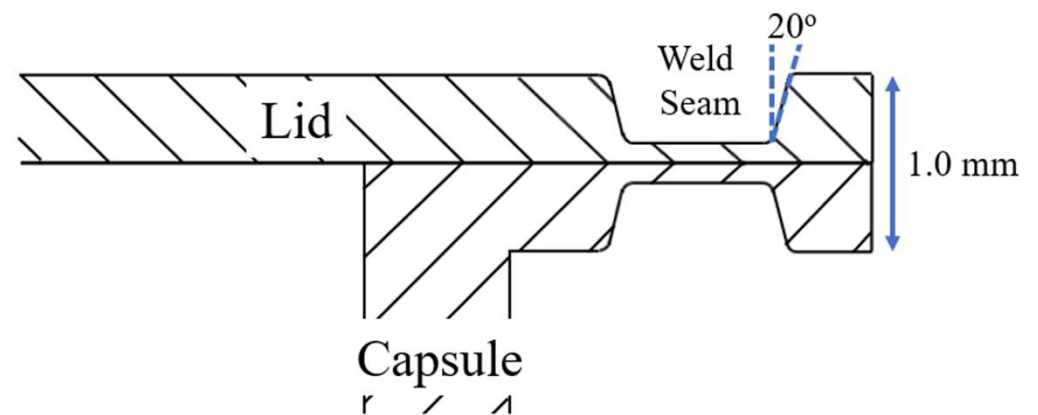
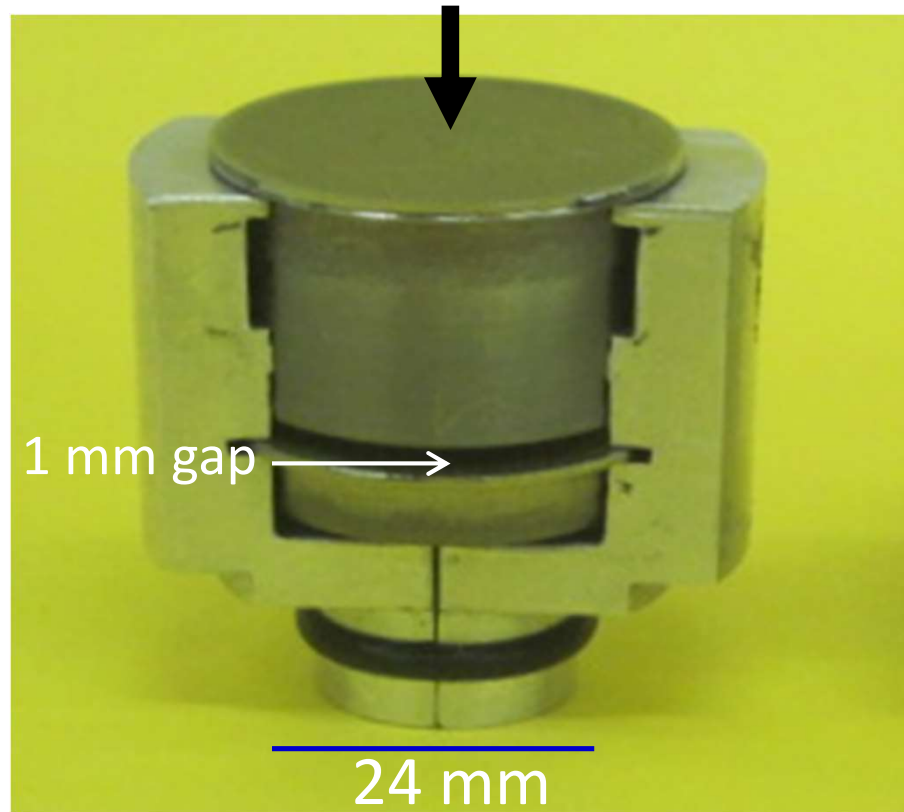
Fig. 9. Exploded view of a tandem target holder, showing (1) beamstop, (2) two target discs behind each other, (3) cooling-water inlet ports, (4) cooling-water outlet ports, (5) molded rubber seals, (6) aluminium target-holder body, (7) metal seal, and (8) beam entrance window.

Commercial Targets

Encapsulation material: Stainless steel (316) for Rb, Niobium for Ga.

Cold indentation welding forms sealed target unit

Beam direction

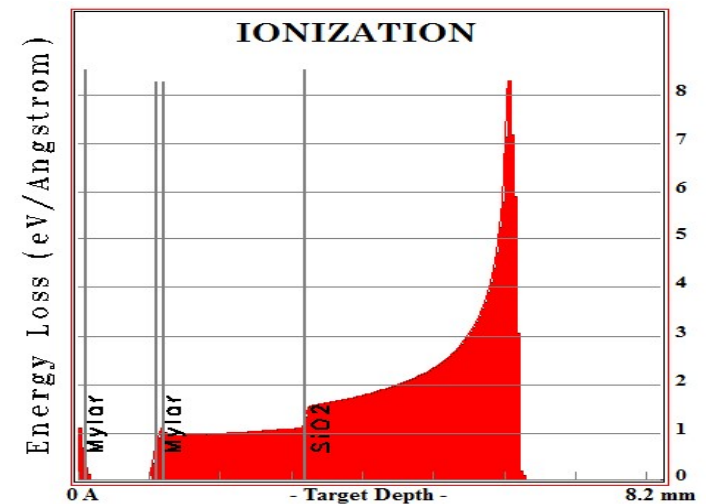
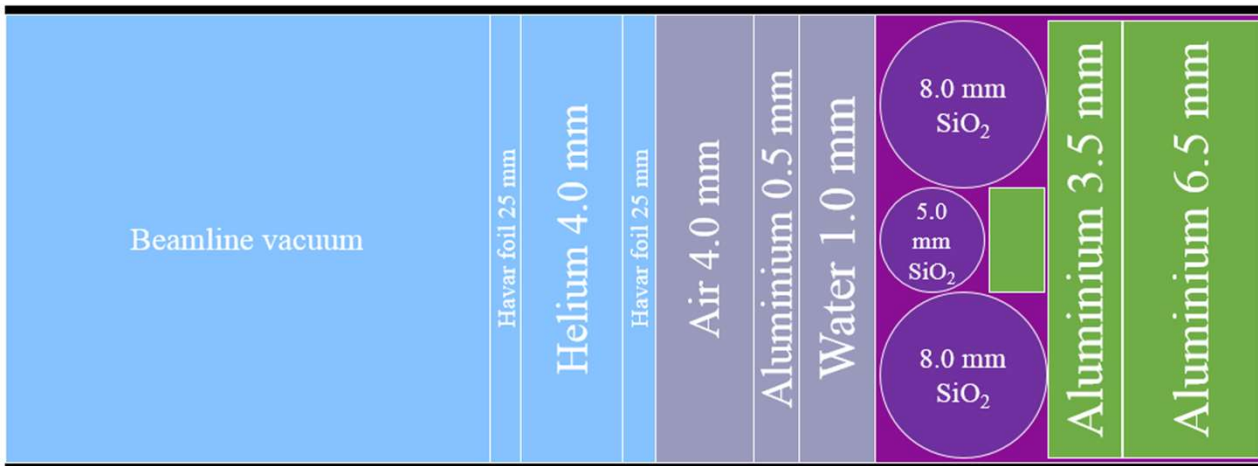


SiO₂ Targets: This Work



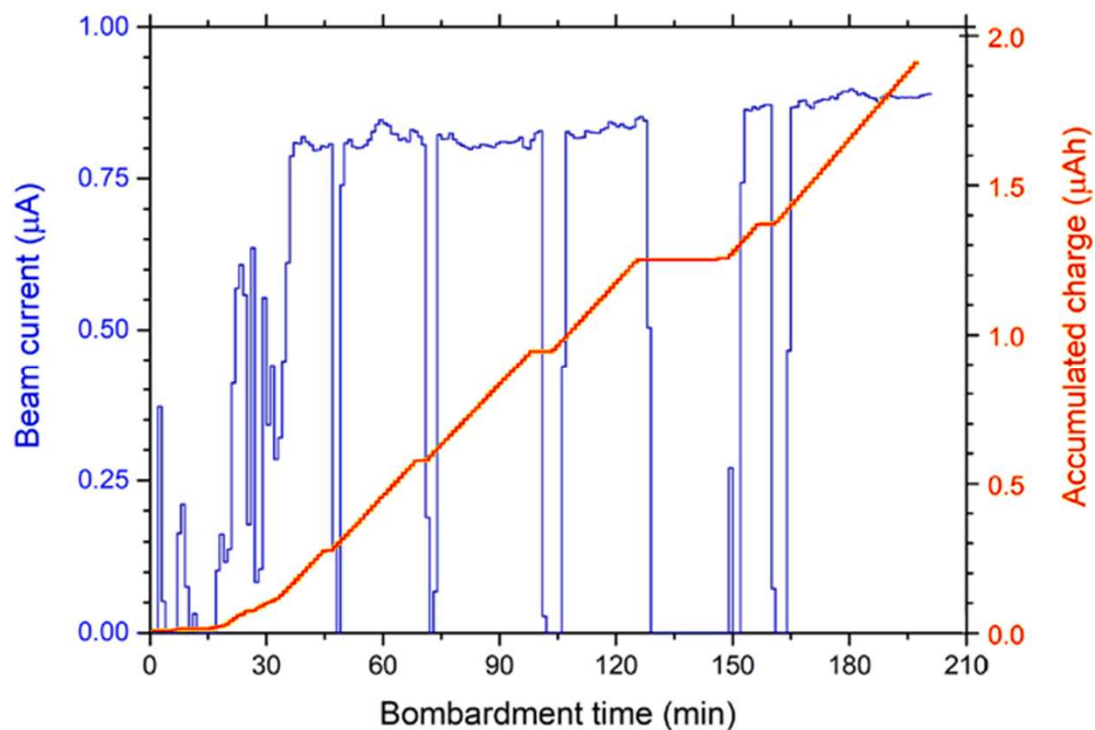
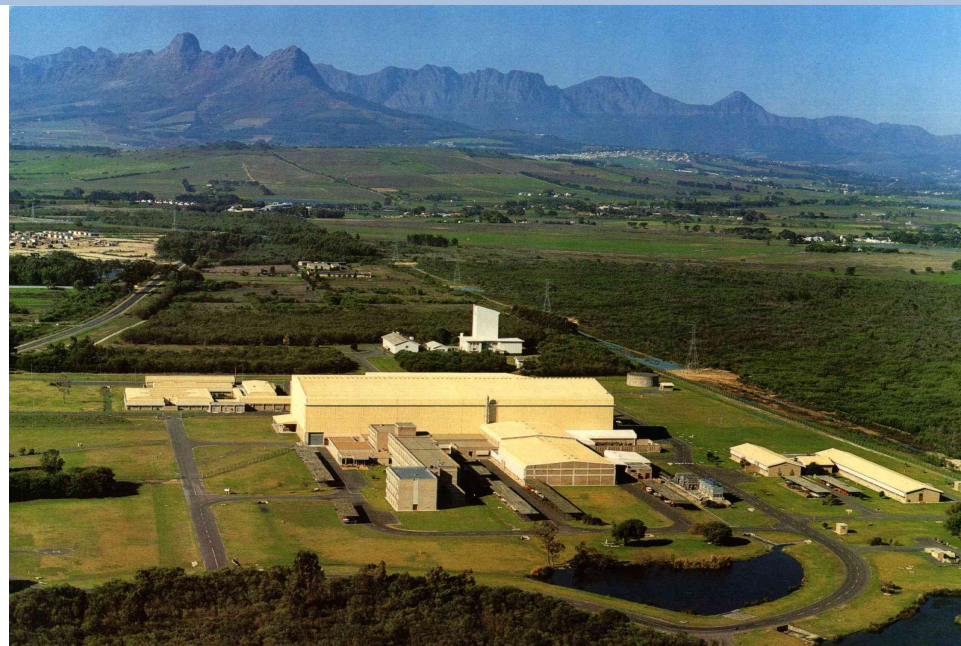
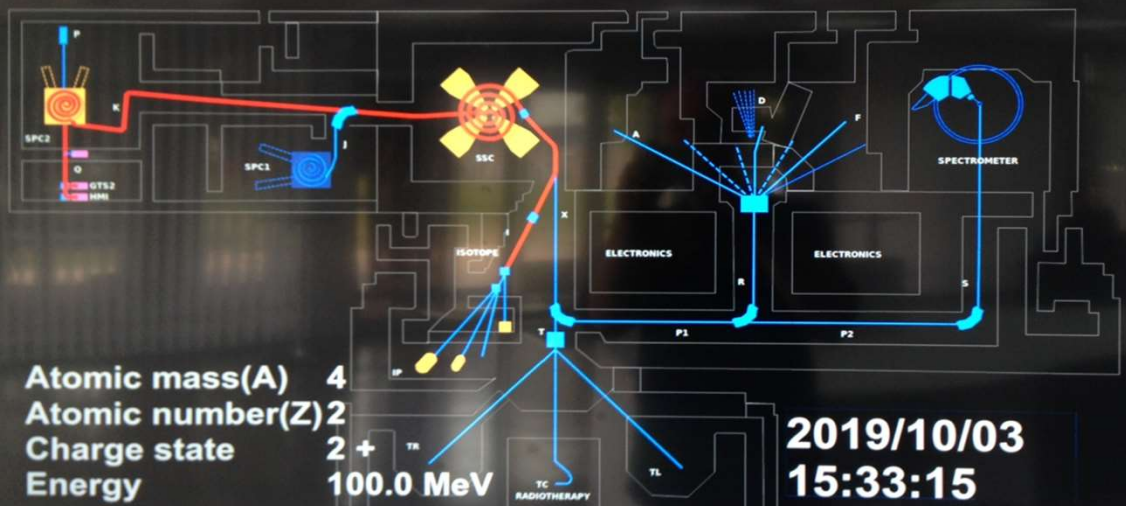
5 – 10 mm diameter SiO₂ (glass) spheres

100 MeV alpha particles, beam direction

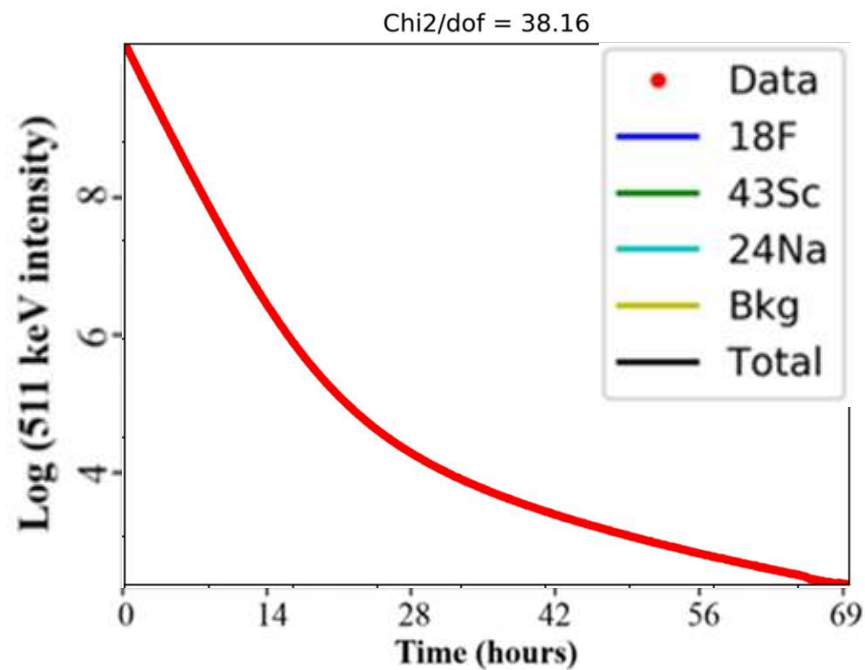
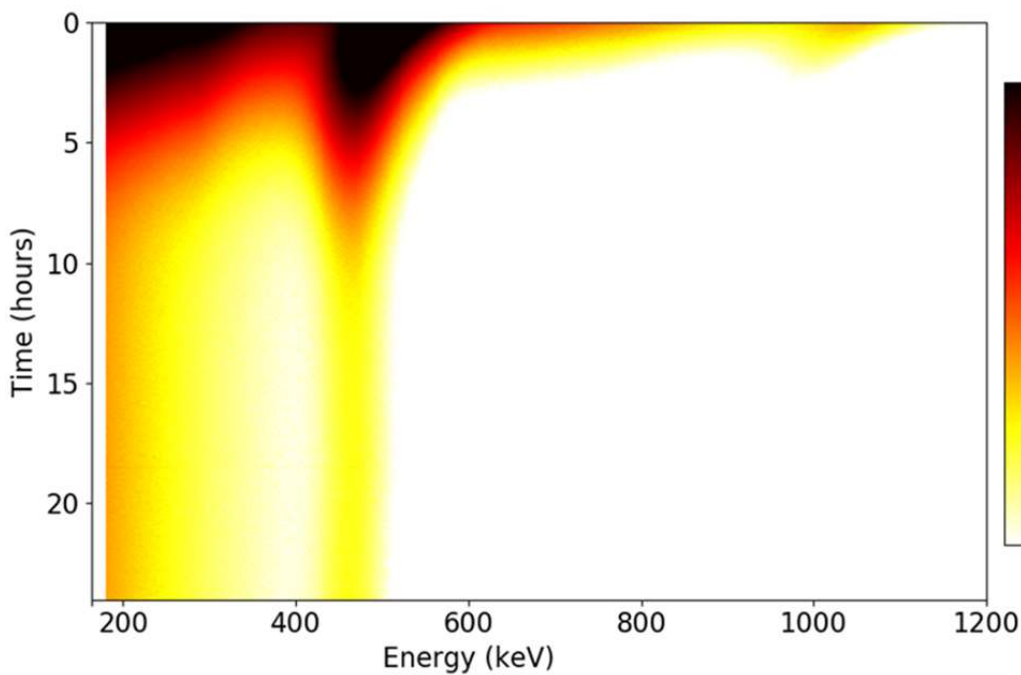
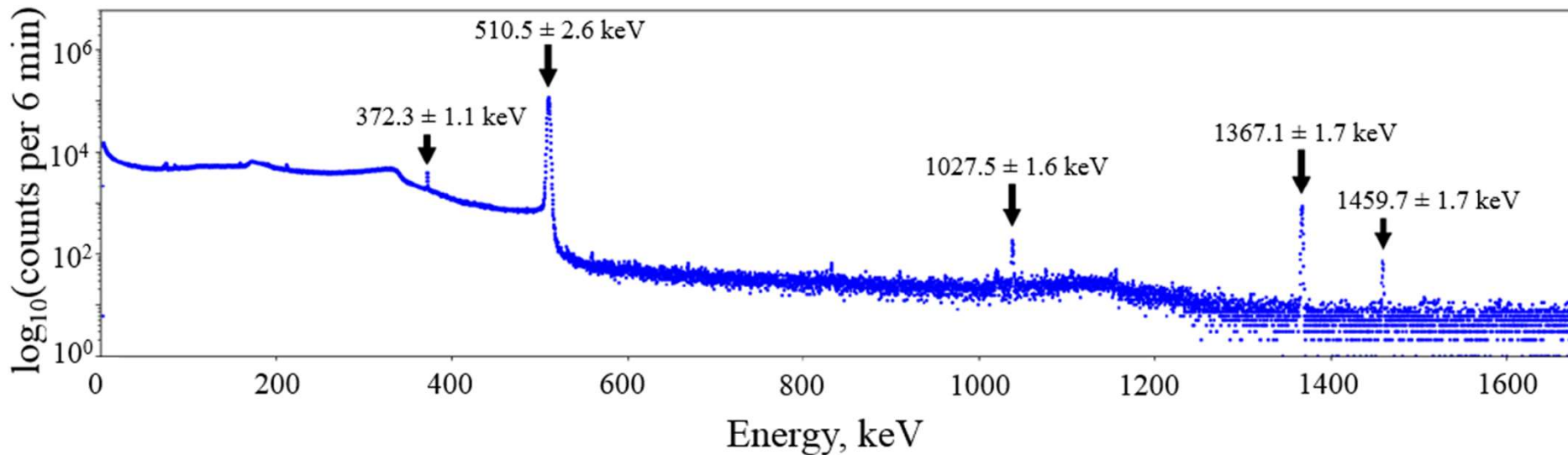


Activation

iThemba LABS Cyclotron Facility Active Beam



Activation Product Characterisation

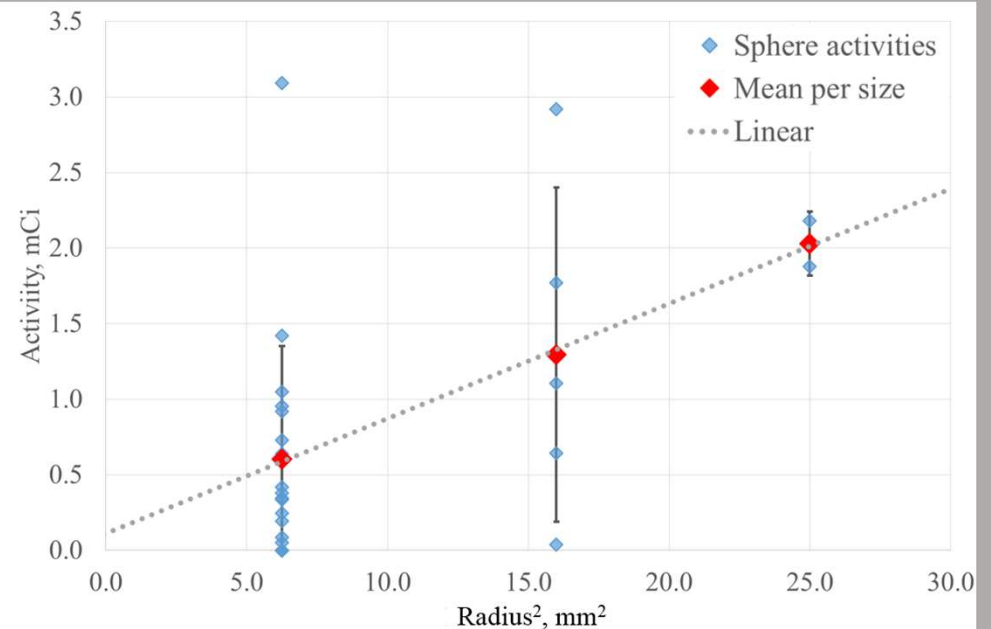
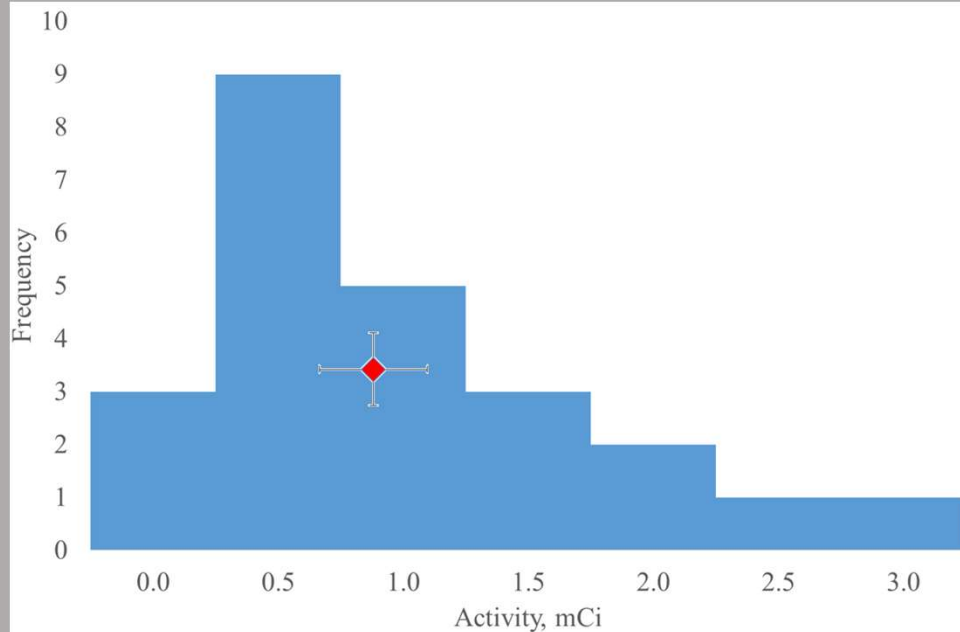


Proof-of-Concept & Reproducibility

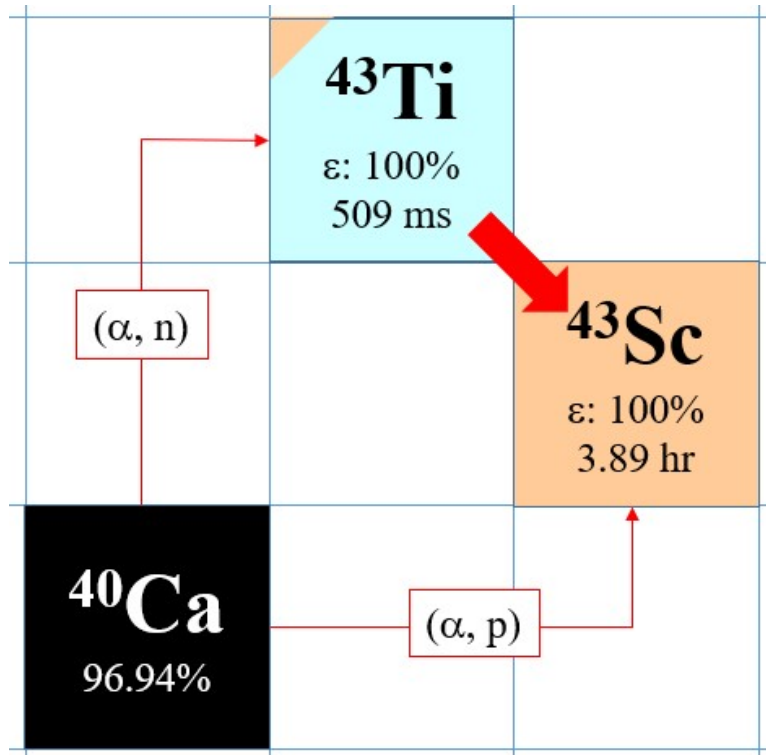
Compound	Chemical Composition [%]
SiO ₂	61-67
Na ₂ O	10-18
CaO	5-10
Al ₂ O ₃	3-8
B ₂ O ₃	1-5
MgO	0.5-3

Identified products (EOB):

¹⁸F (β^+ 1.8 hours) ~95%
⁴³Sc (β^+ 3.9 hours) < 5%
²⁴Na (β^- 14.9 hours) < 5%

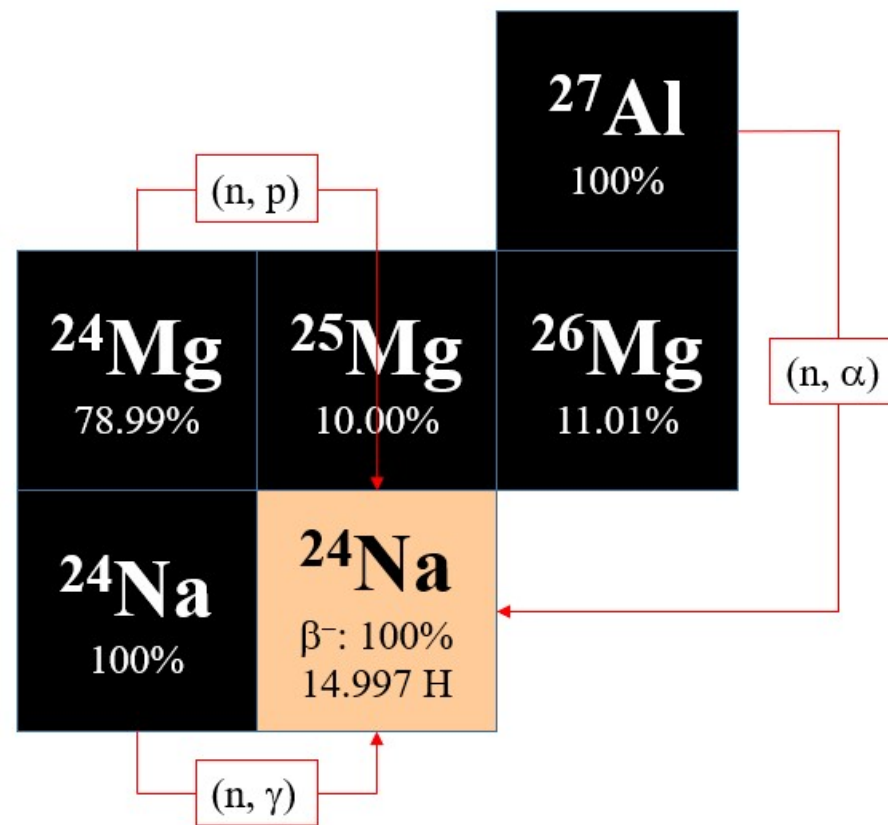


^{43}Sc and ^{24}Na



Gamma and X-ray radiation:

	Energy (keV)	Intensity (%)
	220.4 5	9E-4 \approx 3
	372.9 3	22.5 \approx
Annihil.	511.0	176.2 \approx 16
	593.3 7	0.0021 \approx 7
	1337.9 7	0.00180 \approx 23
	1558.3 6	0.0084 \approx 6
	1930.7 6	0.0151 \approx 9



Gamma and X-ray radiation:

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

Conclusions

- Positron Emission Particle Tracking (PEPT) measures tracer particle trajectories to study the dynamics of flow.
- The $^{16}\text{O}(\alpha, x)^{18}\text{F}$ reaction channels were investigated, using a 100 MeV, 800 nA, alpha particle beam on SiO_2 targets.
- Contaminants were characterised by half-life measurements and spectral analysis. The long lived isotopes produced in activation were determined to be ^{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.

