New results on the role of shell effects in nuclear fission from experiments with secondary beams

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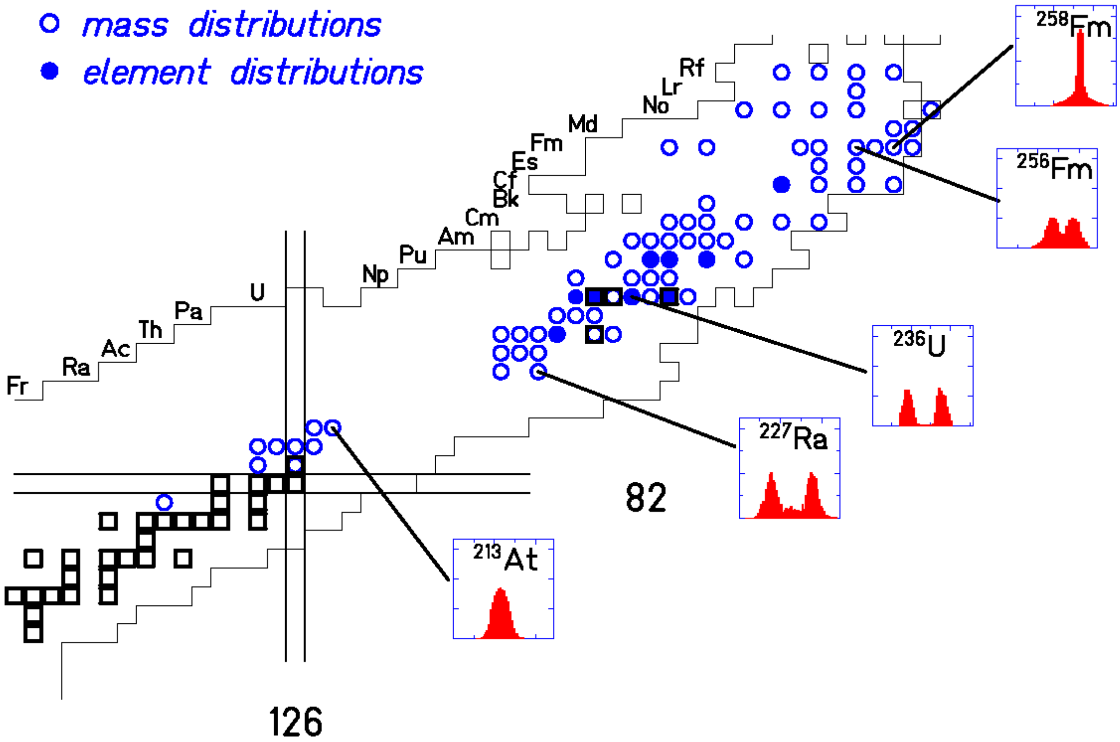
Previous knowledge of low-energy fission



Mass distributions show very strong influence of shell effects

Shell structure and nuclear dynamics

Shell effects at large deformation

($\beta_{saddle} \approx 1$, $\beta_{scission} \approx 0.6$)

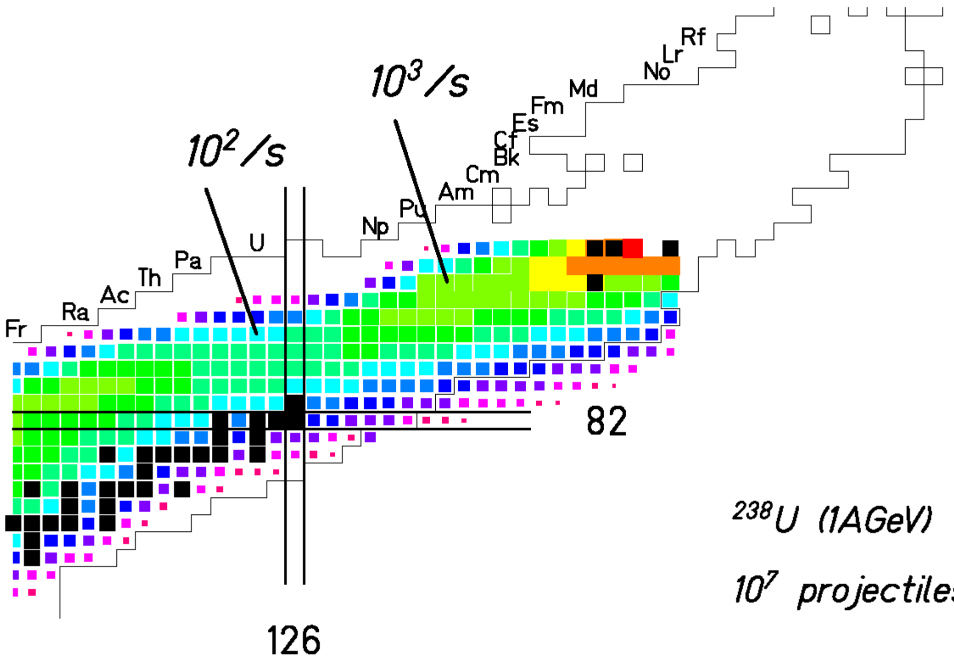
Only small part of the fissioning nuclei has been measured

Limited by available targets and spontaneous fission

No systematic knowledge on transition from symmetric to asymmetric fission

No prospects for extension by conventional techniques

Production rates of secondary beams
(Model calculation adapted to experimental data)

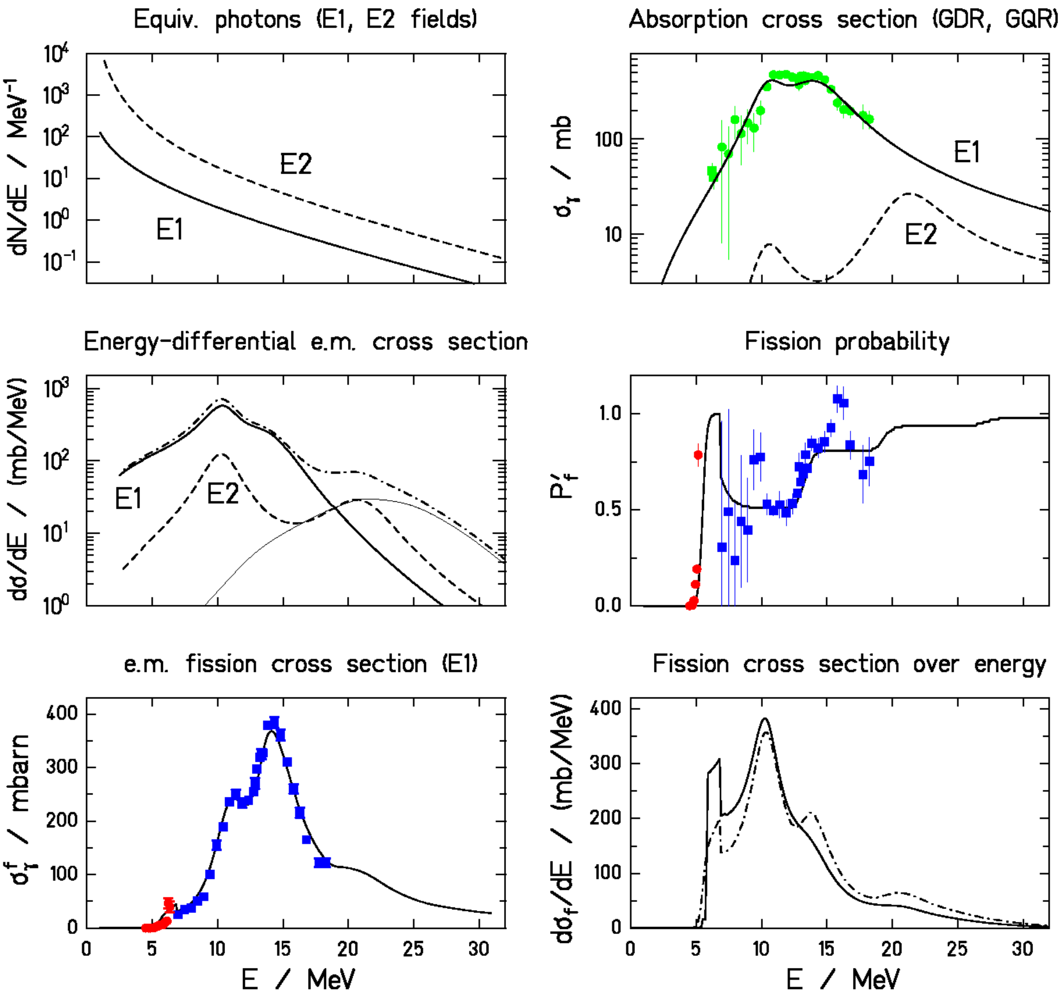


^{238}U (1AGeV) + Be

10^7 projectiles/s

Coverage of the transitional region
from symmetric to asymmetric fission

Excitation process (^{234}U + ^{208}Pb at 430 A MeV)

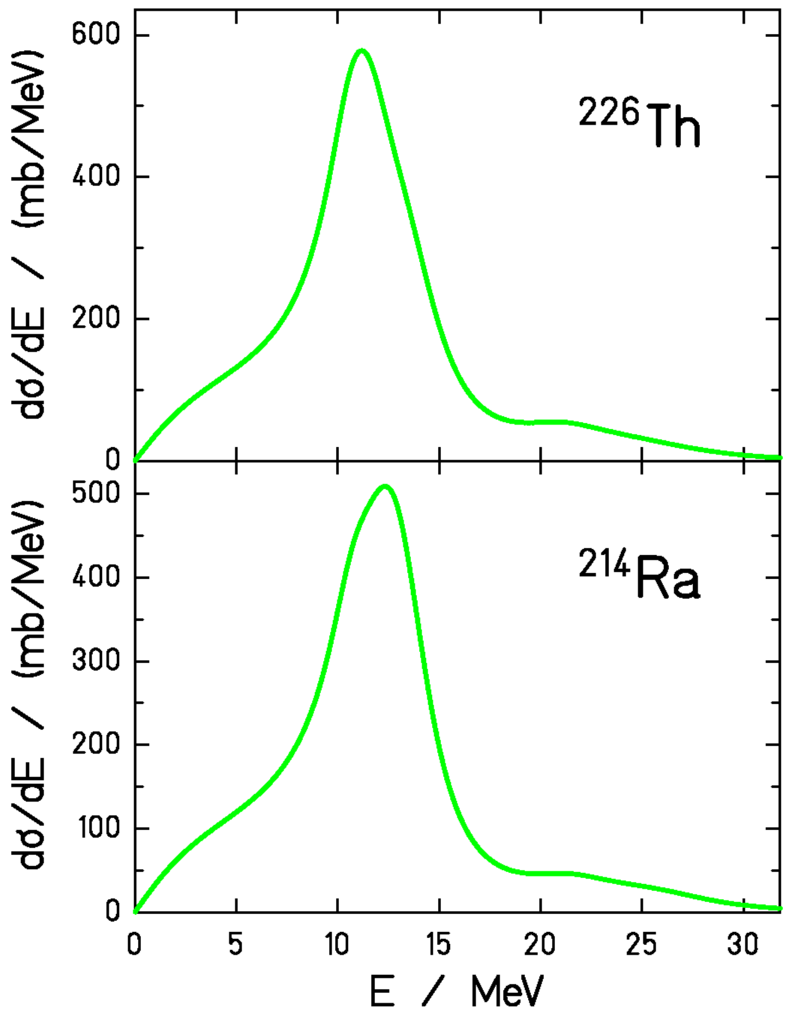


Electromagnetic excitation by heavy target nuclei

Excitation energies just above the fission barrier

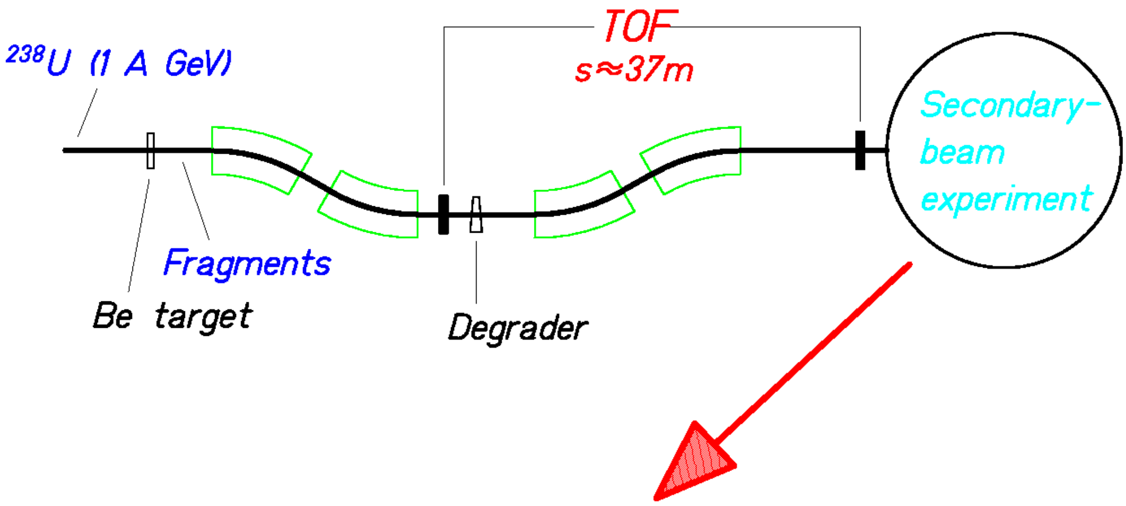
High fission rates

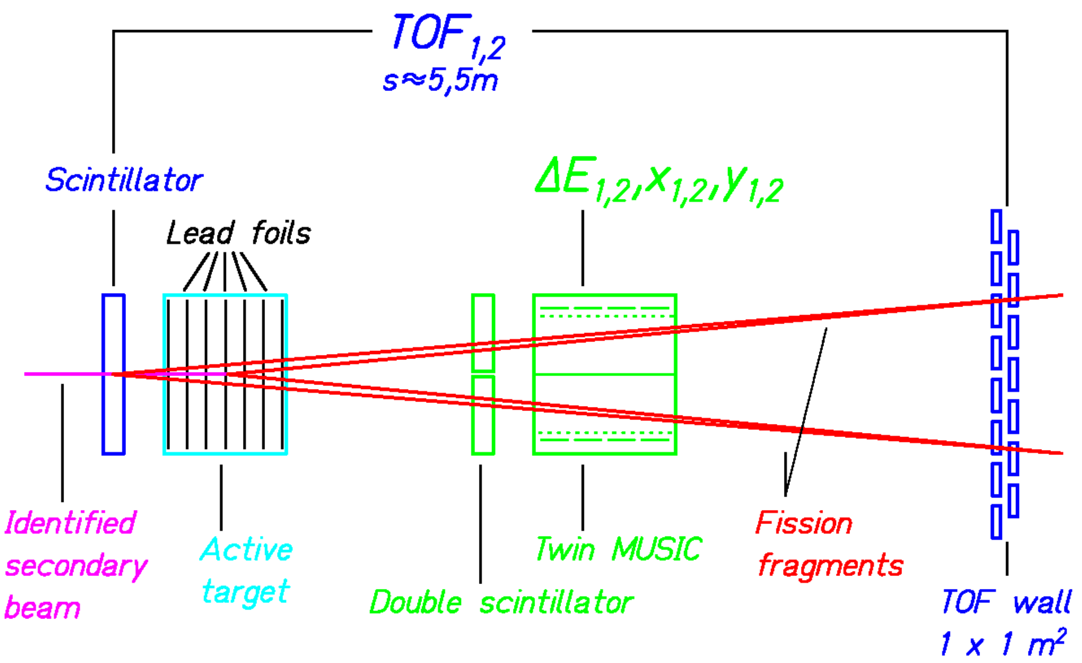
Energies after e.m. excitation in Pb (430 A MeV)



Similar excitation energies for all fissile nuclei

Experimental set-up



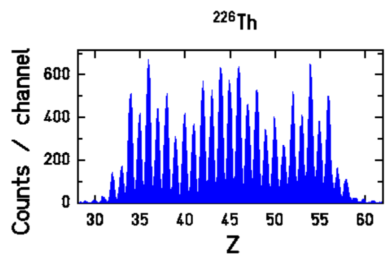


<u>Profit from inverse kinematics</u>

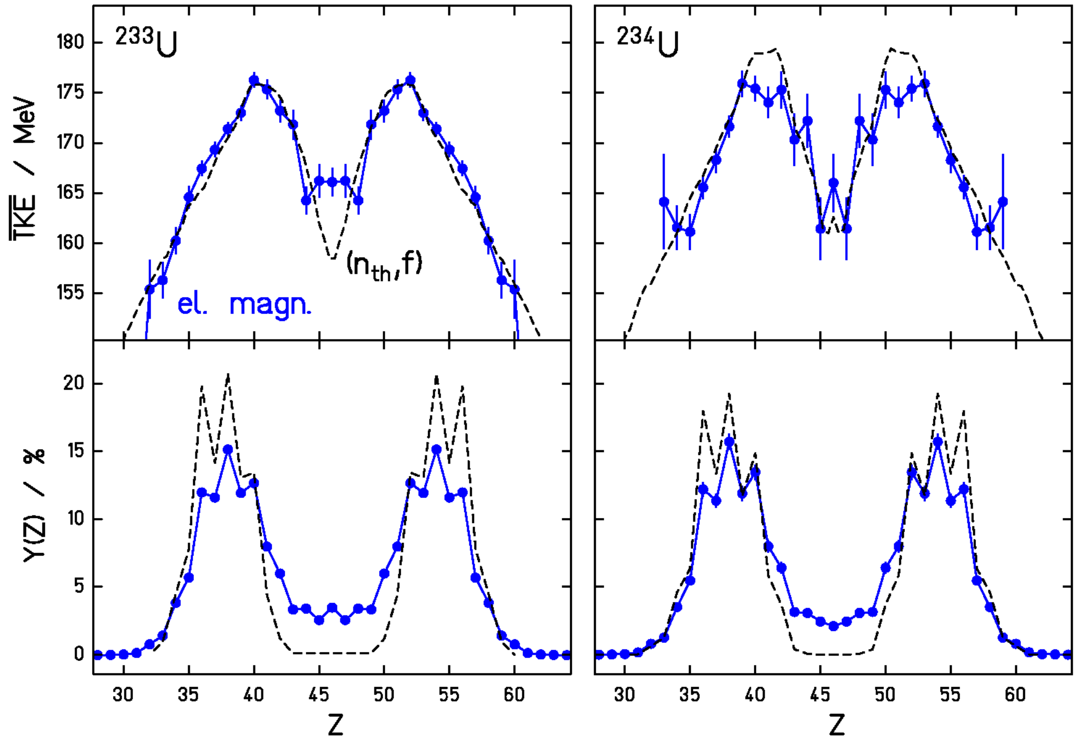
100% detection efficiency

Excellent Z resolution

Kinetic energies measured



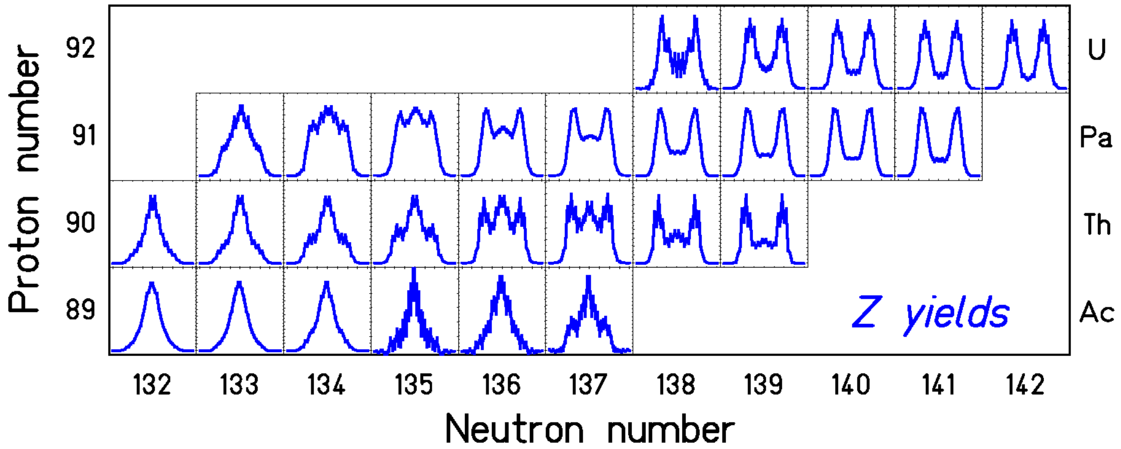
Two test cases

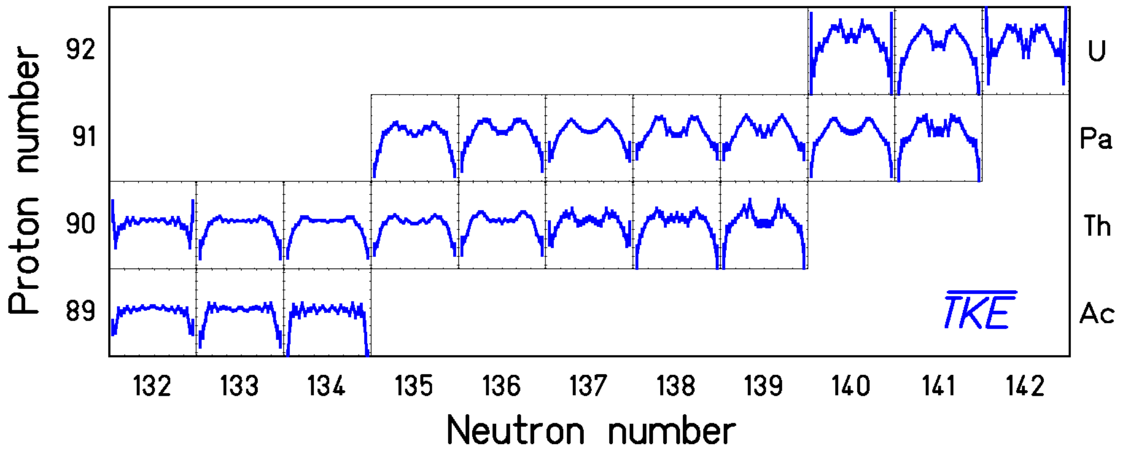


$\overline{TKE}$: almost identical

Z yields: similar, but weaker influence of shells and pairing

Map of Z yields and $\overline{TKE}$

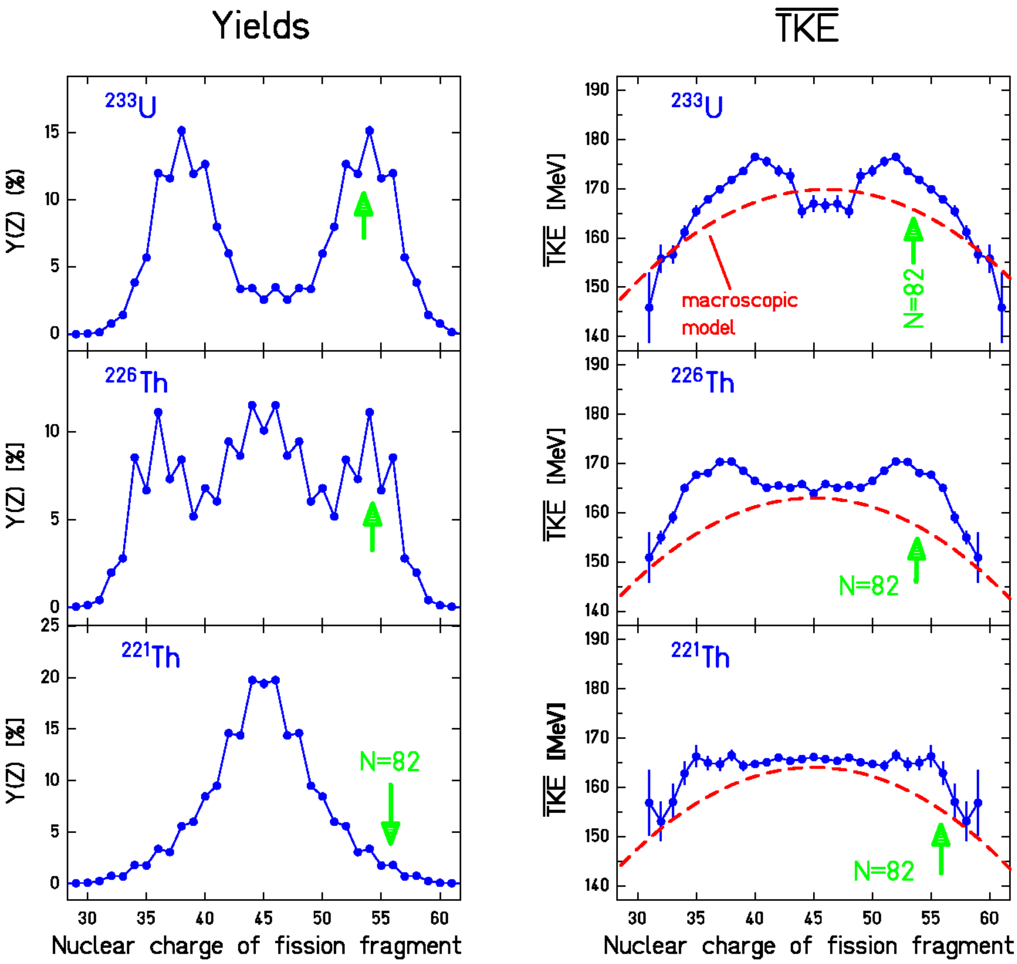




70 systems measured, 28 (21) shown

Systematic coverage of the transitional region

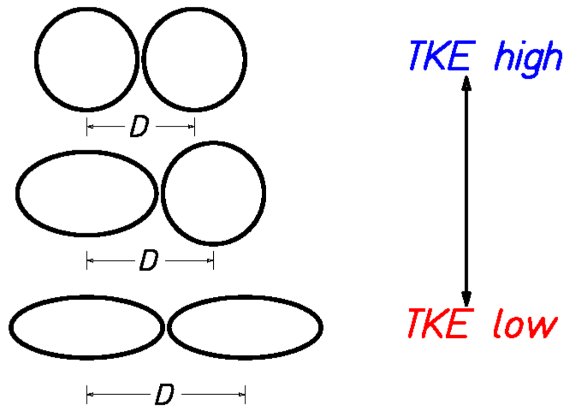
Detailed view on 3 systems

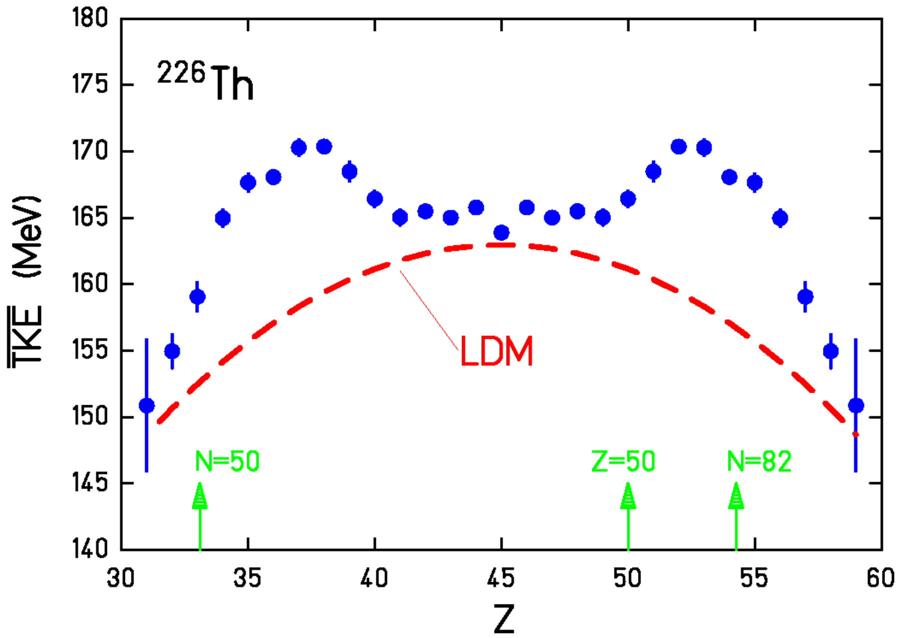


Enhanced Z yields and TKE near N = 82

Scission configuration → TKE

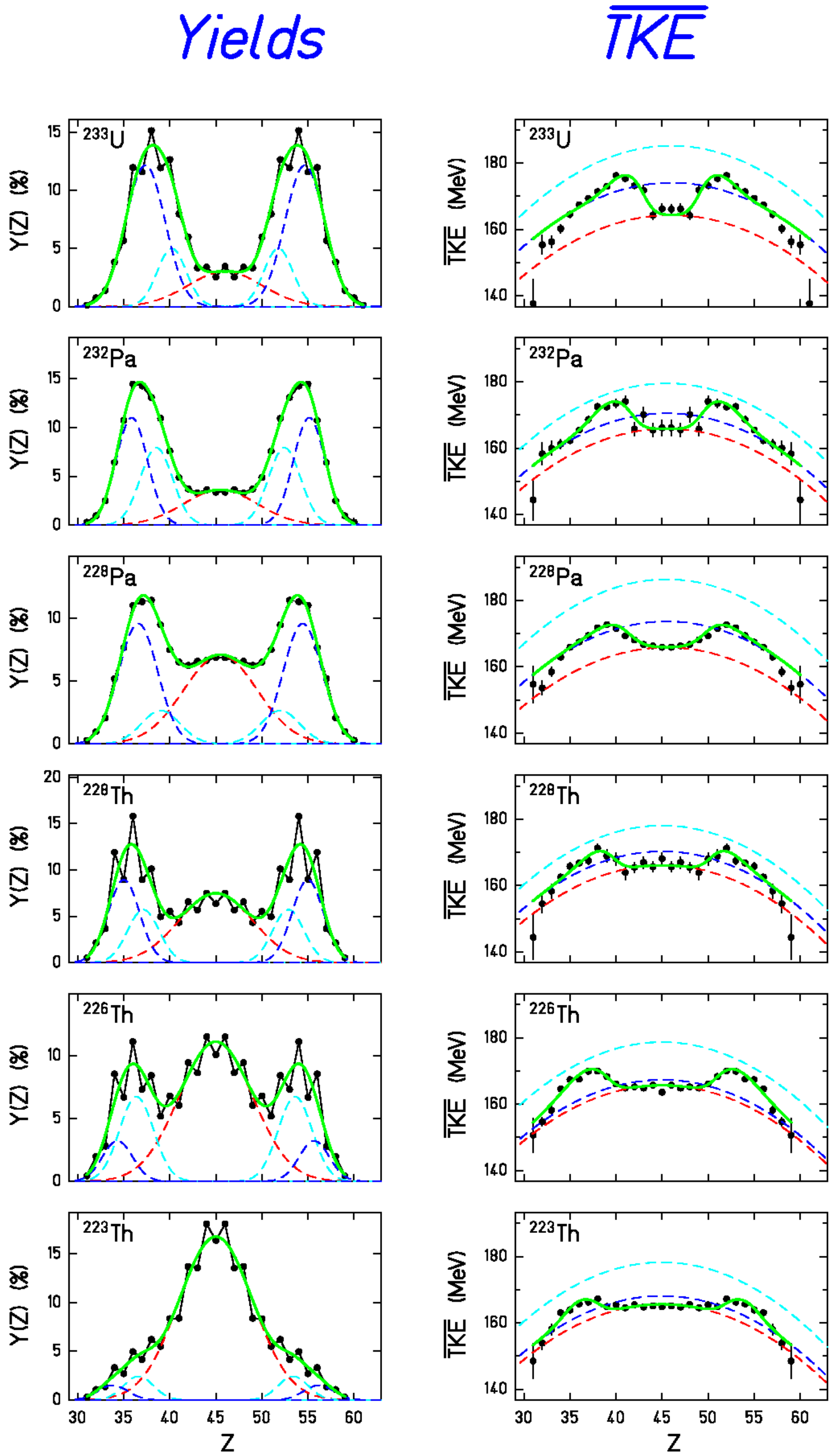
$$TKE \sim \frac{Z_1 \cdot Z_2}{D}$$





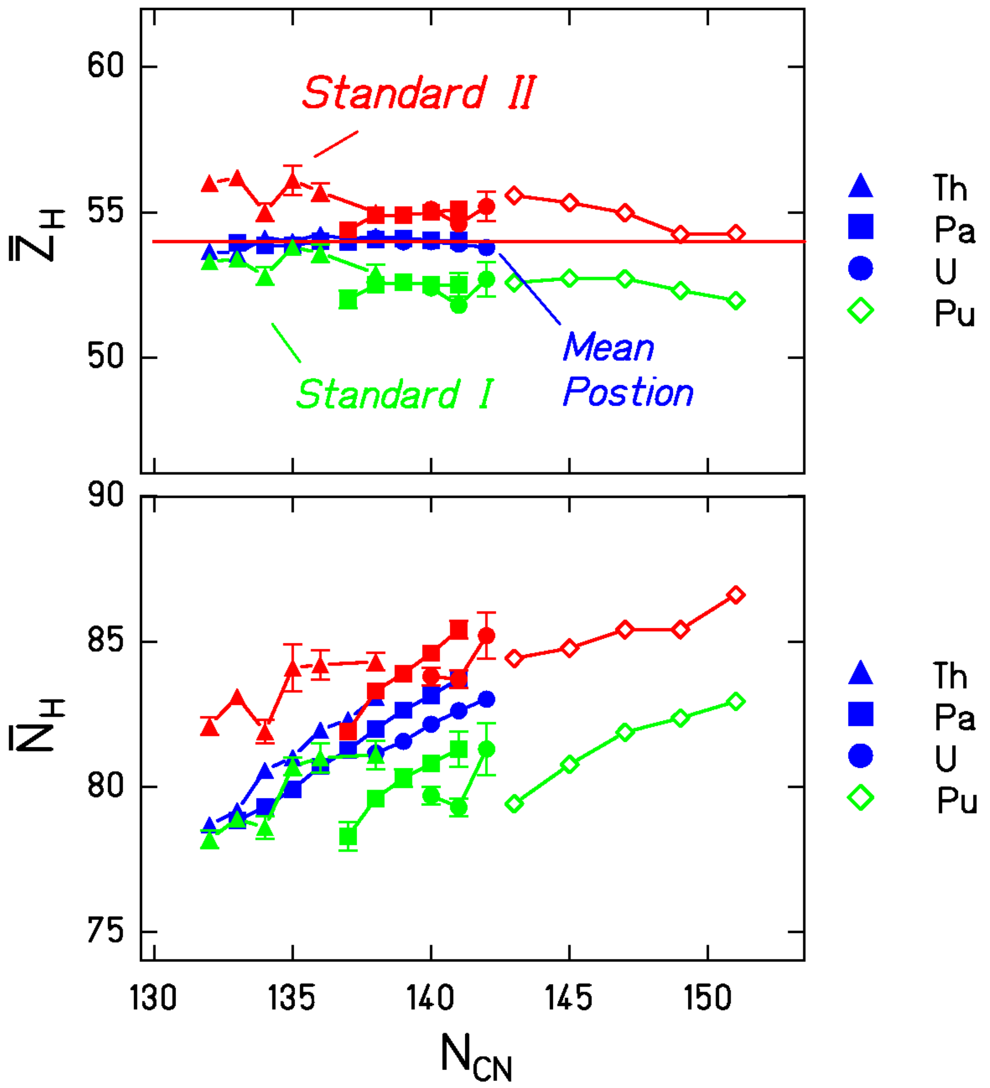
Information on shell effects at β between 0 and 1

Adapted fission channels

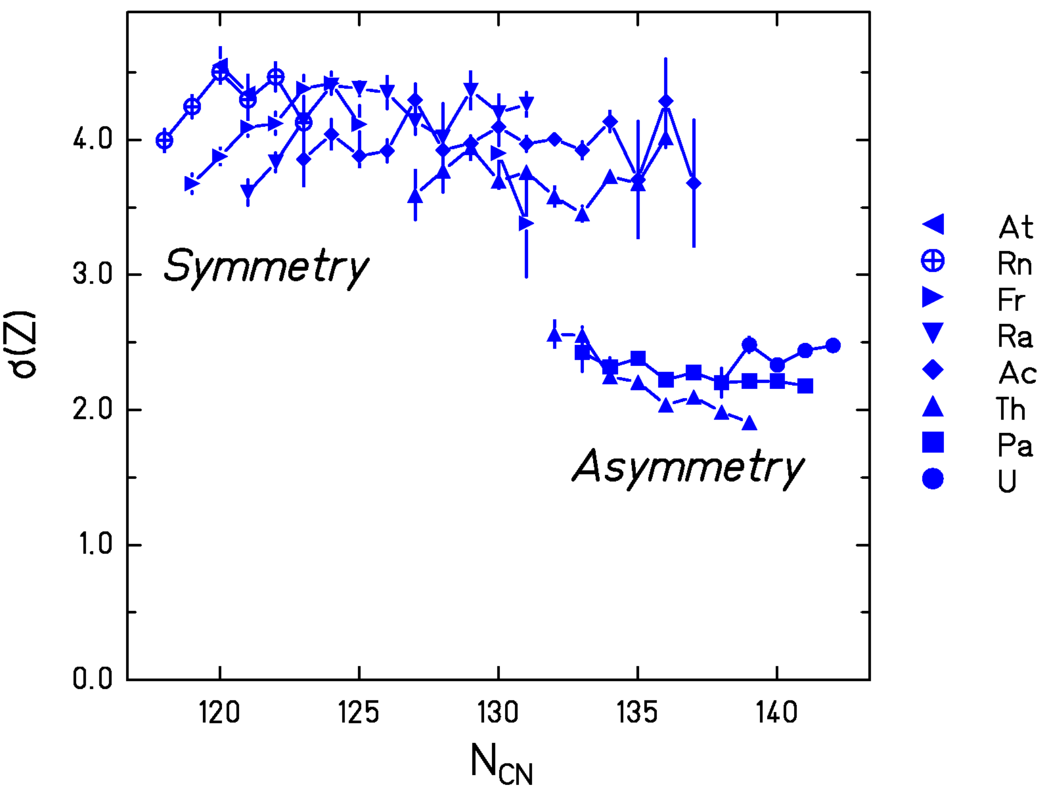


Simultaneous fit to Z yields and TKE
Godd reproduction of data with 3 channels

Positions of the fission channels



Expectation: Shell effects in neutron number are decisive.
Finding: Positions are stable in Z and move in N.



Symmetry
Asymmetry
σ(Z)
N_CN
0.0
1.0
2.0
3.0
4.0
120
125
130
135
140
At
Rn
Fr
Ra
Ac
Th
Pa
U

Semiempirical conditional saddle-point model

An attempt to understand the population of fission channels

Assumption:
Phase space in different fission valleys is decisive

Parameters from theory or systematics:

- *Macroscopic potential at barrier*
  - → *from widths of mass distributions*
- *Level densities*
  - → *from independent-particle model (shell effects)*
- *Mass widhts of fission channels*
  - → *from systematics*

Only neutron shells N = 82 and N ≈ 90 considered

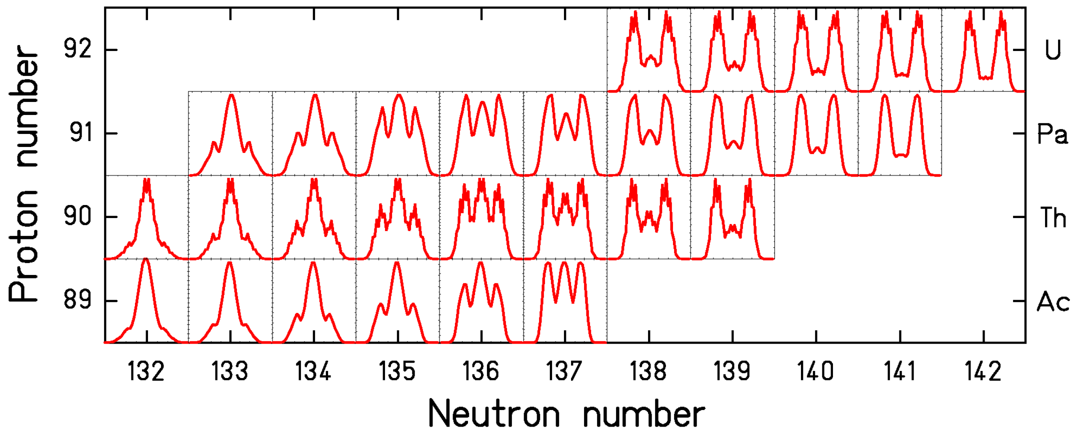
3 Parameters adjusted to the new data
(same values for all systems)

1. *Strength of shell at N = 82*
2. *Strenght of shell at N ≈ 90*
3. *Exact position of shell at N = 91*

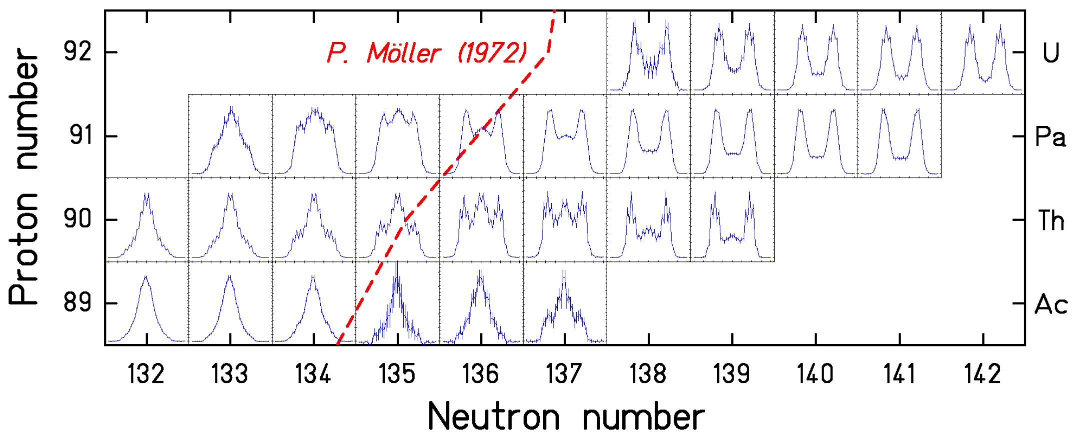
V. V. Pashkevich, Nucl. Phys. A 169 (1971) 275
U. Brosa et al., Phys. Rep. 197 (1990) 167
S. Mulgin et al., Nucl. Phys. A 641 (1998) 389
L. G. Moretto, Nucl. Phys. A 247 (1975) 211
G. A. Kudyaev et al., Sov. J. Nucl. Phys. 45 (1987) 951
J. Benlliure et al., Nucl. Phys. A 628 (1998) 458

Detailed view on transitional region

Z yields: Model calculation

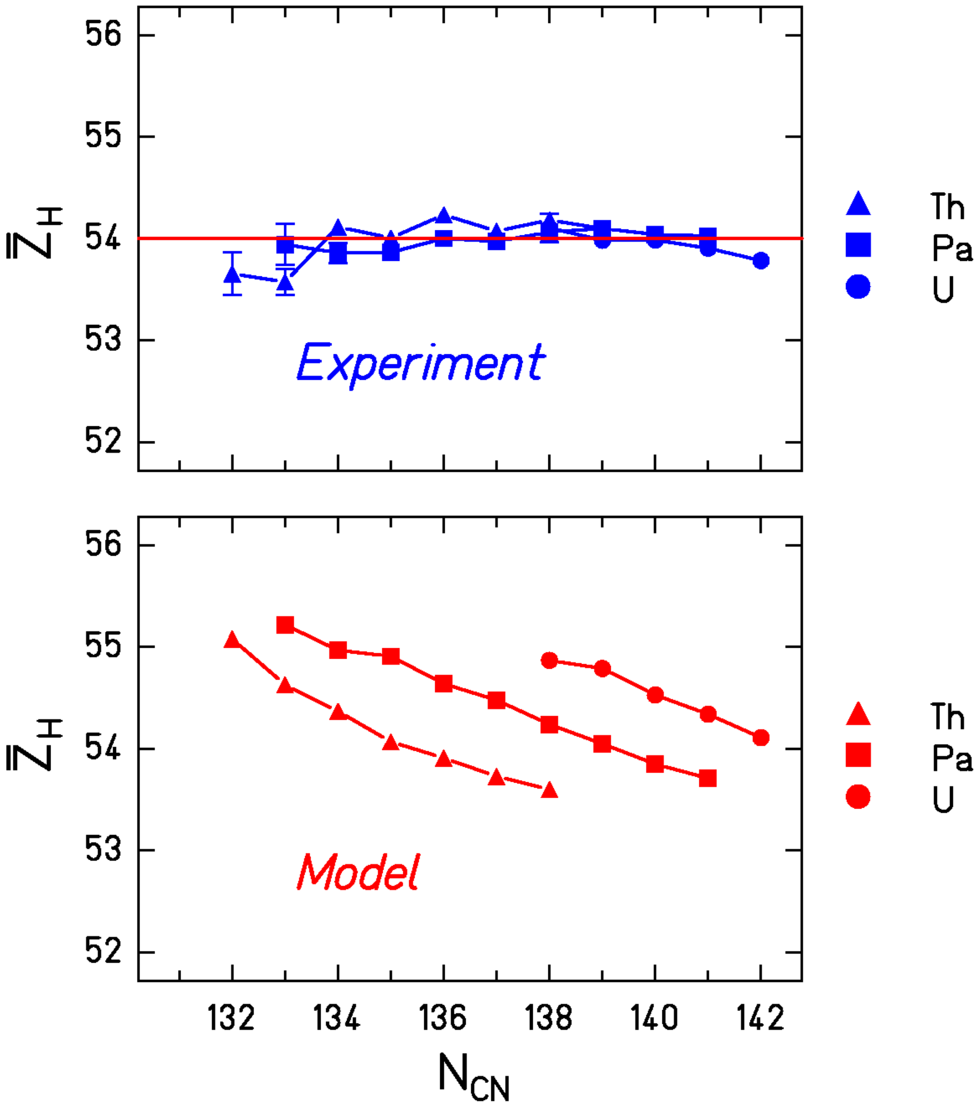


Z yields: Data



Overall good reproduction of the transition
But model scales more with neutron number

Position of asymmetric component



Model does not reproduce the constant position in Z
Challenge for elaborate fission models

Summary

<u>Results:</u>

- *New possibilities for fission studies by use of secondary beams*
- *Requires new experimental methods adapted to*
  low intensity, inverse kinematics
- *Transition from symmetric to asymmetric fission around 227Th*
  systematically mapped
- *Major trends interpreted by competition of shells and liquid drop*
- *Detailed findings are a challenge for dynamical fission models*

<u>Future plans:</u>

- *measure Z, <TKE>, A, gammas, neutrons in inverse kinematics*
- *excitation in an electron - heavy-ion collider*

<u>Aims:</u>

- *Understanding the dynamics of cold nuclear matter (shells, pairing)*
- *Production of neutron-rich secondary-beams by fission*
- *Basic data for incineration of nuclear waste*