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Sulphur Hexafluoride as a Stripper Gas in the ANSTO Tandem Accelerator

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Electron Strippers

Introduction

- For heavy ions where transmission stability is critical such as in AMS, gas stripping is preferred.
- Light gases including argon and nitrogen are normally used
- The gas is recirculated within the terminal to maintain high vacuum hence high mean free path in the accelerator tubes.
- Much of the work on charge state yields was performed in the 1960’s and 70’s, tandem accelerators were quite new and higher voltage machines were being planned.
- Solid strippers, such as carbon or gold foils, could achieve higher mean charge states due to the density effect.
- A shorter, higher density gas stripper tube was shown to achieve higher charge states through a partial density effect.

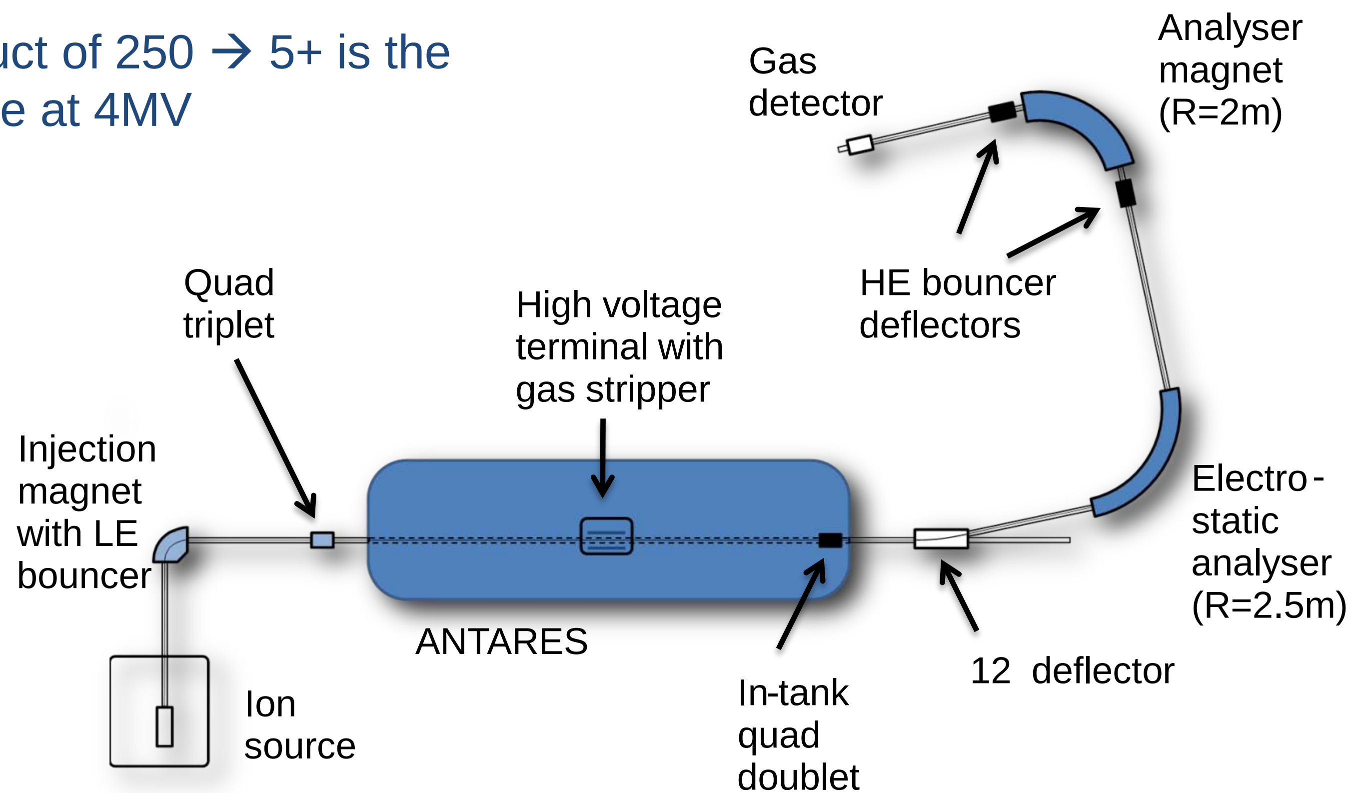
Introduction *continued*

- It was suggested at this time that there could be an advantage using a multi-atom molecular gas, which could have some level of intra-molecular density effect.
- Few reports exist on such experiments but gases including fluorocarbons with a range of molecular weights such as neopentane and sulphur hexafluoride have been tried.
- Most measurements obtained at 12MeV and above.
- At higher energy the difference between results with light gases and multi-atom molecular gases was found to be diminished

Actinides AMS at ANSTO

As used on ANTARES accelerator until recently

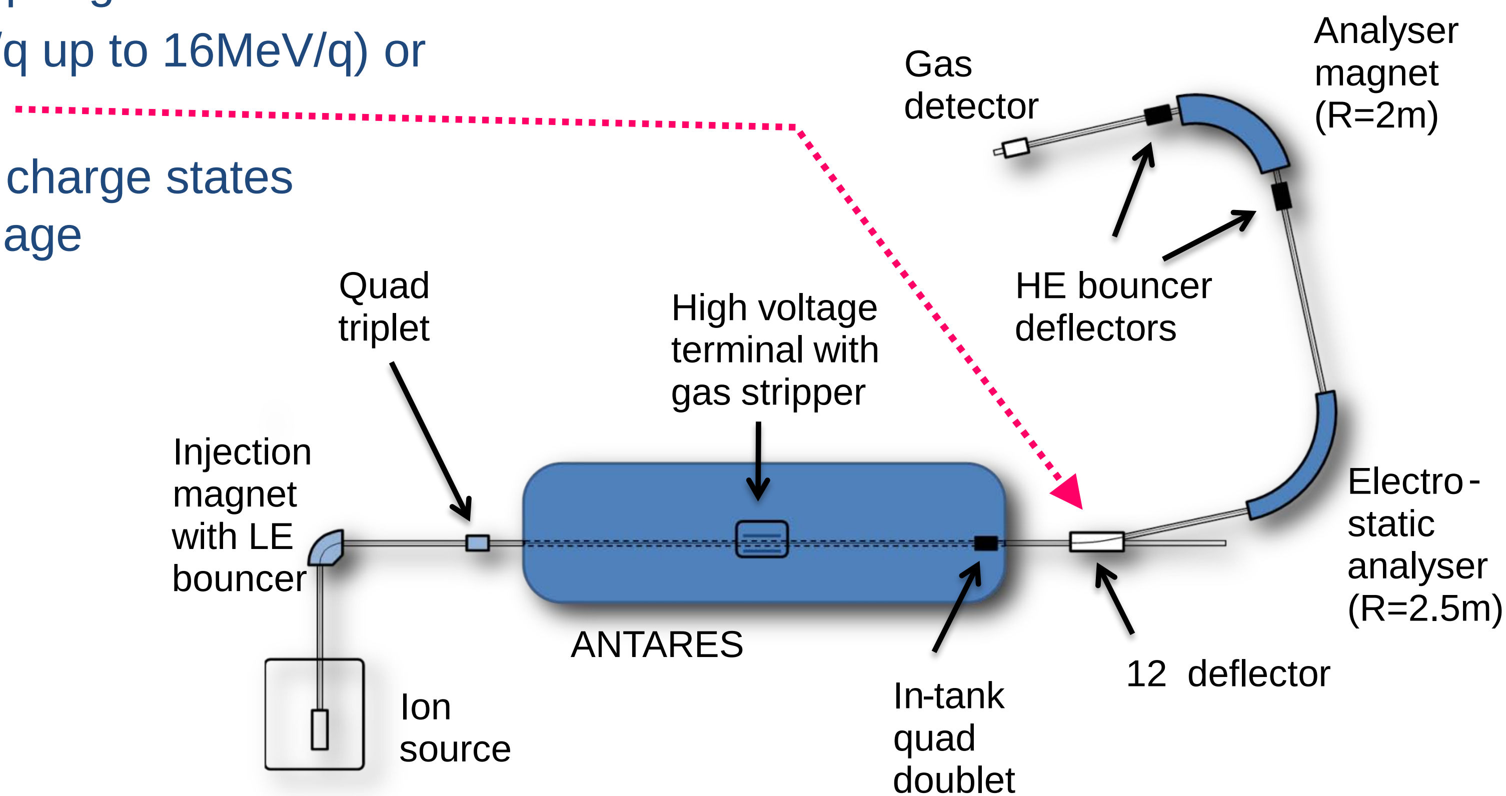
- oxide ions injected
- 4MV
- **argon** stripper gas
- yield up to 5% for 5+ charge state
- main analyser has ME product of 250 → 5+ is the minimum charge state usable at 4MV



Measurements

Systematic investigation of charge state distributions

- injected beams: UO, ThO, Au, I, FeO, Fe, C
- mostly 4MV on terminal; 4.1 MeV beam energy
- data for iodine from 2 to 7 MV; ThO from 2 to 4 MV
- Ar, Xe, He, SF6 stripper gases
- use 12º deflector (E/q up to 16MeV/q) or analysing magnet
- measure all positive charge states in Faraday cup at image position of ESA



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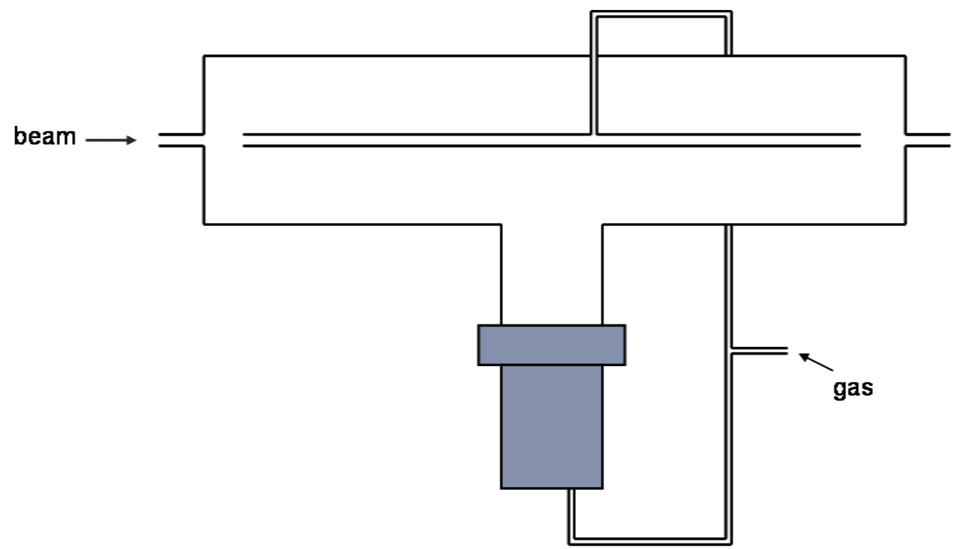
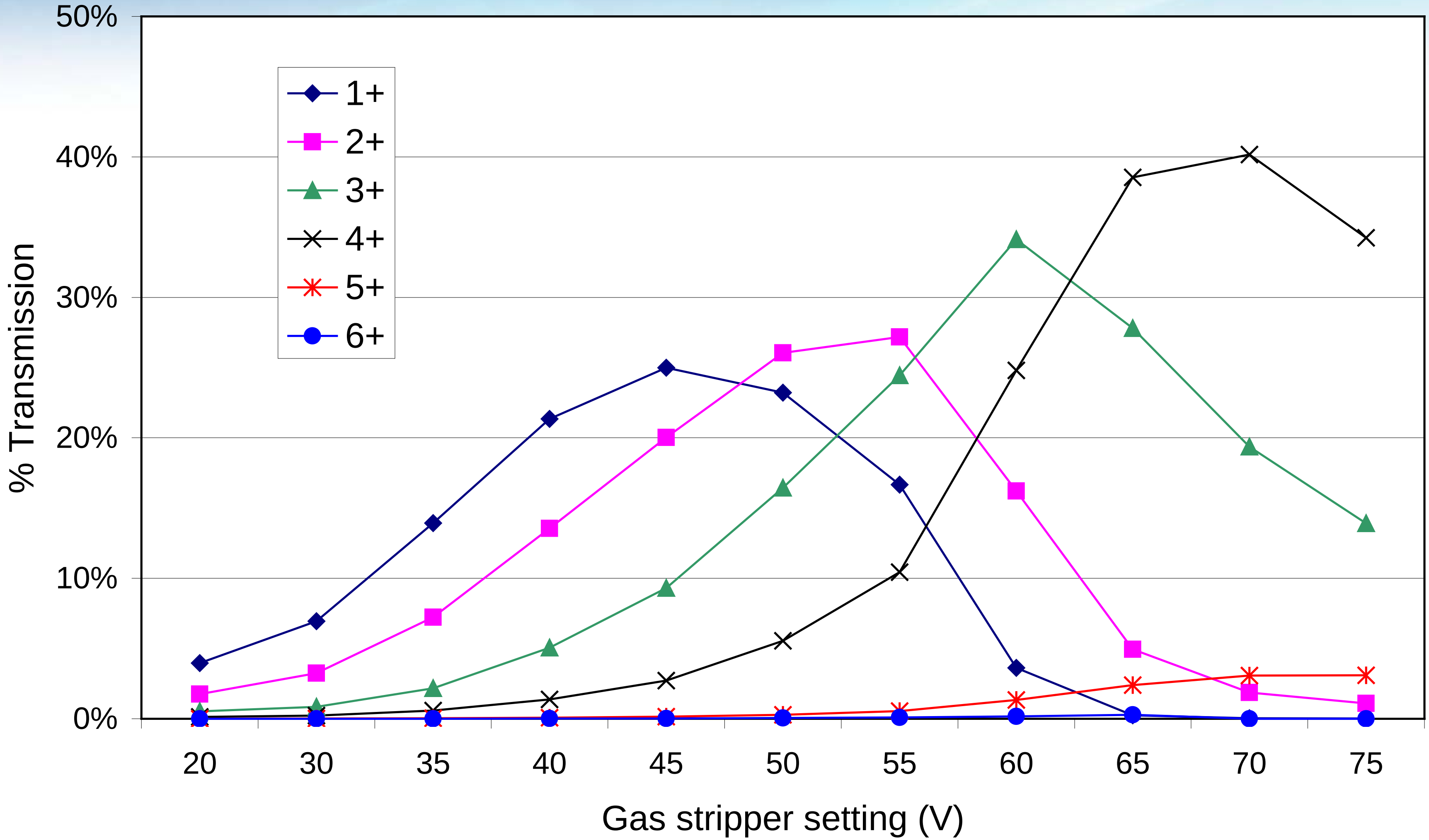
Terminal gas stripper

- originally installed 1995 with Ar gas only
- modified to provide 3 gases
- currently, no effective pressure readout from stripper box

Tube length	**690mm**
Diameter	**9.5mm**
Entrance tube diameter	**12.5mm**
Exit tube diameter	**10mm**
Turbopump	**Alcatel TMP 5400; 400 L/s nominal, 27000rpm (at 450Hz)**
Gas bottles	**Ar, He, Xe (from 2009)** **Ar, N_2, SF_6 (2012)**
Gas control	**voltage applied to three independent thermo-mechanical leaks**



Charge State Yields for C^- ions in Ar



note:

- stripping is progressive, as expected

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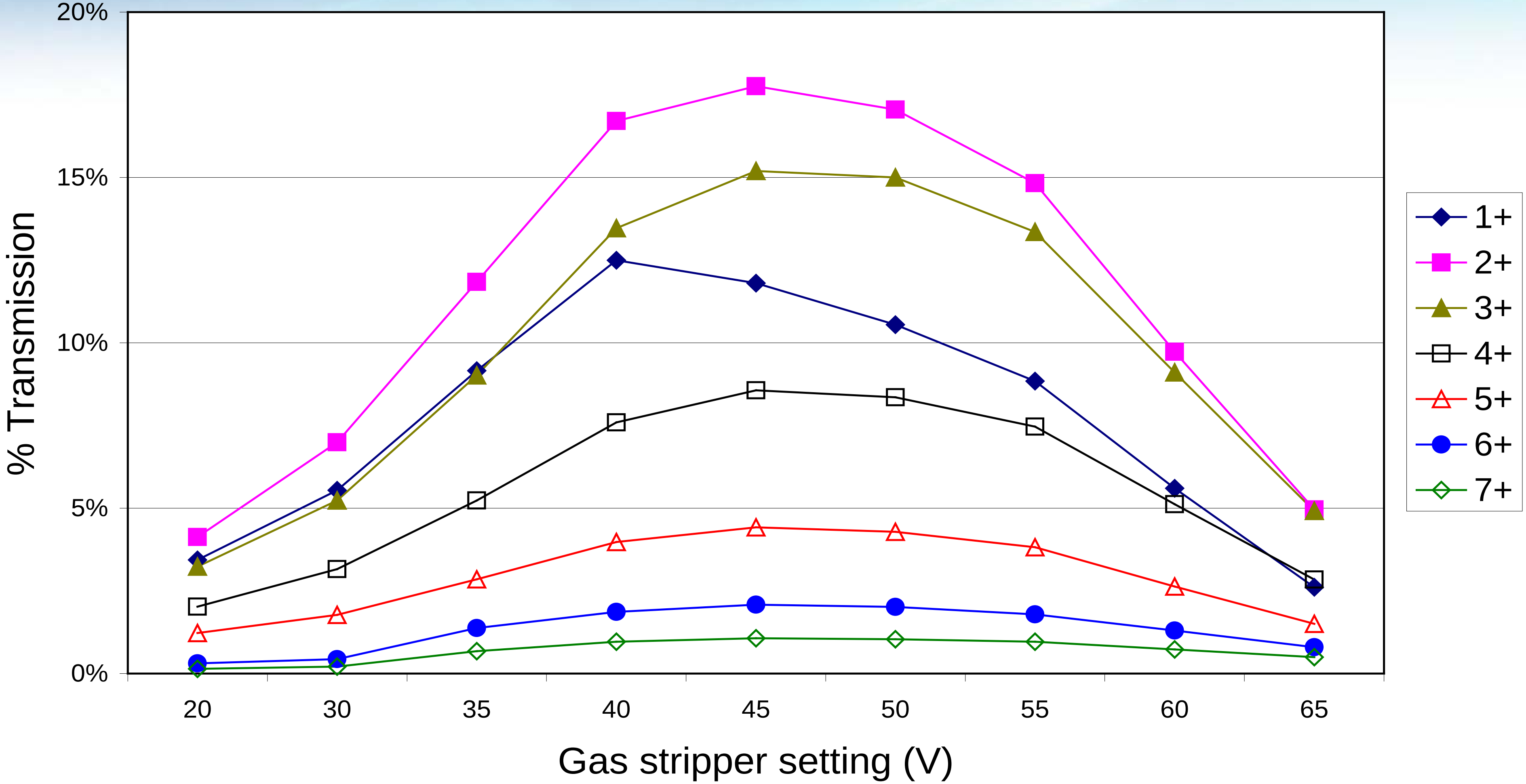
Charge state yields for UO^- in Ar gas



- yield for 5+ as normally used
- charge state maxima nearly coincide ?

Questions

What's going on?

Would an alternative gas give higher yields?

Clues in earlier work – measurements of <u>equilibrium</u> charge state distributions:

→ Helium best for high charge state yields ?

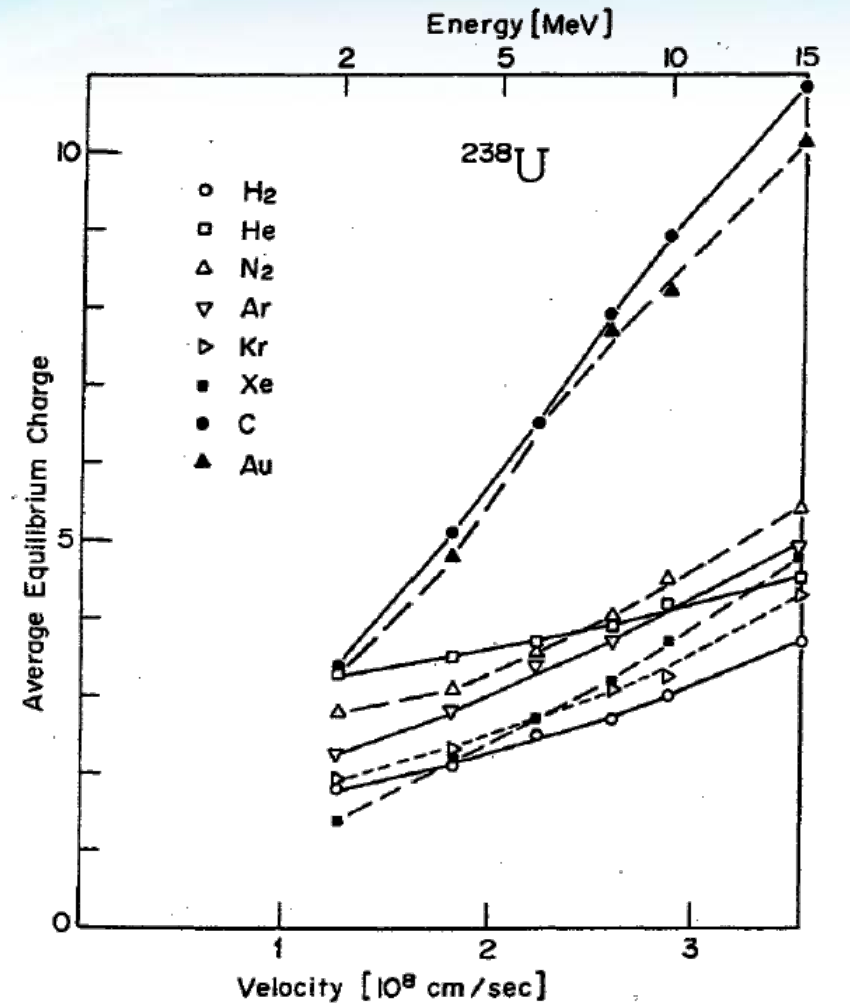


FIG. 1. Average equilibrium charge of uranium ions passing through gases and solids, plotted as a function of the ion velocity.

A.B. Wittkower and H.D. Betz, Phys. Rev. A 7 (1973) 159.

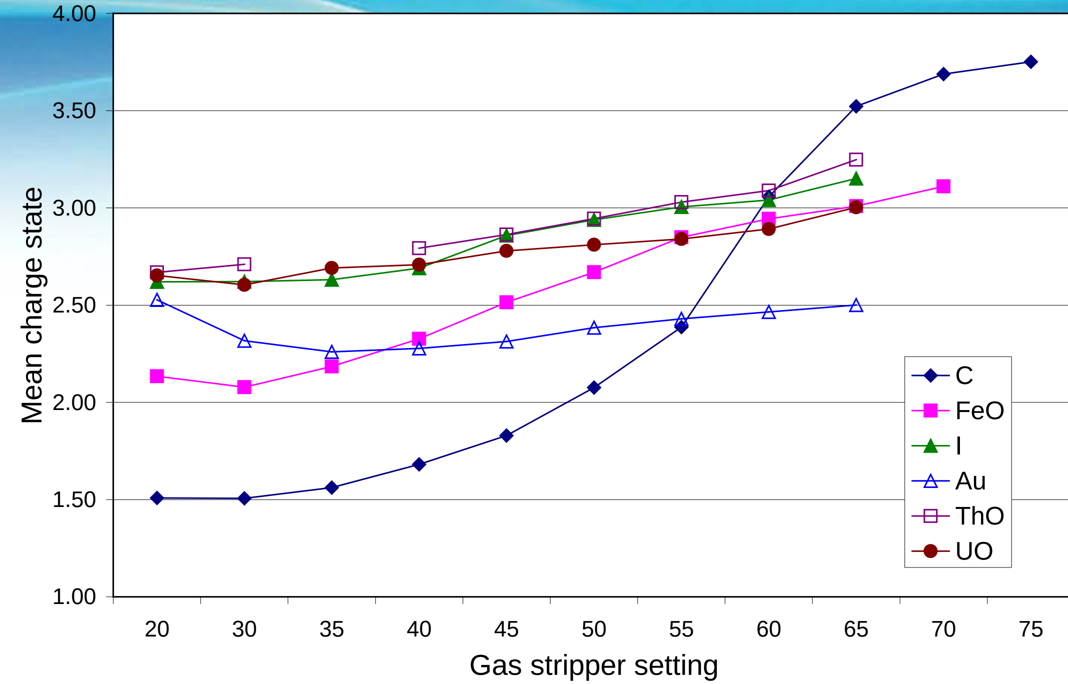
Argon data

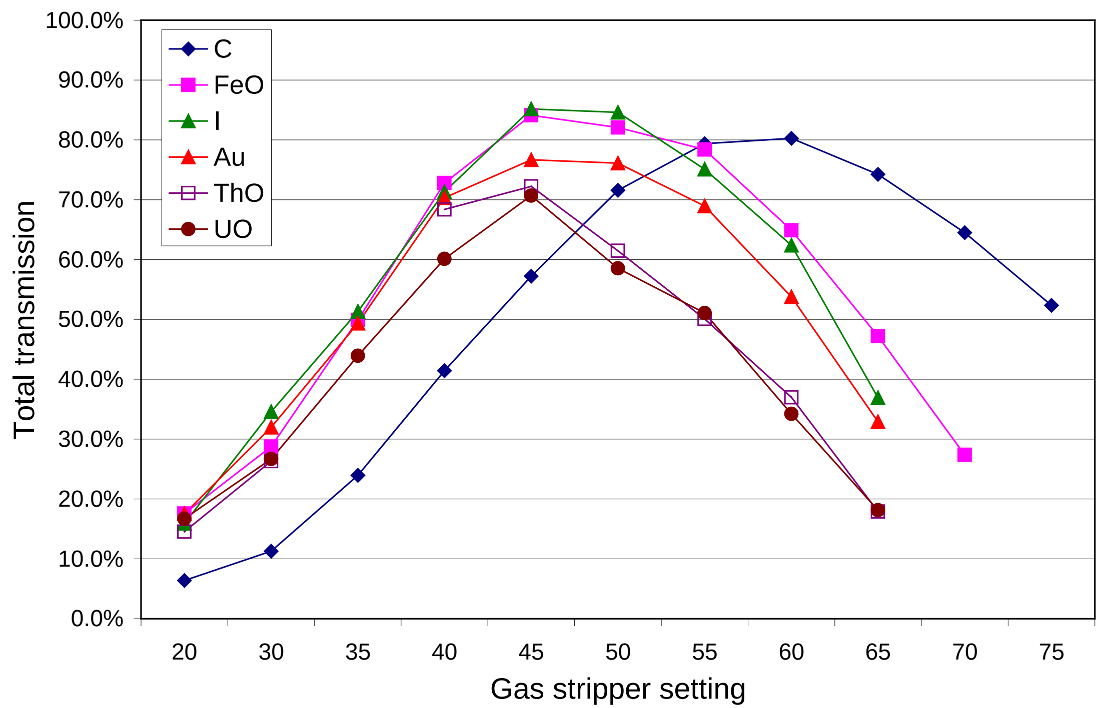
Observations:

- carbon behaves as expected
- for high masses, stripping is not progressive
- mean charge states less sensitive to pressure for high mass ions
- total transmissions 70-85% maximum

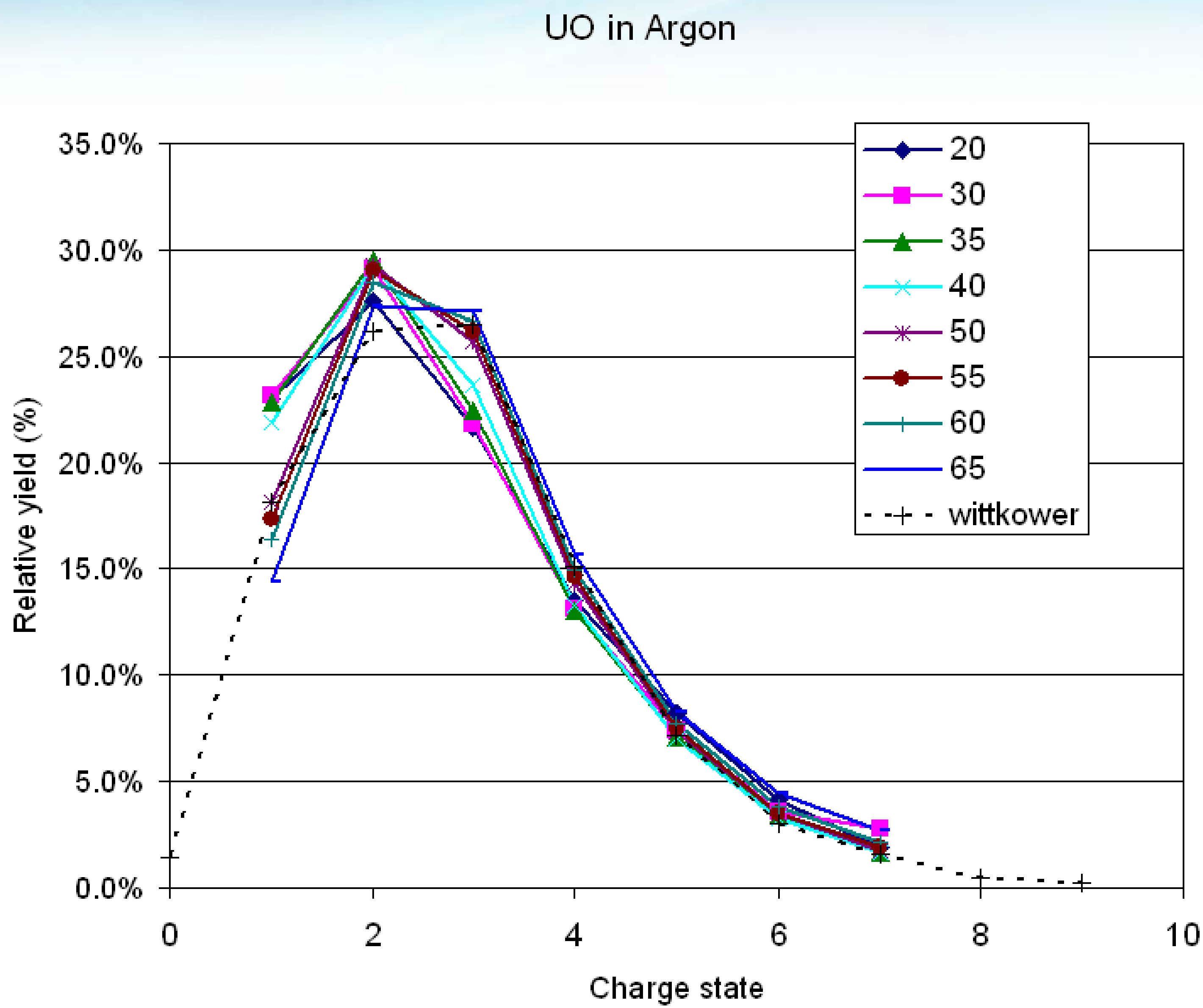
Conclusions:

- first collision of ion with gas has high probability of multiple electron loss, especially for high mass ions
- equilibrium not achieved before losses take over





Relative yields – UO in Argon



Observations:

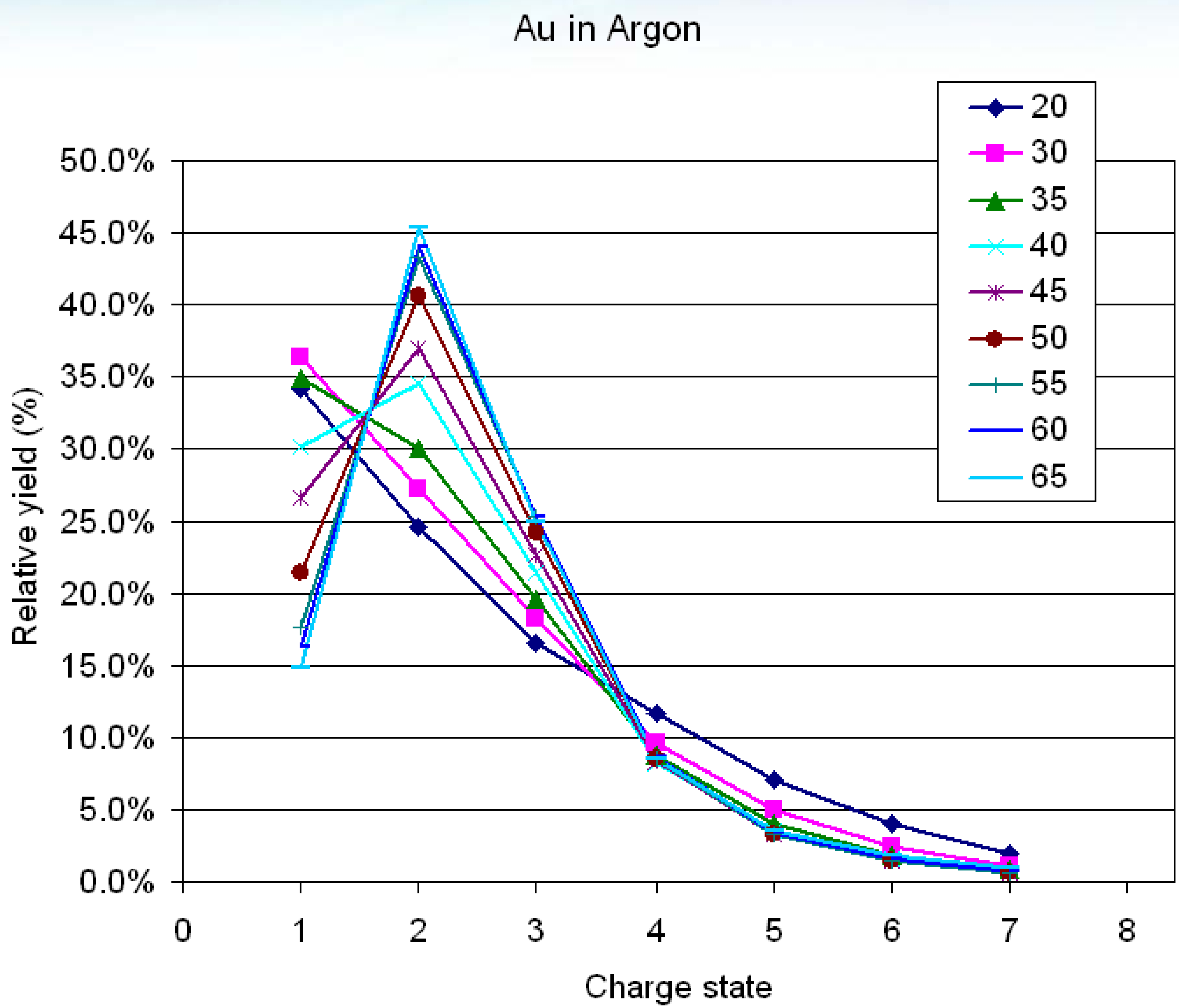
- limited evolution of charge state yields
- equilibrium nearly reached

Relative yields – Au in Argon

Observations:

- high charge state tail at low pressure
- yield concentrating into 2+ as pressure increases

Similar picture with Xenon



Initial conclusions

For high mass negative ions:

- high probability of multiple electron loss in a single collision with the gases investigated
- single collision distribution mostly gas-type independent
- subsequent collisions for Ar stripper tend to narrow the charge state distribution
- under conditions investigated, cannot concentrate yield into 1+ (or any other) charge state

Alternative gases

Solids give high charge states due to the 'density effect': requires collisions with more than one atom

What about multi-atom molecular gases?

Could they provide an 'intra-molecular' density effect?

Let's try SF_6, I'm sure we have some…

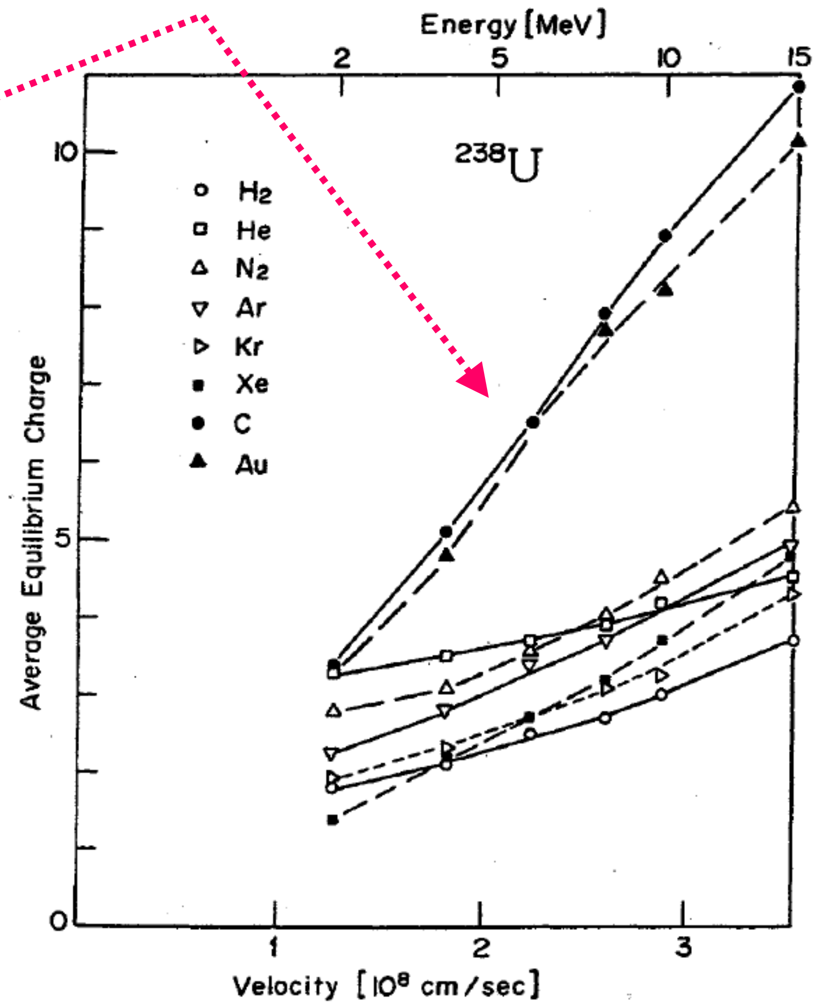


FIG. 1. Average equilibrium charge of uranium ions passing through gases and solids, plotted as a function of the ion velocity.

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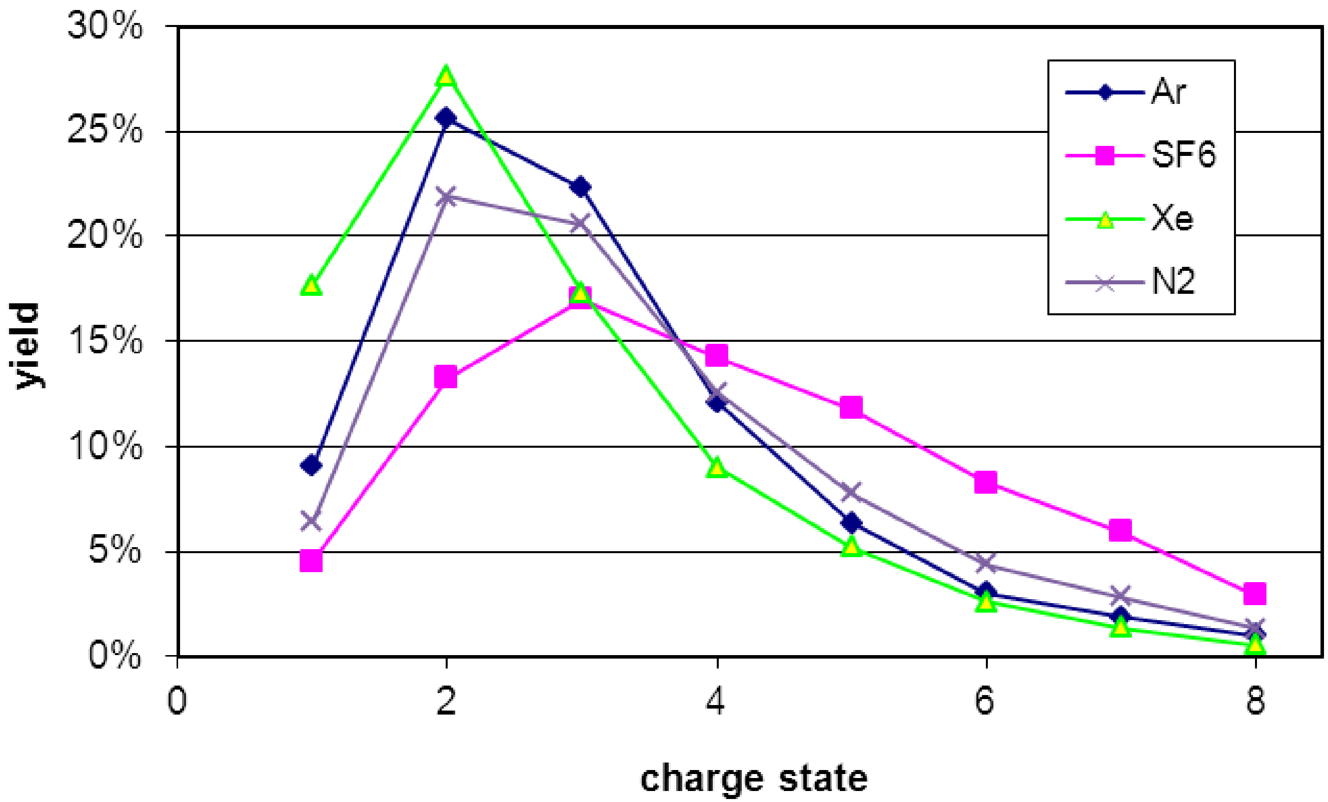
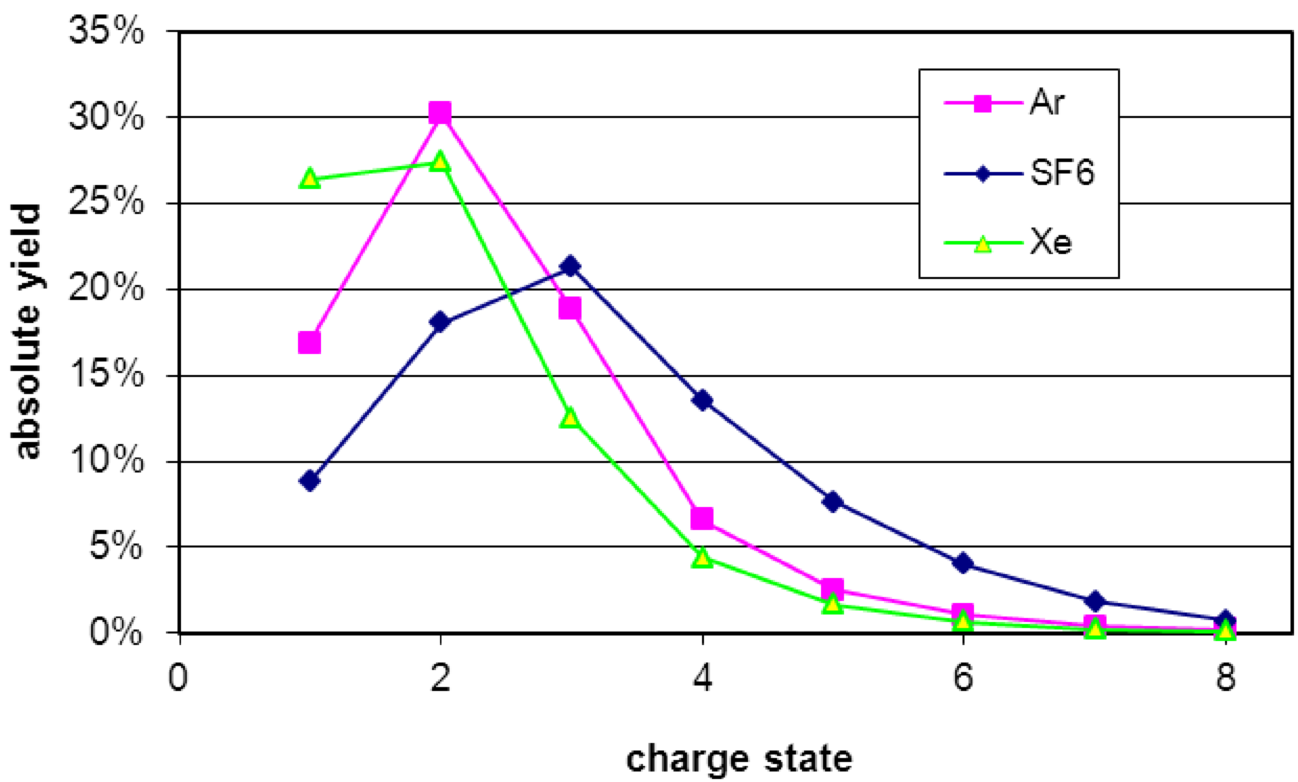
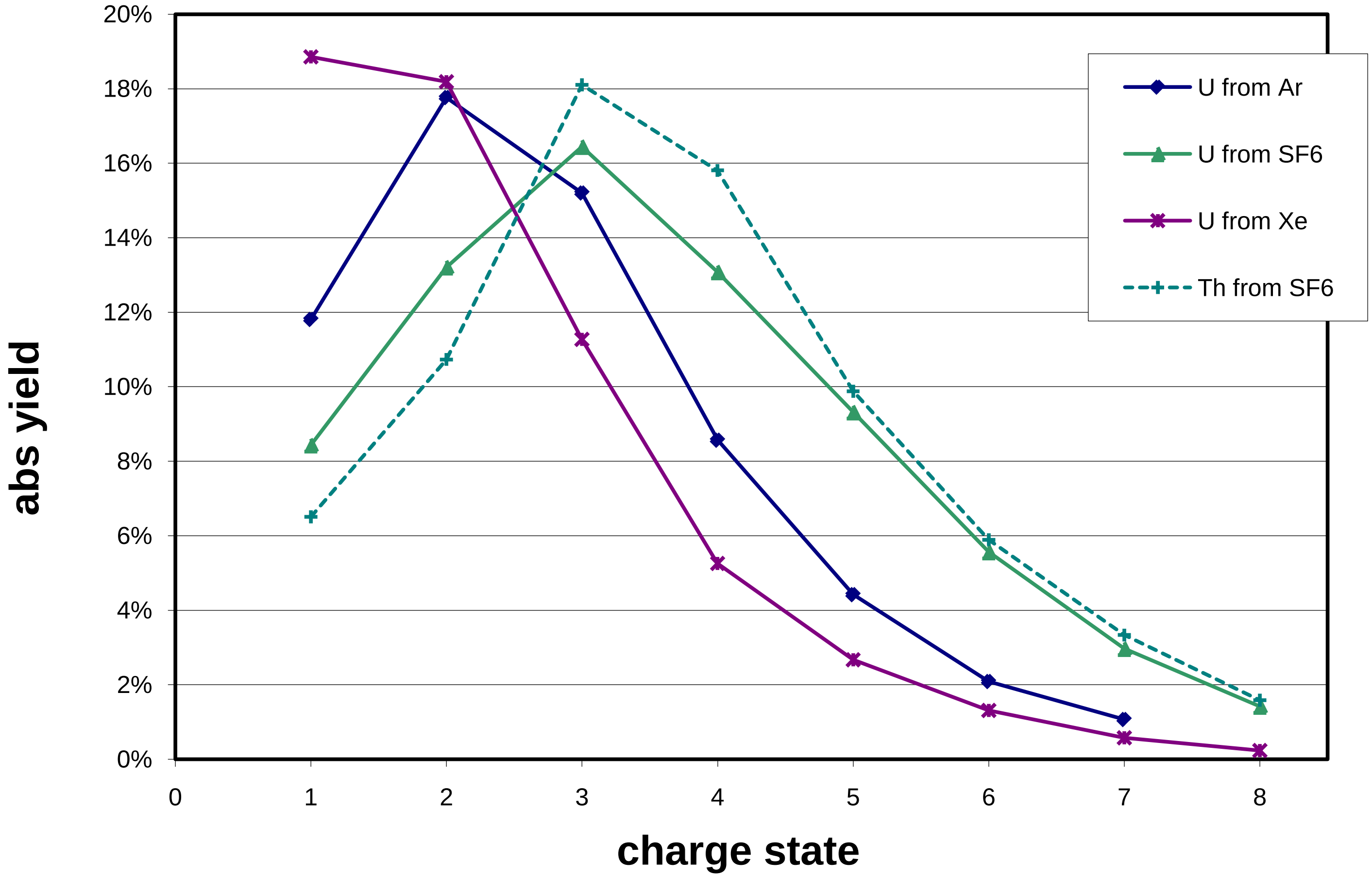
iodine at 4.1MeV

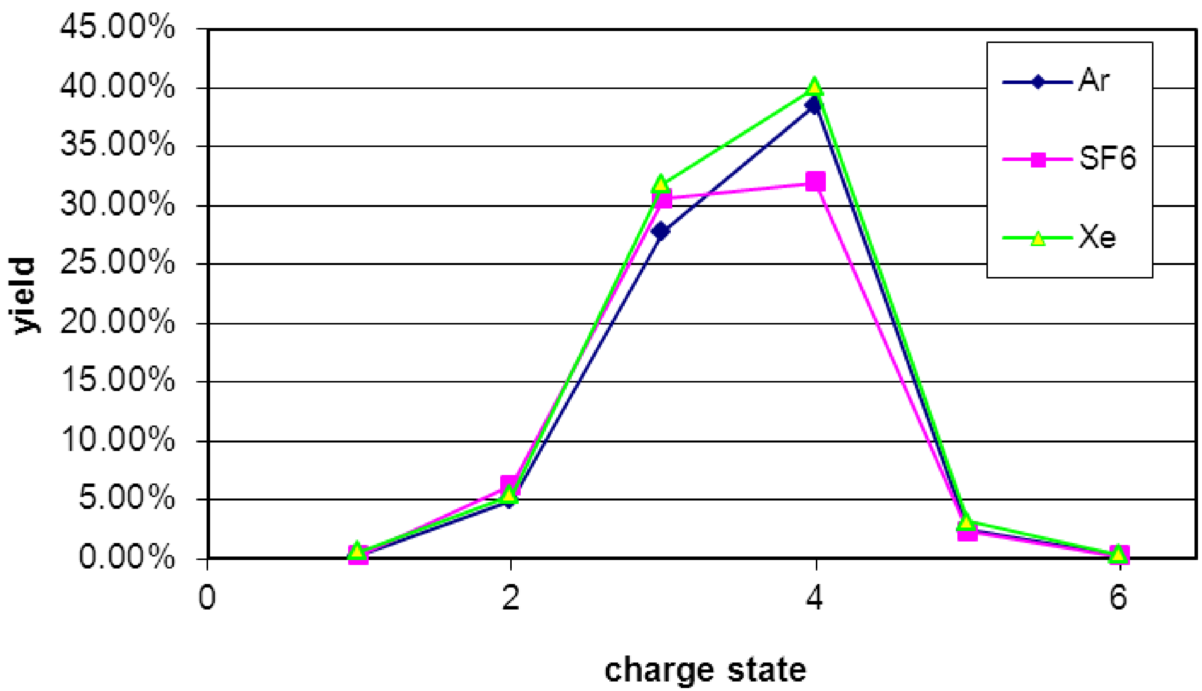


gold at 4.1MeV



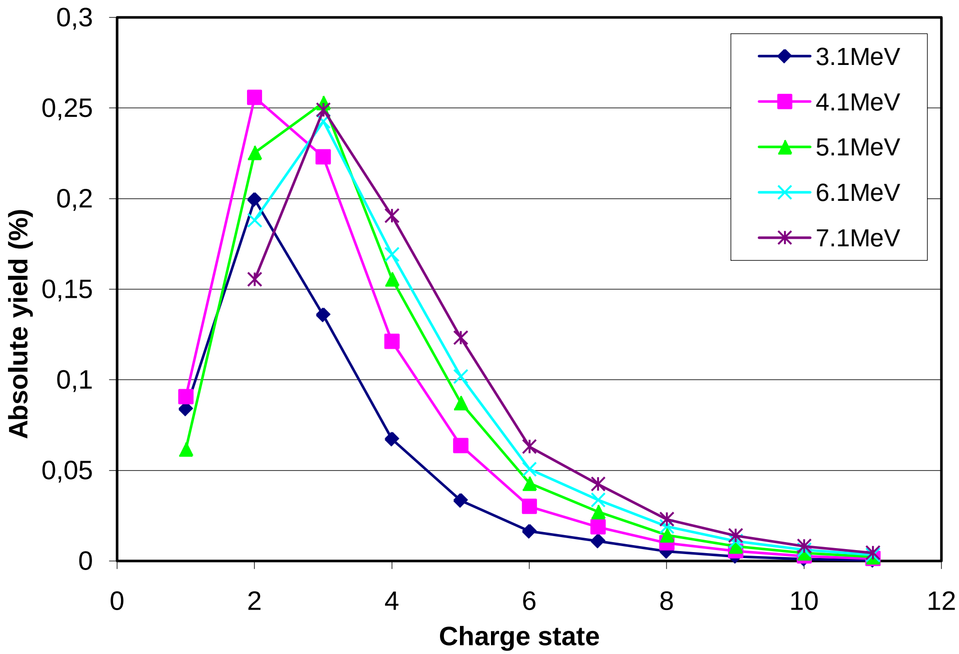

20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
abs yield
0
1
2
3
4
5
6
7
8
charge state
U from Ar
U from SF6
U from Xe
Th from SF6

carbon at 4.1MeV -- peak of 4+ yield



Hm, …SF_6 not so good

Iodine in argon



Iodine in SF6

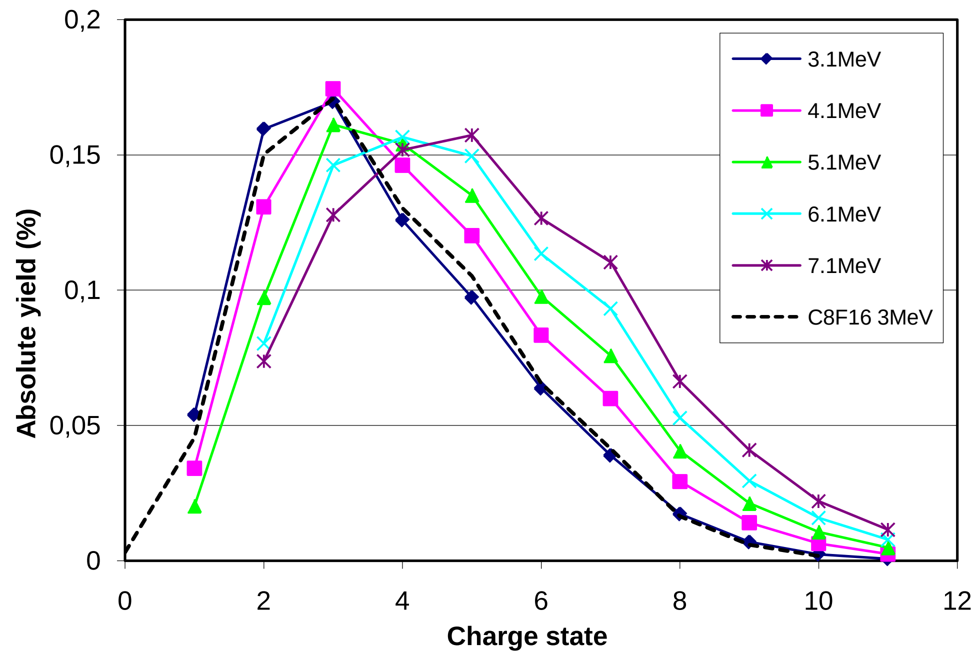


Table 1. The maximum total transmission achieved with SF_6 gas and comparison of 5+ ion yields and q-bar for SF_6 and Ar stripper gases at 4.1MeV.

Injected ion	Total transmission	5+ yield	5+ yield with Ar	q-bar	q-bar with Ar
Au^-	75.9%	7.7%	2.5%	3.21	2.39
I^-	78.0%	11.8%	6.6%	4.01	2.94
ThO^-	72.0%	9.9%	5.6%	3.71	2.86
UO^-	70.7%	9.3%	4.4%	3.53	2.78
FeO^-	82.0%	11.3%	5.1%	3.34	2.85
Fe^-	88.7%	15.2%	8.4%[1]	4.15	3.43[1]
C^- (4+ maximum)	71.3%	31.9%[2]	40.2%[2]	3.43	3.52
C^- (trans. max.)	87.9%	15.0%[2]	24.8%[2]	2.56	3.06

[1]Fe is compared to Xe as it was not measured with Ar.

[2]For carbon beams, the 4+ yield is listed.

Further conclusions

Benefits of SF_6:

- intra-molecular 'density' effect increases mean charge state by up to 1 charge state and broadens the distribution
- increased yield for charge states above the mean: factor of 2 or more
- great for actinides AMS: yield / efficiency doubled!

(→ better quality data or go home earlier?)

What if you want a charge state near the mean?

- use Ar (or N_2?)

For light ions (eg carbon):

- use Ar (or N_2?)

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