The gas-filled recoil separator RITU, an Inelastic Reaction Isotope Separator?

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RITU and Gamma groups
Department of Physics, University of Jyväskylä, Finland

Topical Review R159

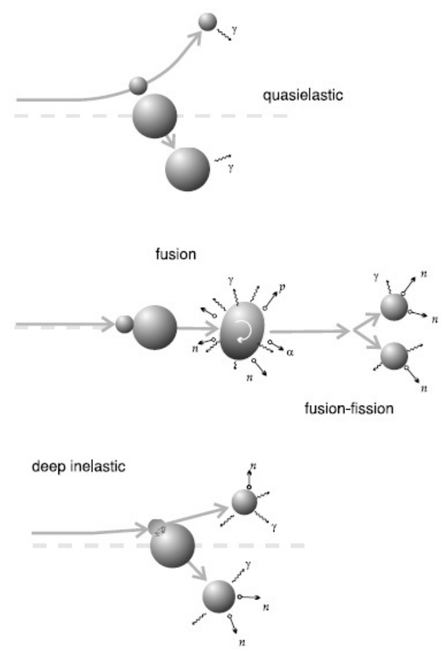

Figure 6. Schematic classification of reactions taking place in collisions of heavy ions at energies above the Coulomb barrier.

IRiS 10

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TOPICAL REVIEW

Spectroscopic studies with the use of deep-inelastic heavy-ion reactions

By R. Broda

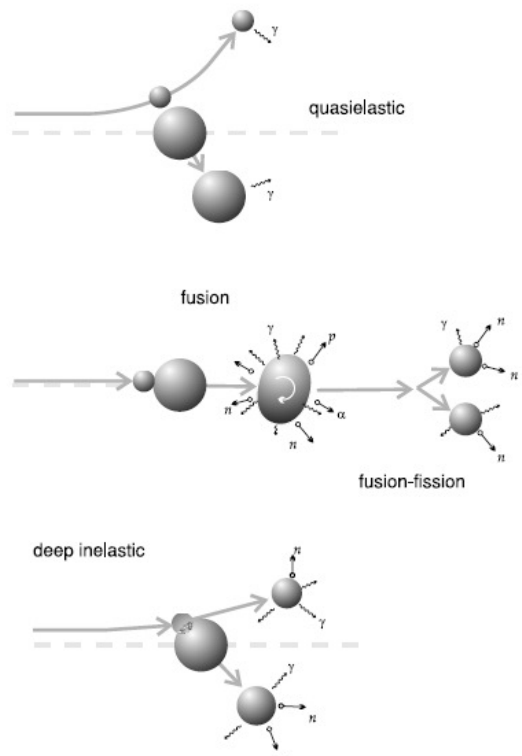


Figure 6. Schematic classification of reactions taking place in collisions of heavy ions at energies above the Coulomb barrier.

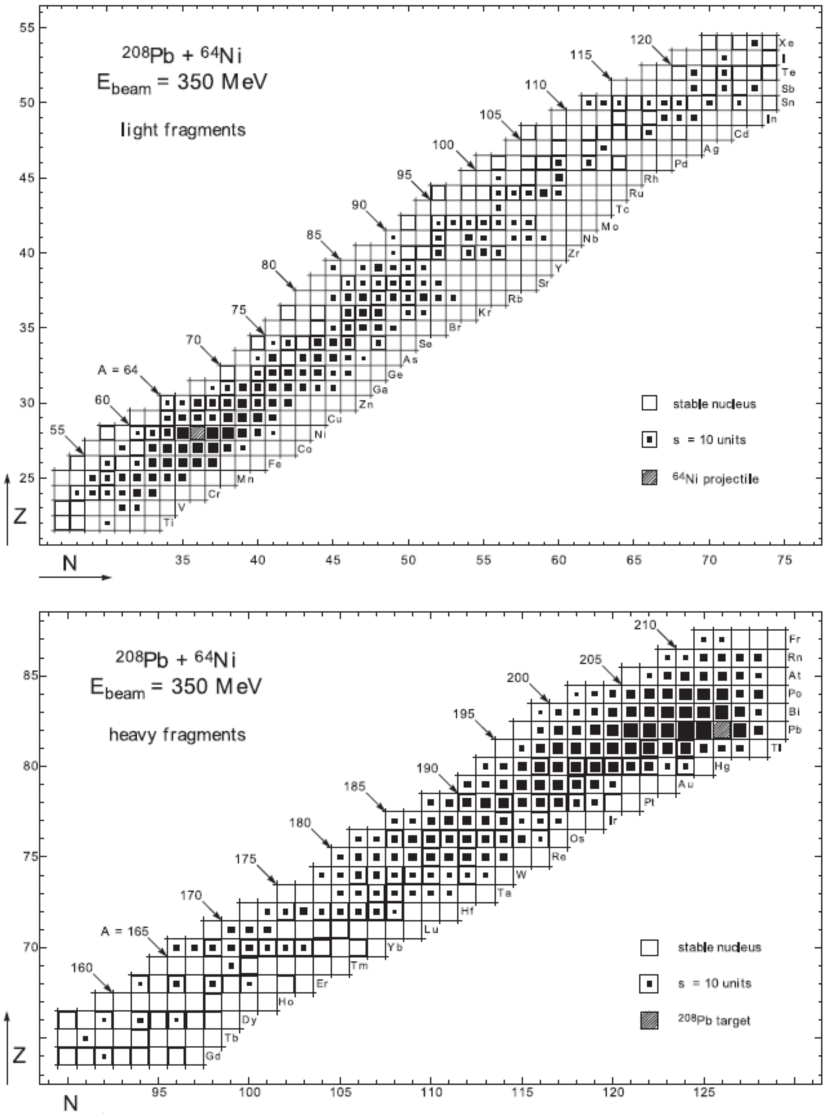


Figure 8. Distribution of heavy (a) and light (b) fragments in ^{208}Pb + 350 MeV ^{64}Ni collisions [18–20].

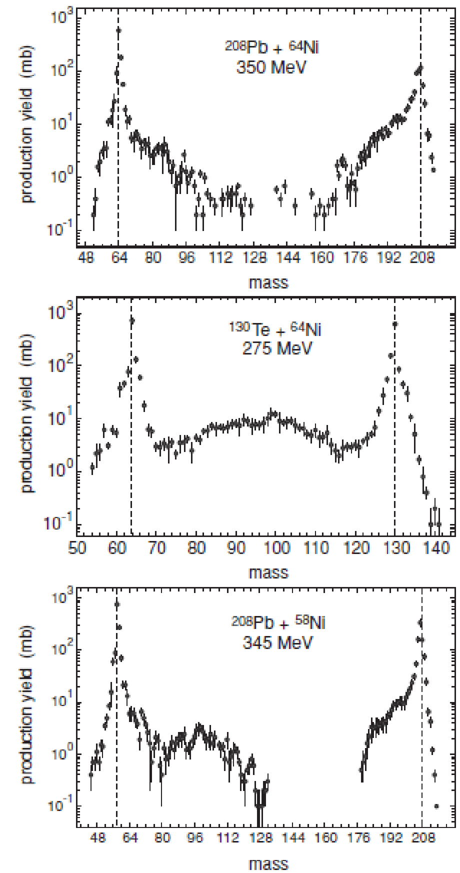


Figure 9. Isobar-integrated fragment mass distributions for three colliding systems [18, 19].

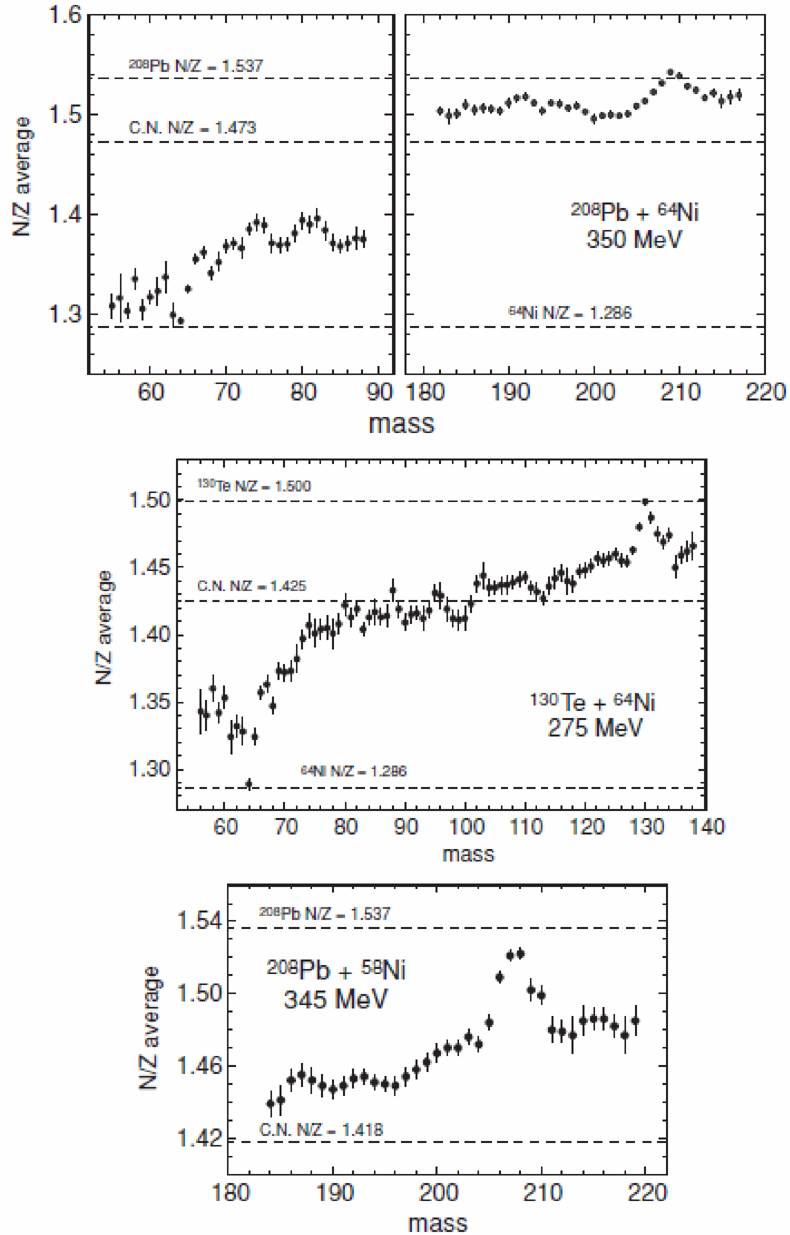
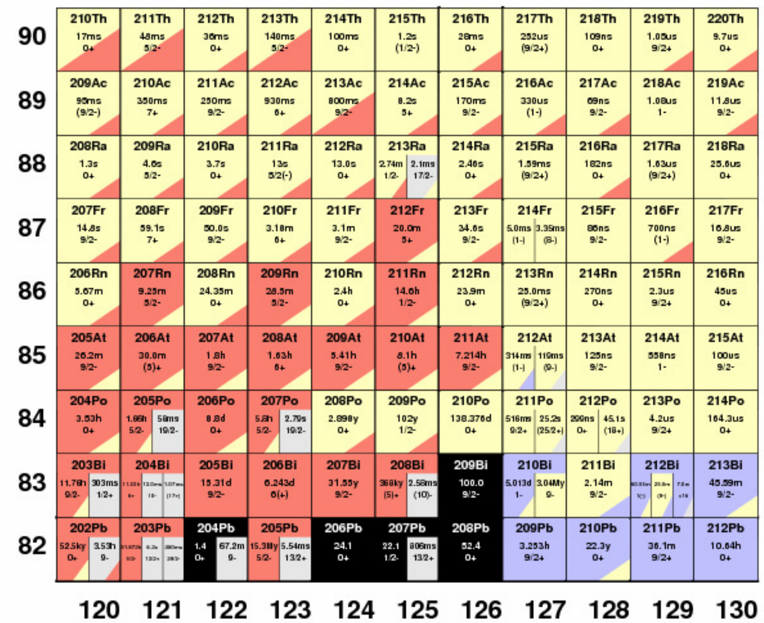


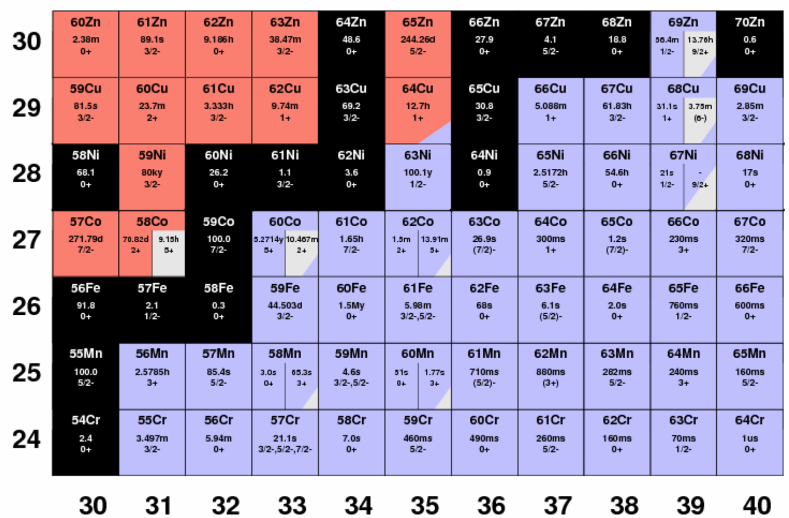
Figure 10. Mass dependence of the average N/Z ratios for isobaric products of binary reactions observed in three colliding systems [18, 19].

Experiments performed using RITU

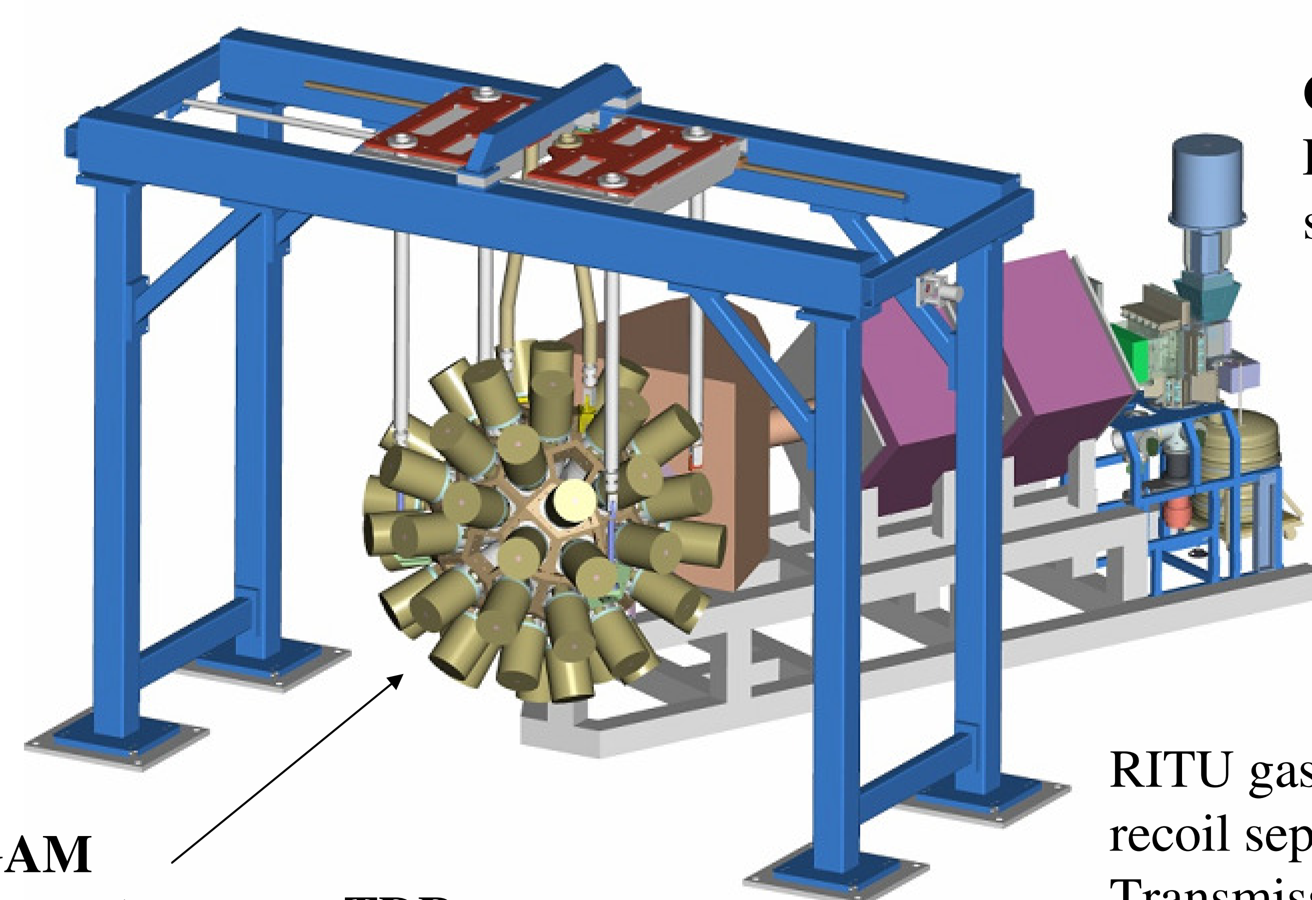
	N/Z			
	beam	target	CN	Method
$^{40}Ar + {}^{208}Pb > {}^{248}Fm^*$	1.22	1.54	1.48	α
$^{40}Ar + {}^{209}Bi > {}^{249}Md^*$	1.22	1.52	1.47	α
$^{44}Ca + {}^{209}Bi > {}^{253}Lr^*$	1.20	1.52	1.46	α
$^{48}Ca + {}^{209}Bi > {}^{257}Lr^*$	1.40	1.52	1.50	α, prompt and delayed γs
$^{65}Cu + {}^{209}Bi > {}^{274}112^*$	1.24	1.52	1.45	α, prompt and delayed γs
$^{86}Kr + {}^{209}Bi > {}^{295}119^*$	1.39	1.52	1.48	α, prompt and delayed γs
$^{136}Xe + {}^{209}Bi > {}^{345}137^*$	1.52	1.52	1.52	α, prompt and delayed γs

$^{65}Cu + {}^{209}Bi$


90
89
88
87
86
85
84
83
82
210Th 211Th 212Th 213Th 214Th 215Th 216Th 217Th 218Th 219Th 220Th
209Ac 210Ac 211Ac 212Ac 213Ac 214Ac 215Ac 216Ac 217Ac 218Ac 219Ac
208Ra 209Ra 210Ra 211Ra 212Ra 213Ra 214Ra 215Ra 216Ra 217Ra 218Ra
207Fr 208Fr 209Fr 210Fr 211Fr 212Fr 213Fr 214Fr 215Fr 216Fr 217Fr
206Rn 207Rn 208Rn 209Rn 210Rn 211Rn 212Rn 213Rn 214Rn 215Rn 216Rn
205At 206At 207At 208At 209At 210At 211At 212At 213At 214At 215At
204Po 205Po 206Po 207Po 208Po 209Po 210Po 211Po 212Po 213Po 214Po
203Bi 204Bi 205Bi 206Bi 207Bi 208Bi 209Bi 210Bi 211Bi 212Bi 213Bi
202Pb 203Pb 204Pb 205Pb 206Pb 207Pb 208Pb 209Pb 210Pb 211Pb 212Pb
120 121 122 123 124 125 126 127 128 129 130


30
29
28
27
26
25
24
60Zn 61Zn 62Zn 63Zn 64Zn 65Zn 66Zn 67Zn 68Zn 69Zn 70Zn
59Cu 60Cu 61Cu 62Cu 63Cu 64Cu 65Cu 66Cu 67Cu 68Cu 69Cu
58Ni 59Ni 60Ni 61Ni 62Ni 63Ni 64Ni 65Ni 66Ni 67Ni 68Ni
57Co 58Co 59Co 60Co 61Co 62Co 63Co 64Co 65Co 66Co 67Co
56Fe 57Fe 58Fe 59Fe 60Fe 61Fe 62Fe 63Fe 64Fe 65Fe 66Fe
55Mn 56Mn 57Mn 58Mn 59Mn 60Mn 61Mn 62Mn 63Mn 64Mn 65Mn
54Cr 55Cr 56Cr 57Cr 58Cr 59Cr 60Cr 61Cr 62Cr 63Cr 64Cr
30 31 32 33 34 35 36 37 38 39 40

RITU + Jurogam at JYFL



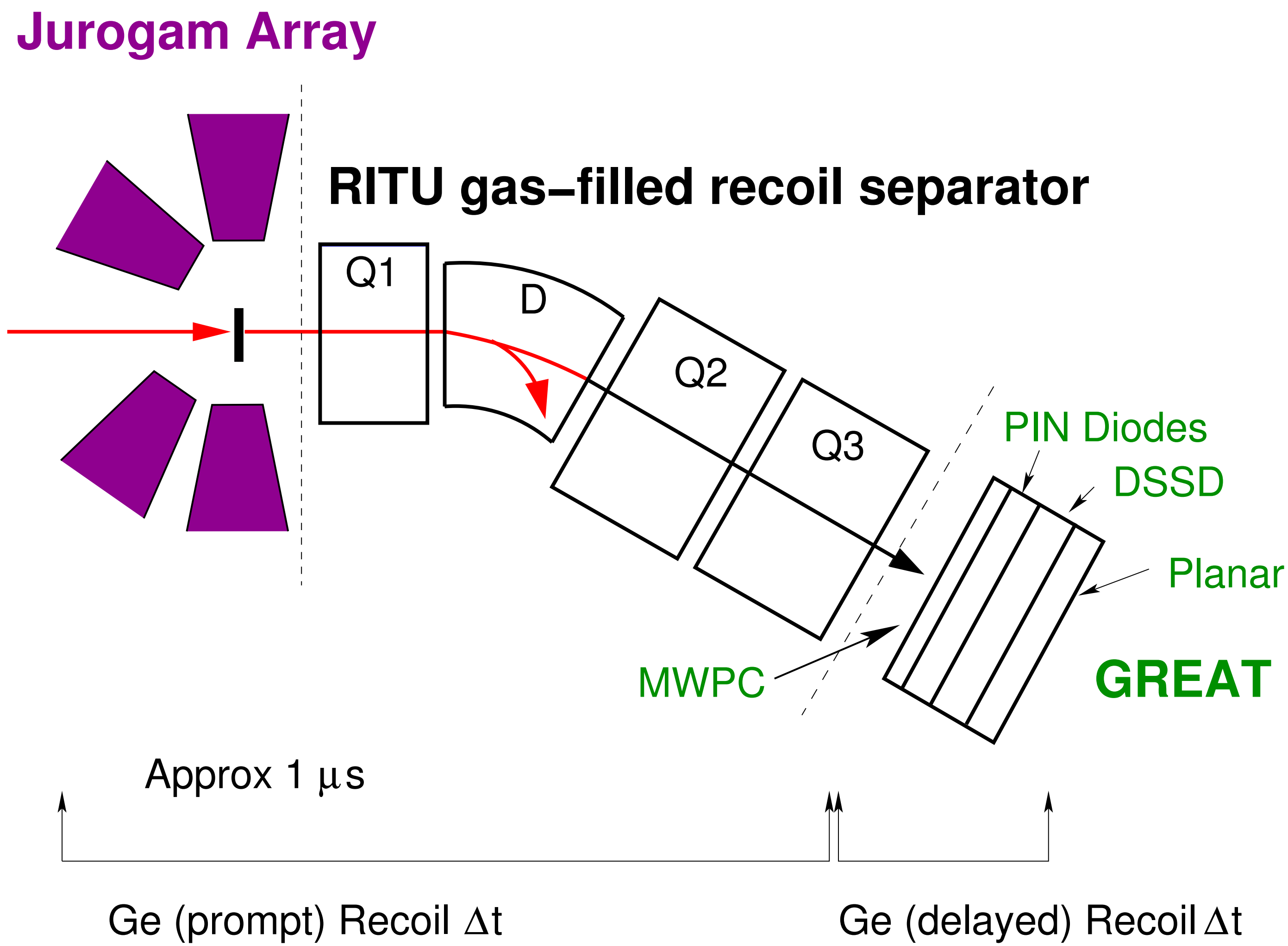
GREAT
Focal plane
spectrometer

JUROGAM
43 Ge+BGO detectors
Eff. 4%

TDR
Total Data Readout
Triggerless data acquisition system
with 10 ns time stamping

RITU gas-filled
recoil separator
Transmission 20 - 40%

$$\Theta_{gr} = 2 \bullet \arcsin[2 \bullet (V_c/E_{cm})-1] \qquad @E_{cm}=V_c \; \Theta_{gr} = 180^o$$



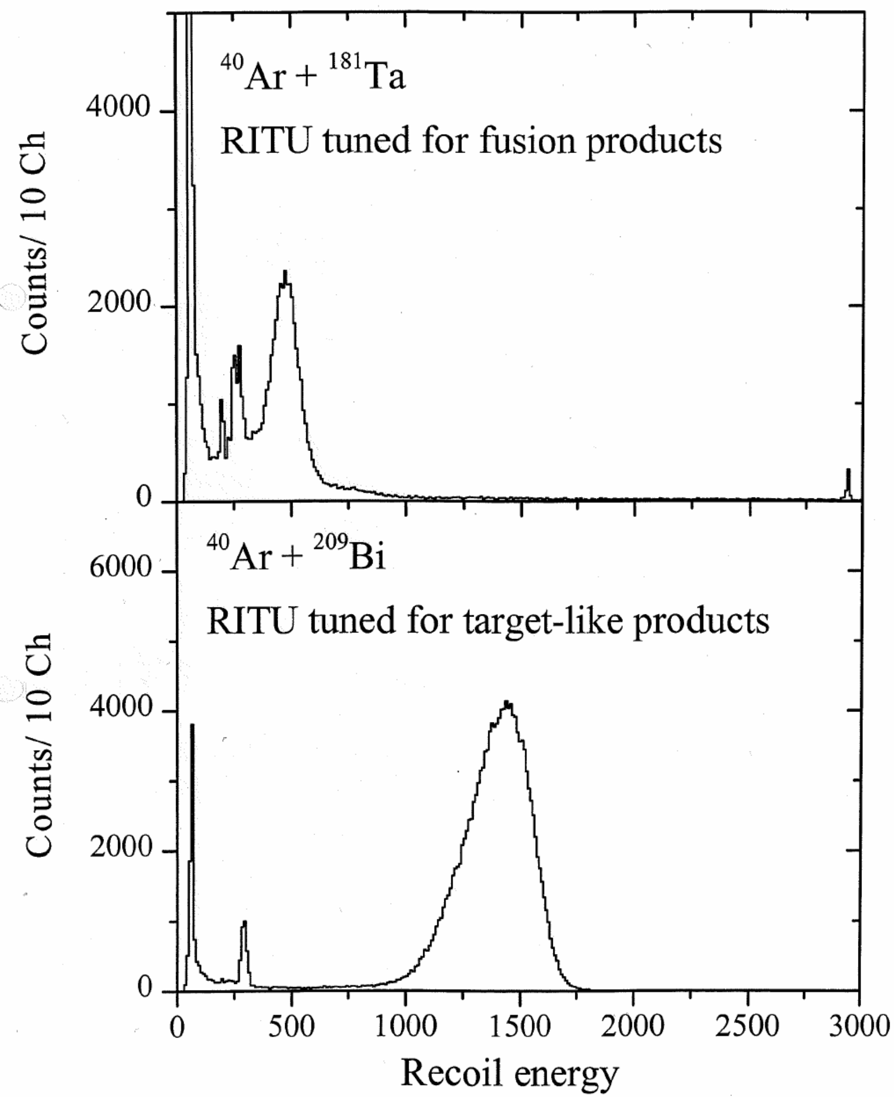


Figure 2.

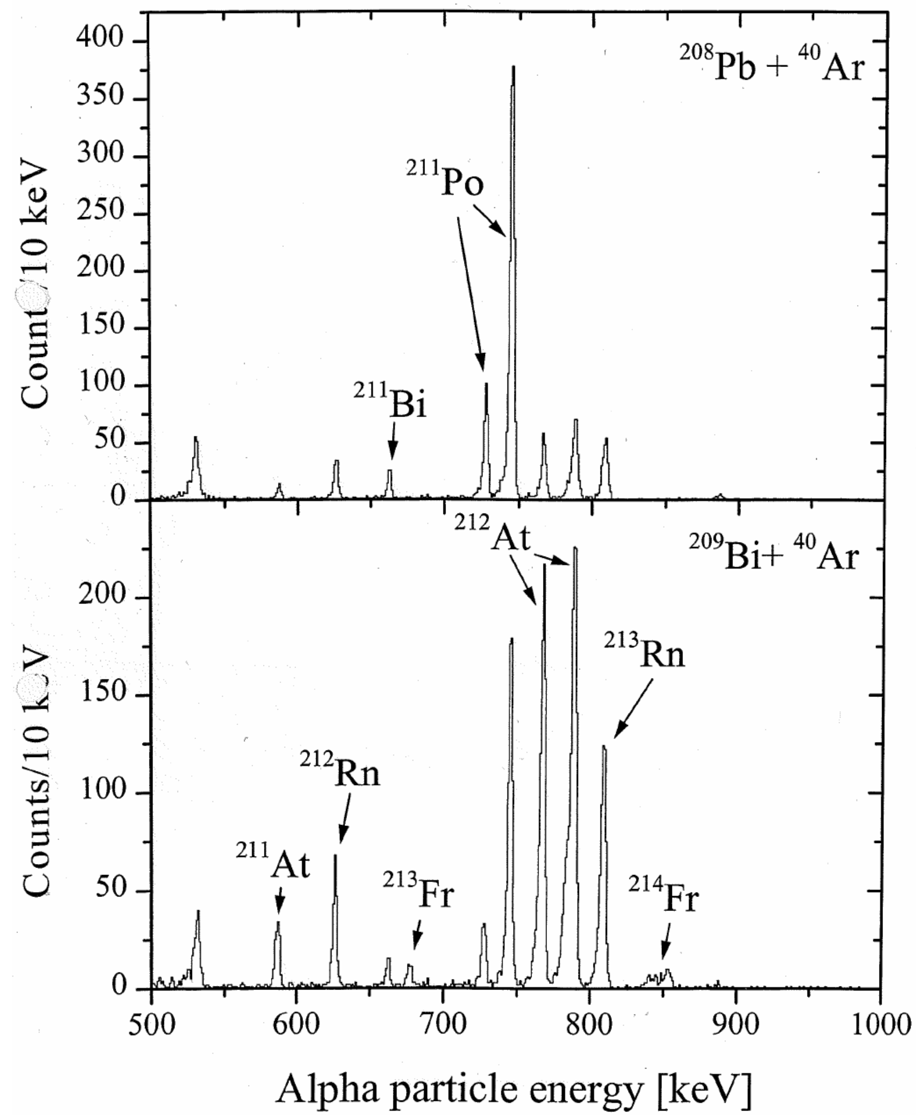
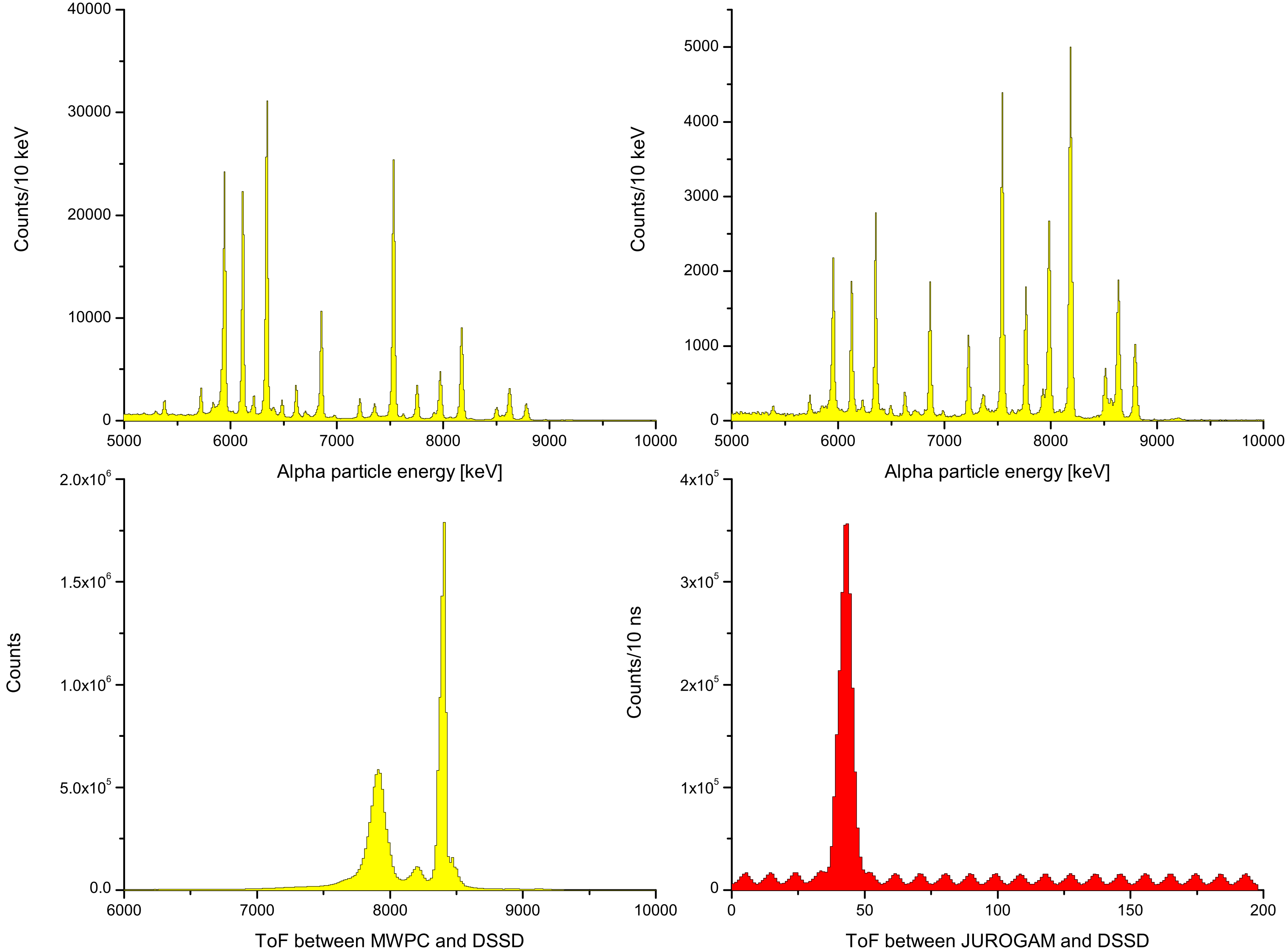
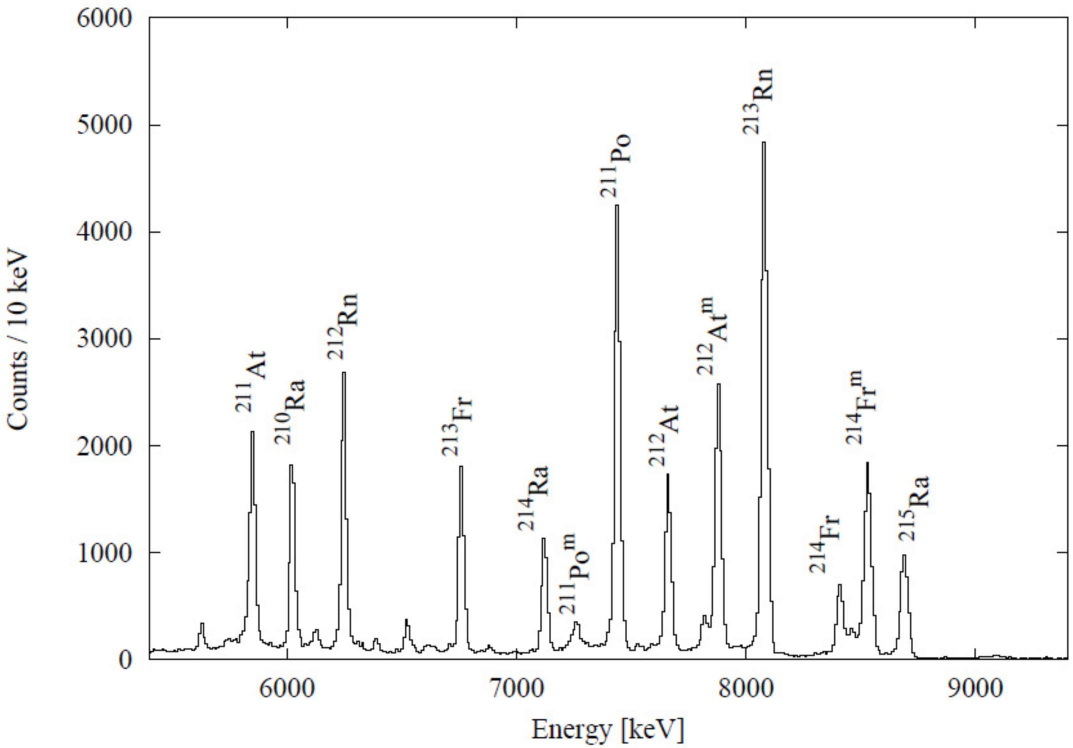


Figure 1.

$^{65}Cu + ^{209}Bi$



Counts/10 keV
Alpha particle energy [keV]
Counts/10 keV
Alpha particle energy [keV]
Counts
ToF between MWPC and DSSD
Counts/10 ns
ToF between JUROGAM and DSSD



^{65}Cu + ^{209}Bi

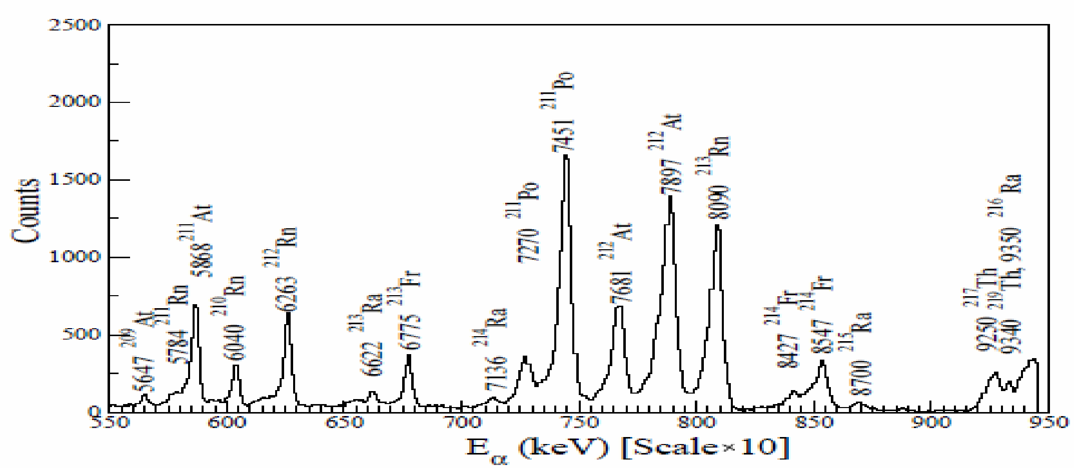
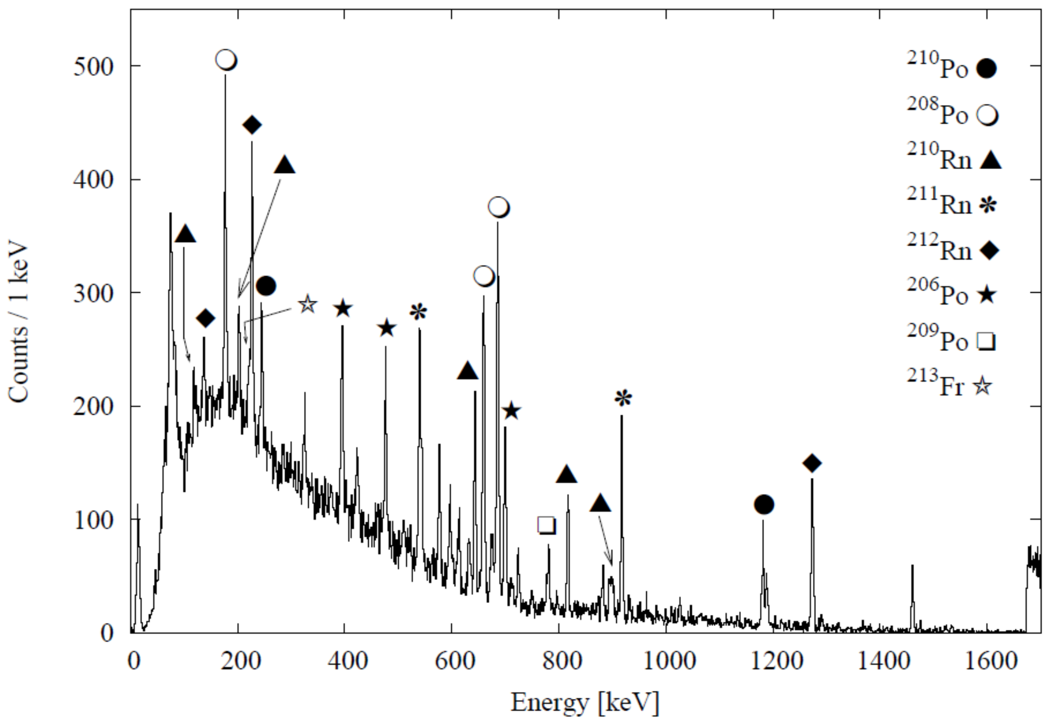


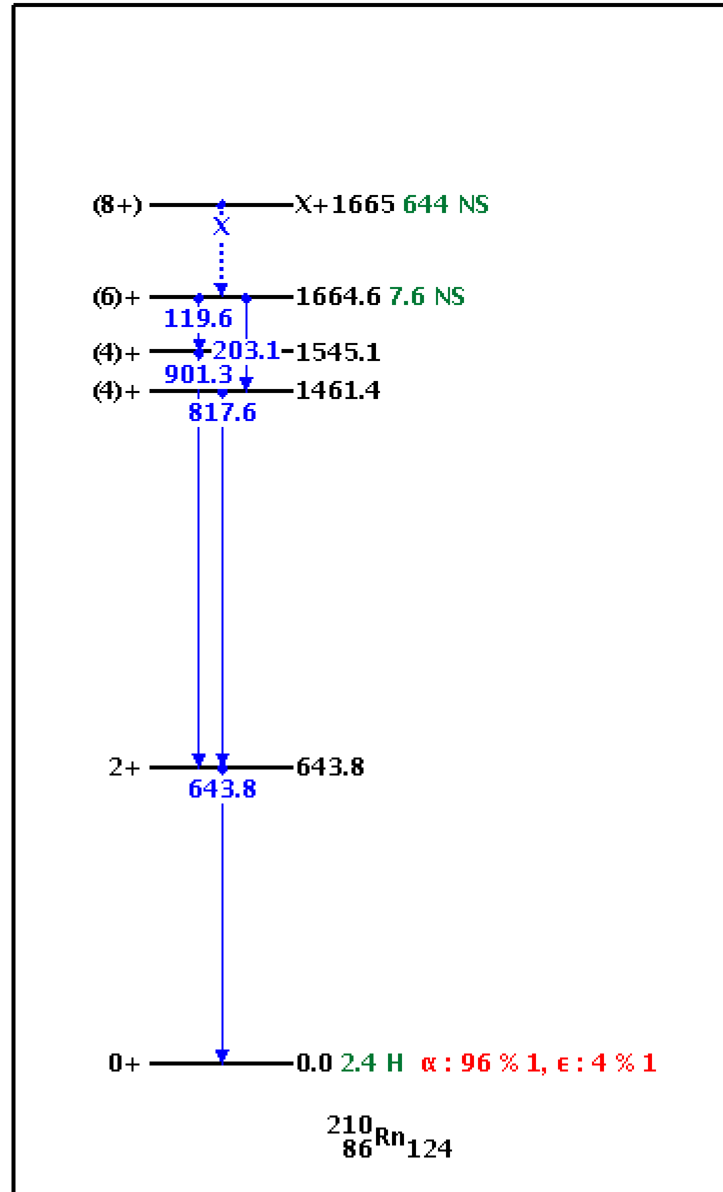
Figure 1: Correlated α particle spectrum.

^{86}Kr + ^{209}Bi

$^{65}Cu + ^{209}Bi$

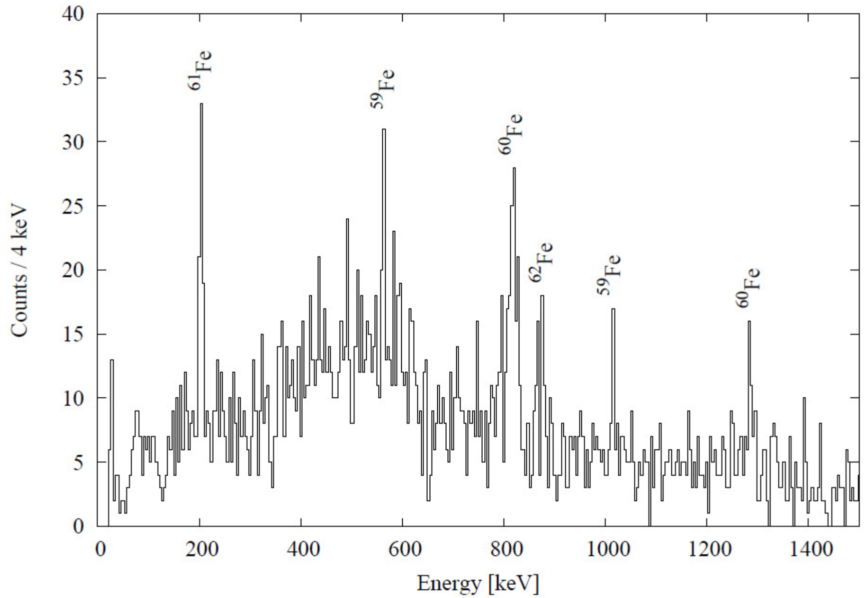


Counts / 1 keV
Energy [keV]
210Po
208Po
210Rn
211Rn
212Rn
206Po
209Po
213Fr

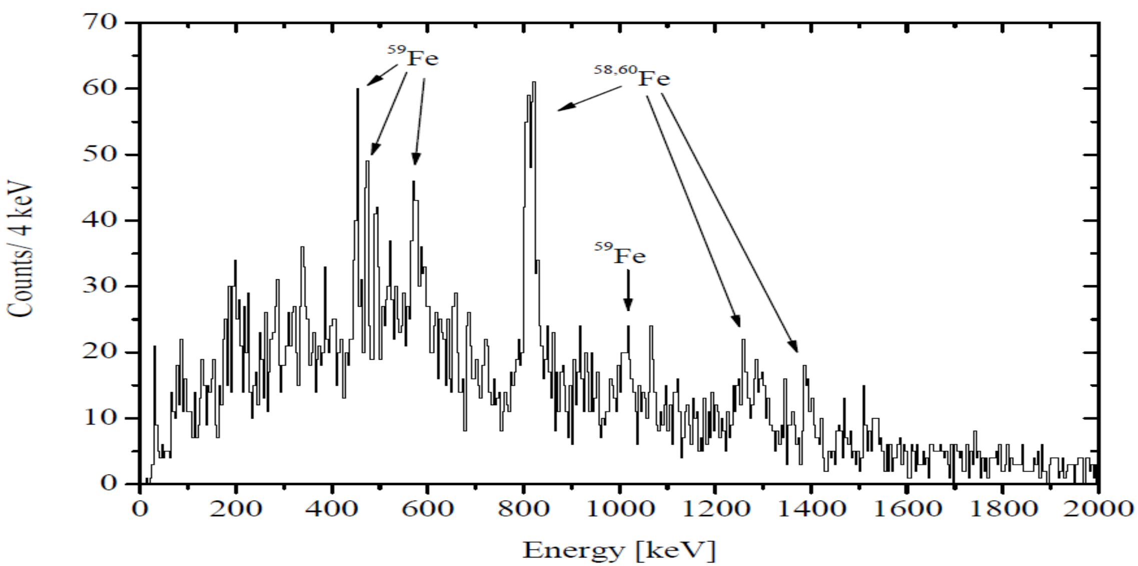


(8+)
X+1665 644 NS
X
(6)+
1664.6 7.6 NS
119.6
(4)+
203.1
1545.1
901.3
(4)+
1461.4
817.6
2+
643.8
643.8
0+
0.0 2.4 H α : 96 % 1, ε : 4 % 1
210 86 Rn 124

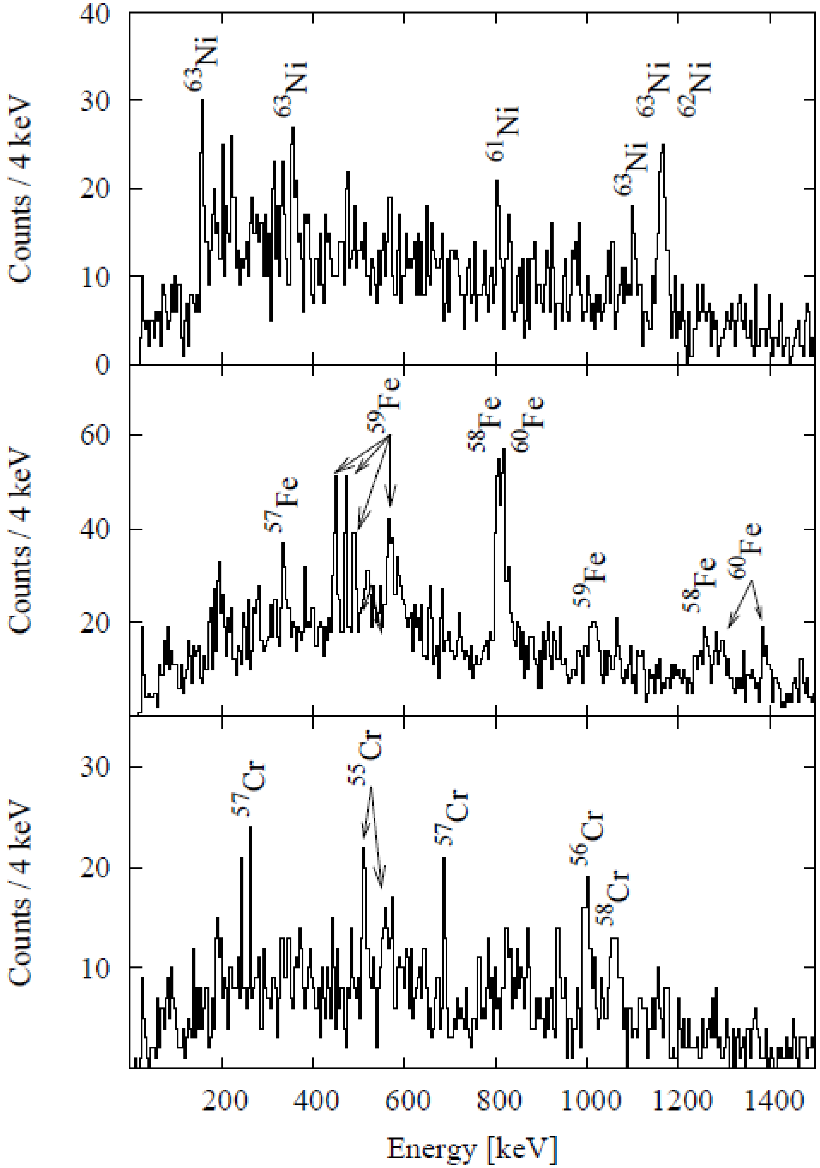
$$E = E_0[1+(v/c)\cos\theta]$$



210,211,212Rn
(64,63,62Fe)



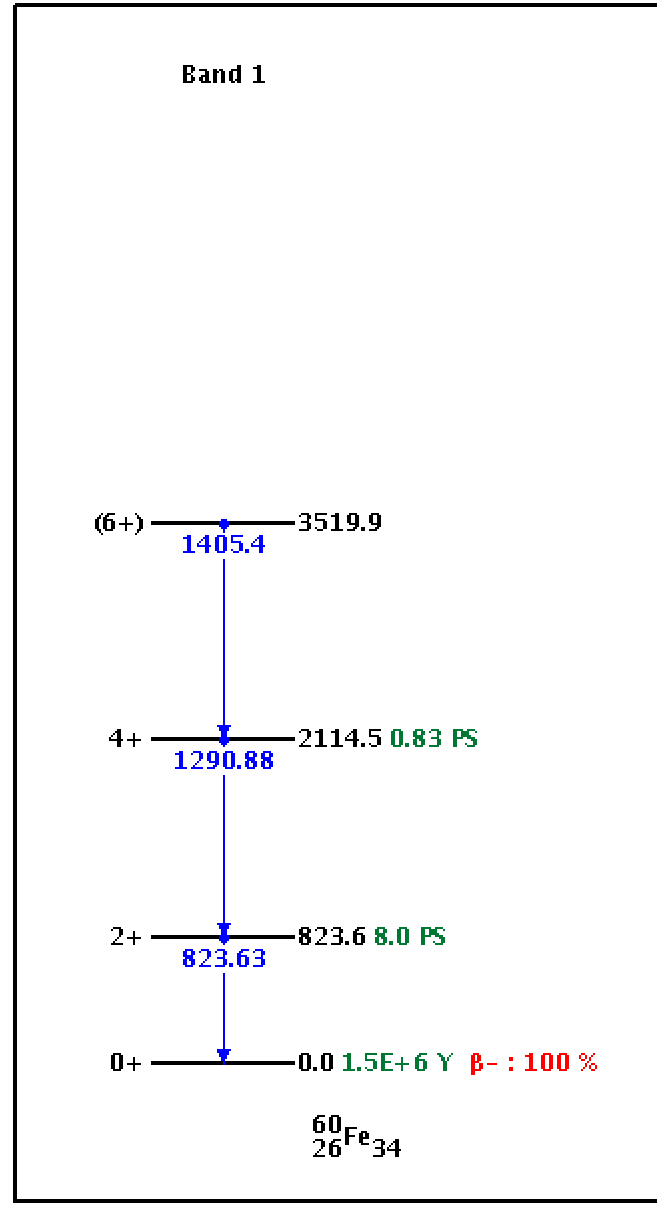
213Rn
(61Fe)



211Po
(63Ni)

213Rn
(61Fe)

214,215Ra
(60,59Cr)

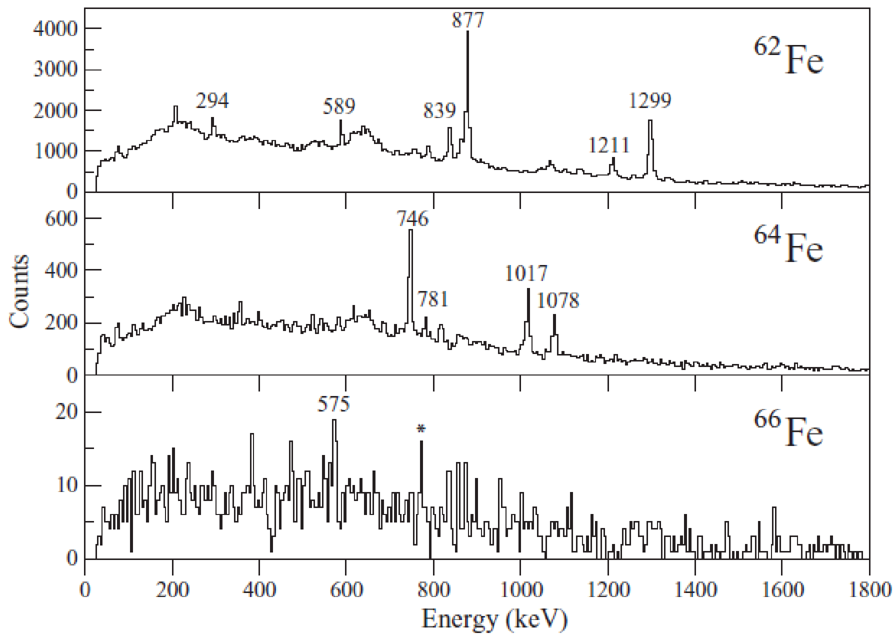


PHYSICAL REVIEW C **76**, 034303 (2007)

Spectroscopy of neutron-rich Fe isotopes populated in the ^{64}Ni + ^{238}U reaction

S. Lunardi,[1] S. M. Lenzi,[1] F. Della Vedova,[2] E. Farnea,[1] A. Gadea,[2] N. Mărginean,[2,3] D. Bazzacco,[1] S. Beghini,[1] P. G. Bizzeti,[4] A. M. Bizzeti-Sona,[4] D. Bucurescu,[3] L. Corradi,[2] A. N. Deacon,[5] G. de Angelis,[2] E. Fioretto,[2] S. J. Freeman,[5] M. Ionescu-Bujor,[3] A. Iordachescu,[3] P. Mason,[1] D. Mengoni,[1] G. Montagnoli,[1] D. R. Napoli,[2] F. Nowacki,[6] R. Orlandi,[2] G. Pollarolo,[7] F. Recchia,[1] F. Scarlassara,[1] J. F. Smith,[5] A. M. Stefanini,[2] S. Szilner,[8] C. A. Ur,[1] J. J. Valiente-Dobón,[2] and B. J. Varley[5]

SPECTROSCOPY OF NEUTRON-RICH Fe ISOTOPES . . .



	N/Z	
Beam	target	CN
1,29	1,59	1,52

PHYSICAL REVIEW C VOLUME 18, NUMBER 3 SEPTEMBER 1978

Excitation functions for quasielastic transfer reactions induced with heavy ions in bismuth

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A. Fleury, F. Hubert, and Y. Llabador
Centre d'Etudes Nucléaires, Bordeaux Gradignan, Laboratoire de Chimie Nucléaire, ERA No. 144, Le Haut-Vigneau, 33170 Gradignan, France

(Received 24 October 1977)

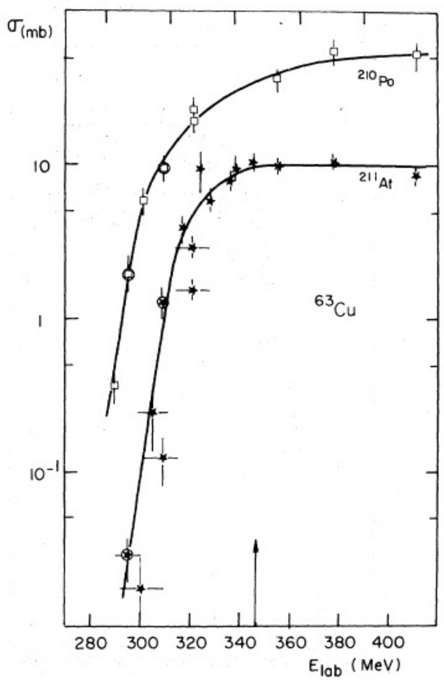


FIG. 12. Excitation functions for the reactions ^{63}Cu $+ ^{209}$Bi $\rightarrow$ ^{210}Po (squares) and ^{211}At (stars). The symbols in a circle correspond to experiments in which the beam energy was measured by the scattered proton technique.

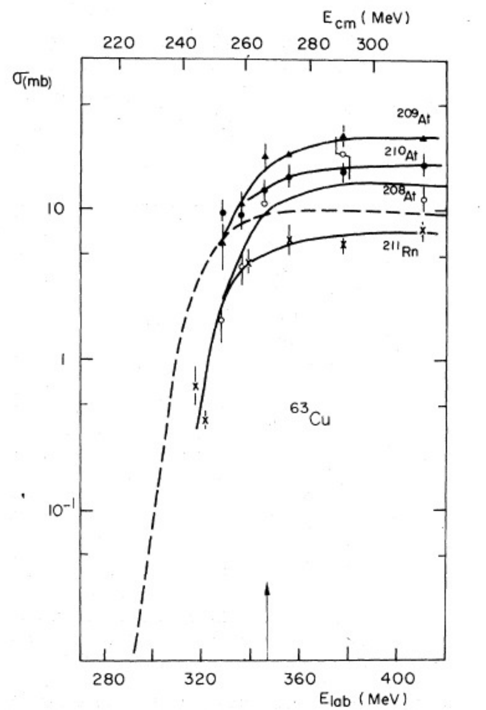


FIG. 13. Excitation functions for the reactions ^{63}Cu $+ ^{209}$Bi $\rightarrow$ ^{210}At (points), ^{209}At (triangles), ^{208}At (circles), and ^{211}Rn (crosses). The dotted line represents the ^{211}At excitation function from Fig. 12.

Isotope	Cross section [μb] α	γ
216Ac	0,1	
214Ra	0,3	
215Ra	0,8	
213Fr	1,7	1,8
214Fr	2,0	
210Rn		9,4
211Rn		14,6
212Rn		11,6
213Rn	3,4	2,4
212At	2,1	
206Po		20,6
208Po		31,3
209Po		22,6
210Po		25,6
211Po	3,0	
Total		150
Recoils		230

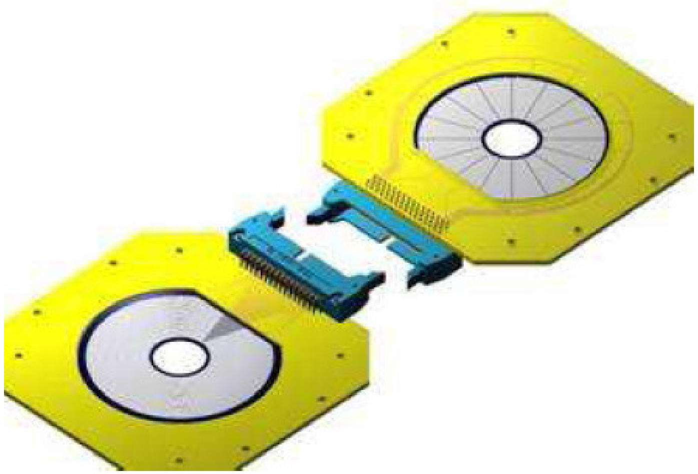
-Yields (cross sections) for the production of heavy target-like isotopes from transfer of the same nucleons are very similar for all projectiles studied in this work except 48Ca and 136Xe.

- After the deep-inelastic process both the acceptor and donor have excitation energy of several MeVs. Neutron evaporation is involved.

- The equilibration of the N/Z ratio for above-target products occurs by the transfer of protons and not by neutrons (except 48Ca).

-The maxima of the yields of the target-like translead nuclei are located near the N = 126 closed shell of the target nucleus which might have some effect (Q-value effect).

-The mass distribution for above-target elements is about FWHM ≈ 2-3 mass units.



S2 detector and PCB as viewed from the p- and n-side

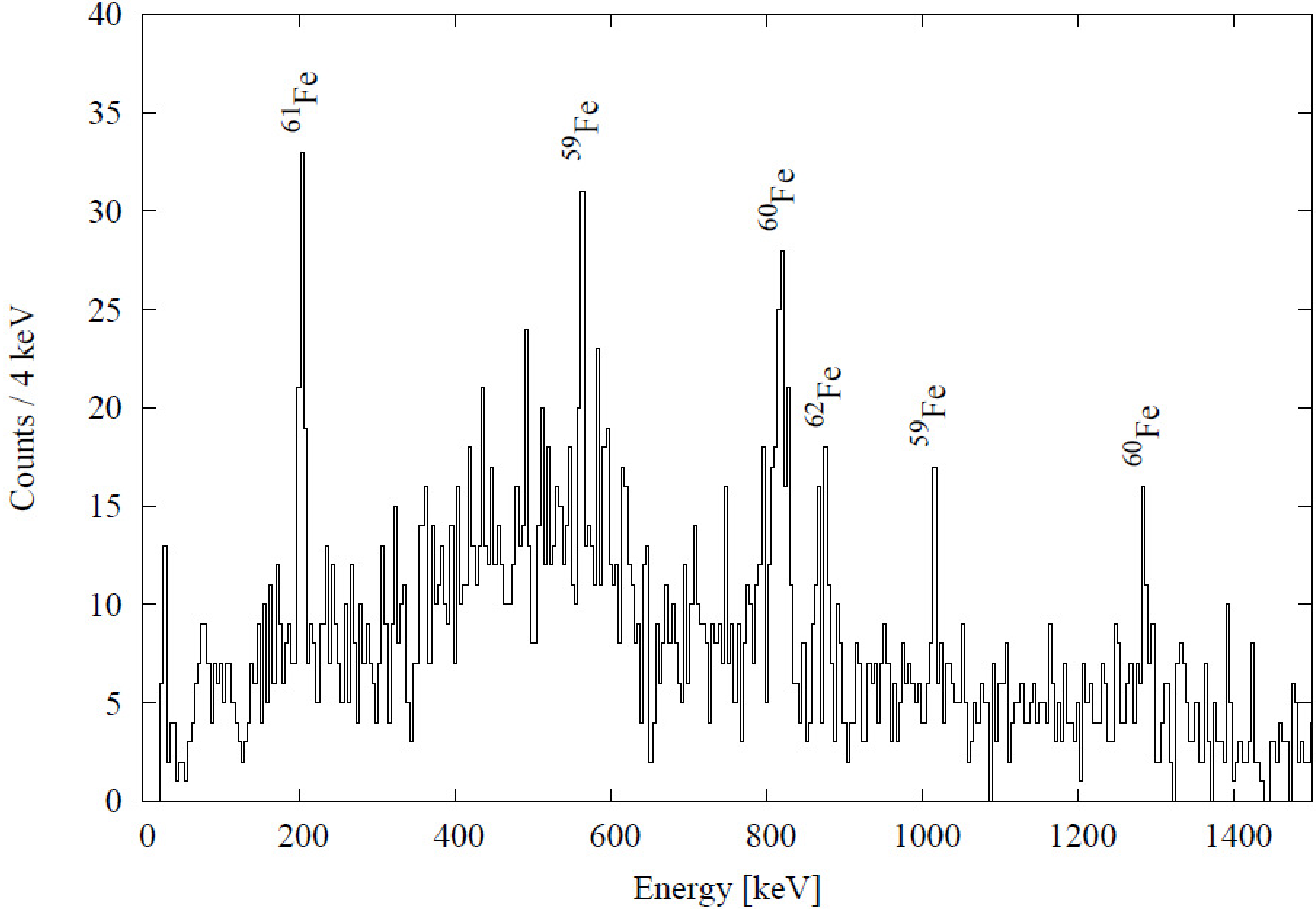
$E = E_0[1+(v/c)\cos\theta]$
-better Doppler correction
-fast isomers from stopped components

-big-acceptance separator,
-VAMOS, gas-filled mode?

IRIS considerations:

It is planned to be used for collecting heavy target-like transuranium elements
Need for a big acceptance → in-flight mass and Z-identification impossible →
A gas-filled magnetic separator or a solenoid (gas-filled).

With solenoid type separator it is more difficult to shield the auxiliary detectors against the unwanted radiation.



^{61}Fe
^{59}Fe
^{60}Fe
^{62}Fe
^{59}Fe
^{60}Fe
Counts / 4 keV
Energy [keV]
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400

Isotope	Cross section [μb]	
	α	γ
214Ra	0,3	
215Ra	0,8	
213Fr	1,7	1,8
214Fr	2,0	
210Rn		9,4
211Rn		14,6
212Rn		11,6
213Rn	3,4	2,4
206Po		20,6
208Po		31,3
209Po		22,6
210Po		25,6
211Po	3,0	
212At	2,1	
Total		150
Recoils		230

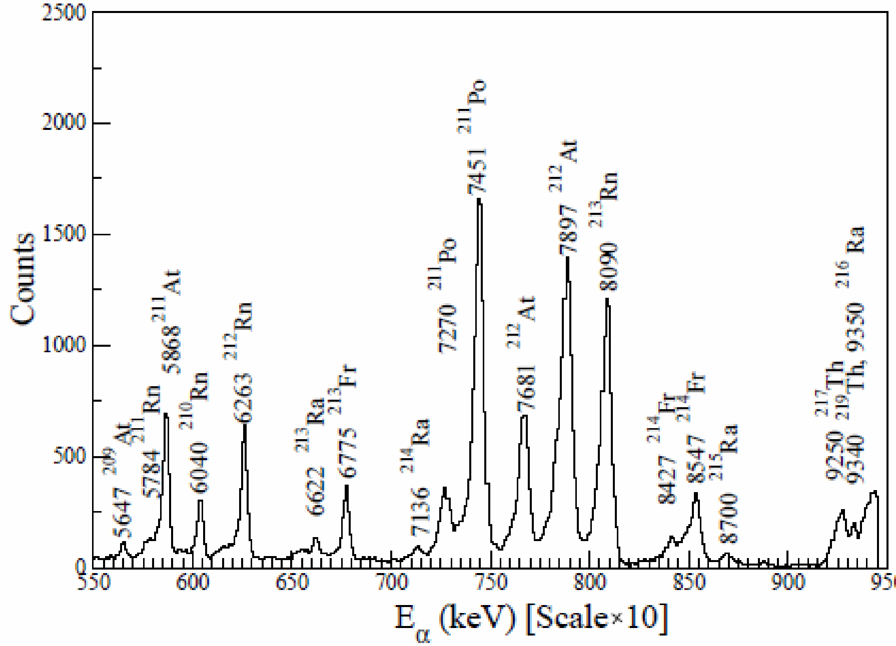
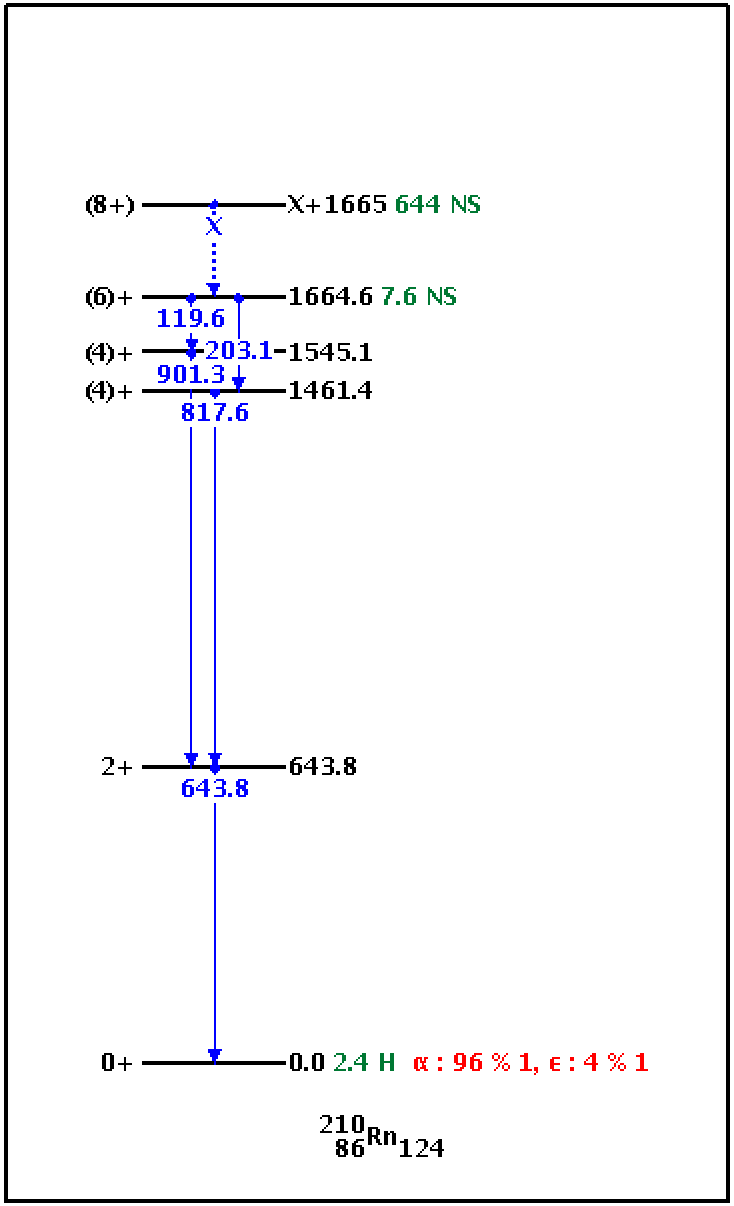
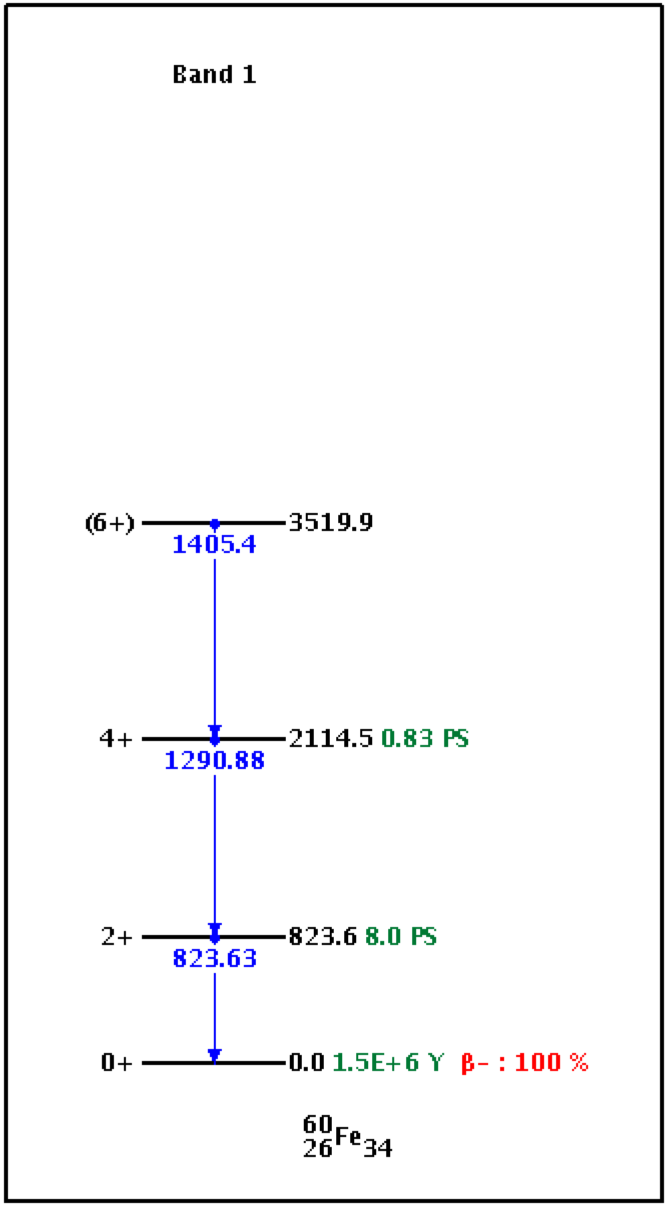


Figure 1: Correlated α particle spectrum.

$$\Theta_{gr} = 2 \bullet \arcsin[2 \bullet (V_c/E_{cm})-1]$$

$$E = E_0[1+(v/c)\cos\theta]$$


(8+)
X+1665 644 NS
X
(6)+
1664.6 7.6 NS
119.6
(4)+
203.1
1545.1
901.3
(4)+
1461.4
817.6
2+
643.8
643.8
0+
0.0 2.4 H α : 96 % 1, ϵ : 4 % 1
$^{210}_{86}Rn_{124}$


Band 1
(6+)
3519.9
1405.4
4+
2114.5 0.83 PS
1290.88
2+
823.6 8.0 PS
823.63
0+
0.0 1.5E+6 Y β- : 100 %
$^{60}_{26}Fe_{34}$