Exploring Multinucleon Transfer for Super-Heavy Element Formation

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Super-Heavy Elements and the Island of Stability

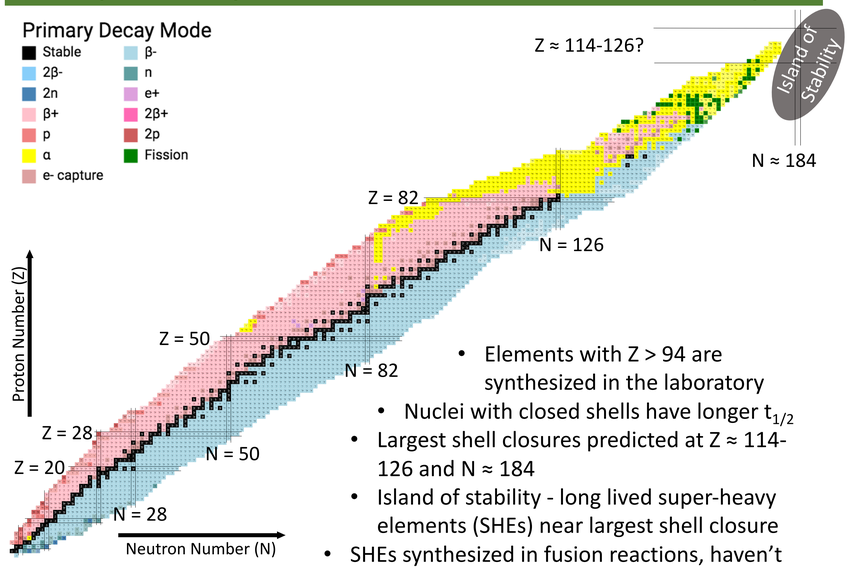
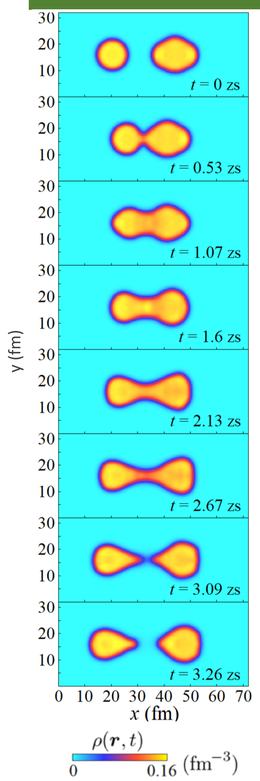
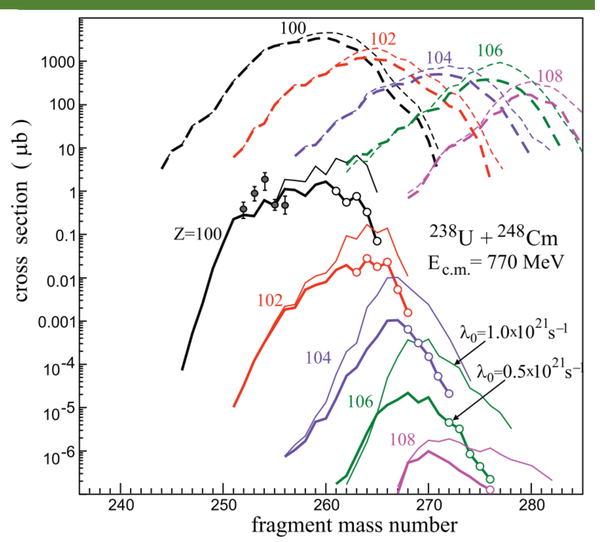


Image taken from:
https://people.physics.anu.edu.au/~ecs103/chart/

- Elements with Z > 94 are synthesized in the laboratory
- Nuclei with closed shells have longer $t_{1/2}$
- Largest shell closures predicted at Z ≈ 114-126 and N ≈ 184
- Island of stability - long lived super-heavy elements (SHEs) near largest shell closure
- SHEs synthesized in fusion reactions, haven't reached the Island of Stability
- Multinucleon Transfer (MNT) may produce neutron-rich isotopes near the island of stability

Multinucleon Transfer Reactions





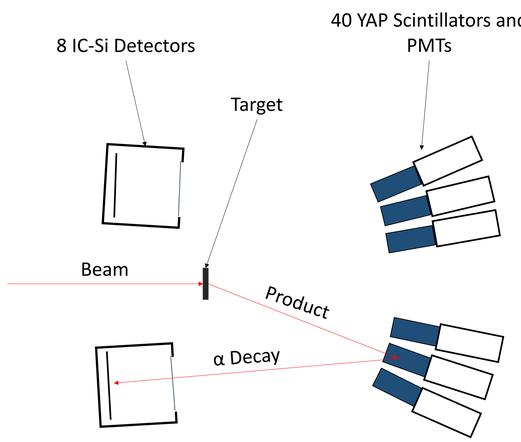
Left: Density evolution over time for $^{238}U+^{124}Sn$ head-on collision at $E_{c.m.}$ = 465 MeV, reproduced from Sekizawa (2017)
Right: mass distribution of different elements produced in multinucleon transfer reactions for $^{238}U + ^{248}Cm$ at $E_{c.m.}$ = 770 MeV.
- Dashed lines – primary products, Solid lines – surviving nuclei
- Thin lines – faster nucleon transfer rates, Thicker lines – slower
- Closed circles – experimental data, Open circles – new isotopes

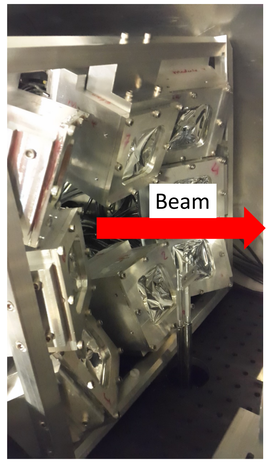
Image reproduced from Zegrabaev & Greiner (2013).

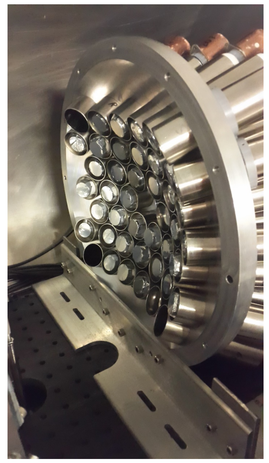
- With enough energy, interacting nuclei transfer nucleons (protons and neutrons) from one nucleus to the other.
- MNT has a variety of products of different elements and isotopes.
- Most products are radioactive, some decay by α emission.

Active Catcher Array

Active catcher array for studying MNT:
- Solid target
- 40 radiation hard Yttrium-Aluminum-Perovskite (YAP) scintillators coupled with photo-multiplier tubes
- 8 ionization chamber – silicon (IC-Si) detectors



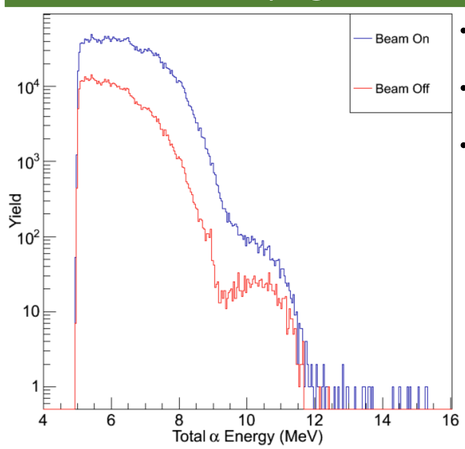




Event detection:
1. MNT product implants in YAP, signal read by PMT
2. α decays from products leave YAP, detected by the IC-Si

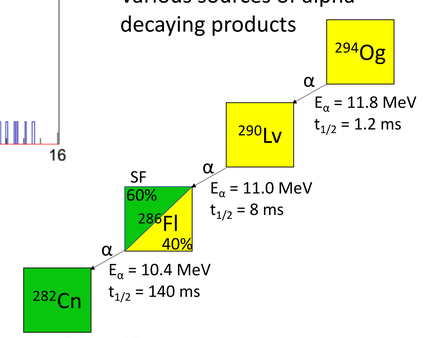
Above: simplified schematic of the active catcher setup.
Left: photographs of the IC-Si array (left) and YAP-PMT array (right).

Identifying Products: Alpha Decay



- Super-heavy elements α-decay with energy E_α > 9 MeV
- We see enhancement in number of α's in energy region of interest
- Possible background:
  - Ternary fission
  - Isomeric states with high-energy alpha decay
  - Various sources of alpha decaying products

- To identify an element, identify a chain of alpha decays
- Pick out of background using half-life and E_α



$^{238}U + ^{232}Th$ Experimental Results

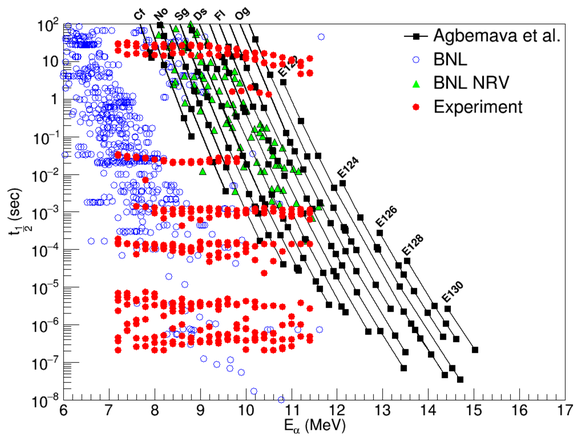
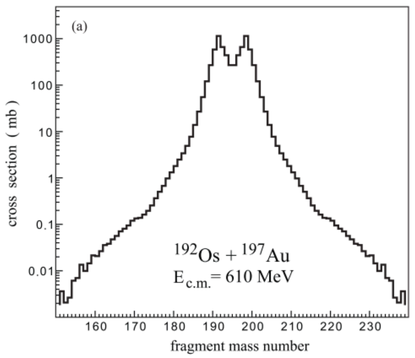
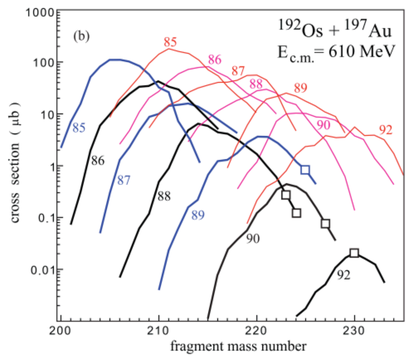


Image reproduced from Wuenschel et al. (2018). See reference for more detailed information.

Results obtained with active catcher at TAMU Cyclotron Institute:
- Black lines - correlation between $t_{1/2}$ and E_α for isotopes of different elements (theoretical)
- Open circles – known values
- Solid triangles – known values
- Red solid circles – active catcher data for $^{238}U + ^{232}Th$ at $E_{c.m}$ = 881 MeV

Future Plans





1. Experimental Setup Improvements
   - Better geometric efficiency
   - Linear energy response
   - Segmented active catcher
2. Benchmarking with $^{12}C+ ^{209}Bi$ fusion
3. $^{192}Os + ^{197}Au$ MNT
4. $^{238}U + ^{248}Cm$ MNT
5. Incorporate machine learning into analysis

Figures: (a) mass distribution of multinucleon transfer products for $^{192}Os + ^{197}Au$ at $E_{c.m.}$ = 610 MeV
(b) mass distribution for each element. Thin lines represent primary products, thick lines represent surviving nuclei. Image reproduced from Zegrabaev & Greiner (2013).

References

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V. Zagrebaev and W. Greiner Phys. Rev. C **87**, 034608 (2013)
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Acknowledgements

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