Measurements for Reactor Decay Heat

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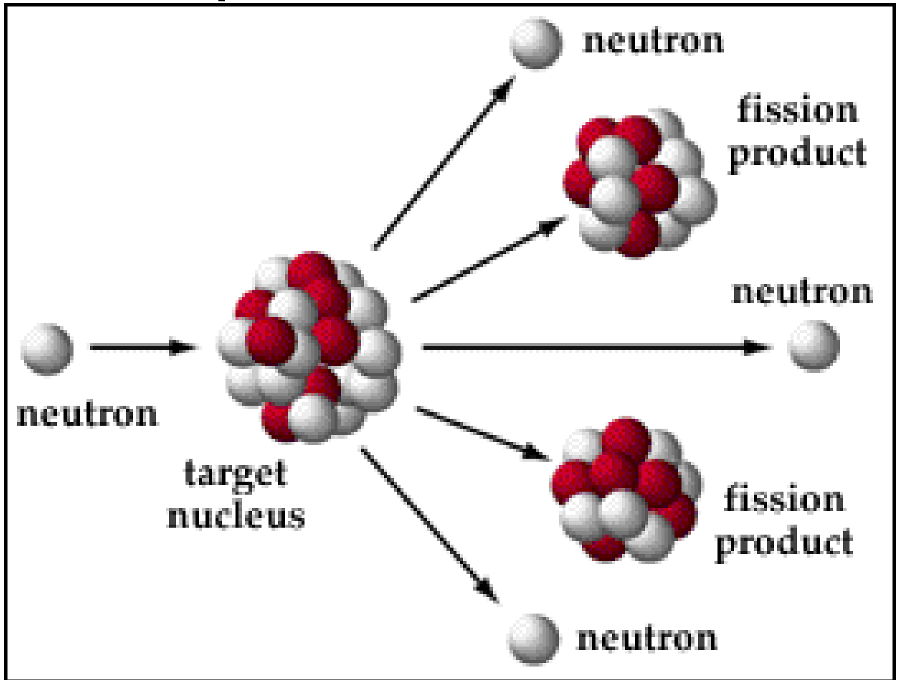
Fission process

- Kinetic energy of fission products (FP) and neutrons
- Prompt γ radiation from FP
- γ and β decay energy through the natural decay of fission products



Decay heat: definition

$$f(t) = \sum_i E_i \lambda_i N_i(t)$$

E_i Decay energy of the nucleus i

λ_i Decay constant of the nucleus i

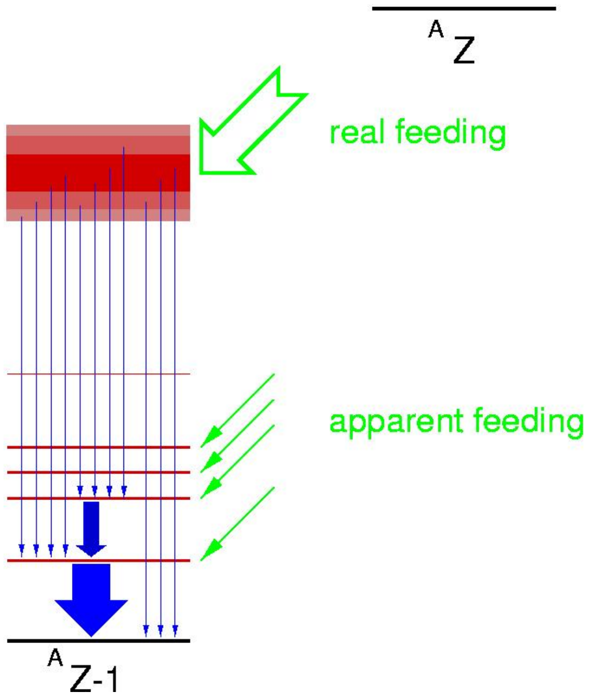
N_i Number of nuclei i at the cooling time t

Requirements for the calculations: large databases that contain all the required information (nuclides, lifetimes, mean γ- and β-energy released in the decay, n-capture cross sections, etc, etc …

Example of database: JENDL FP decay data file 2000

No. of Nuclides	Data types, comments
581	With theor. estimated average γ-decay energy
506	With measured average γ-decay energy
543	With theor. estimated average β-decay energy
506	With measured average β-decay energy
197	First isomeric states
8	Second isomeric states
1229	Tot. num. of nuclides (142 stable , 1087 unstable)

Pandemonium effect



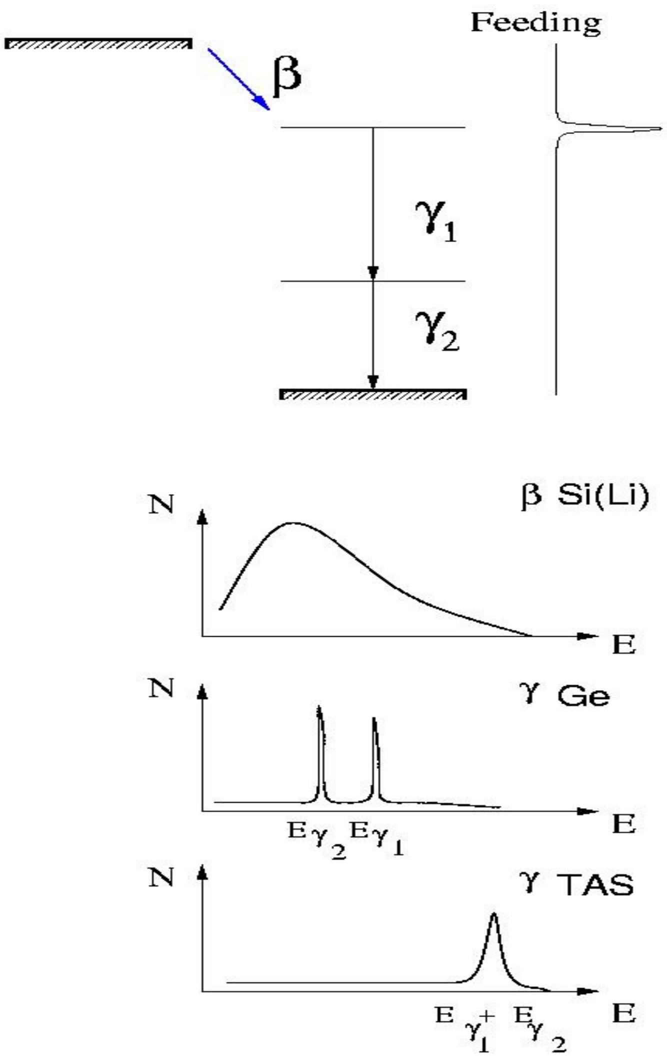
Introduced by the work of Hardy *et al* (Phys. Lett 71B (1977) 307). Their study questions the possibility of building correctly a level scheme from a beta decay experiment using conventional techniques.

Several factors can contribute to this problem:

• if the feeding occurs at a place where there is a high density of levels, there is a large fragmentation of the strength among different levels and there is a large number of decay paths, which makes the detection of the weak gamma rays difficult

• we can have gamma rays of high energy, which are hard to detect

TAS measurements



Since the gamma detection is the only reasonable way to solve the problem, we need a highly efficient device:

A TOTAL ABSORTION SPECTROMETER

Instead of detecting the individual gamma rays we sum the energy deposited by the gamma cascades in the detector

Problems associated with TAS

- Analysis
- Contaminants
- Technique not well known: what can be expected from a TAS measurement ?

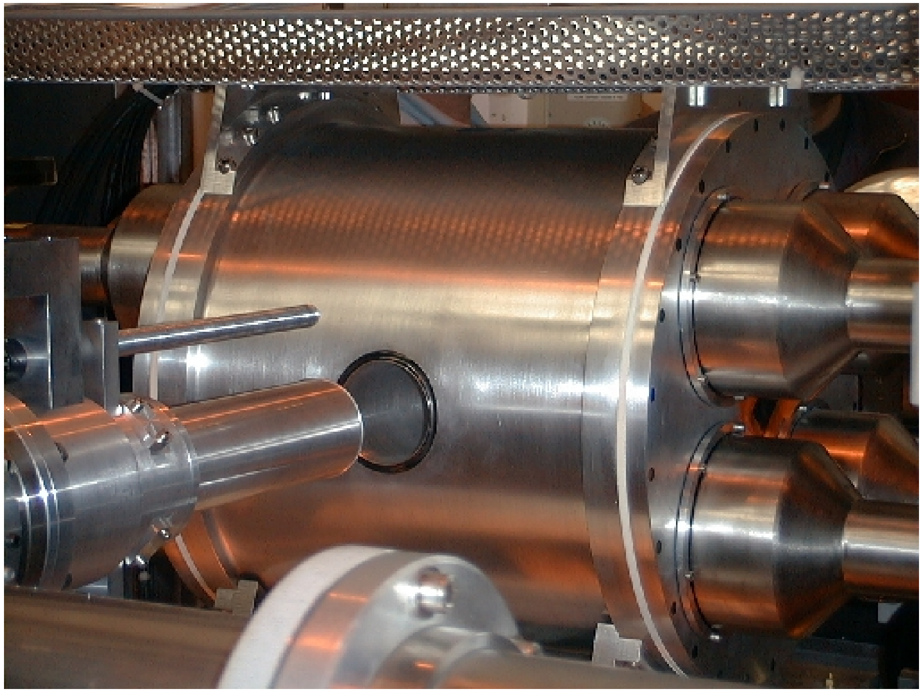
Analysis

$$S_i = \frac{I_i}{f(Q_\beta - E_i)T_{1/2}}$$

$$d_i = \sum_j R_{ij} f_j \quad or \quad \mathbf{d} = \mathbf{R} \cdot \mathbf{f}$$

R is the response function of the spectrometer, $\boldsymbol{R_{ij}}$ means the probability that feeding at a level ***j*** gives counts in data channel ***i***

Contaminants: TAZ measurements



TAS-manian devil: "Taz" for short, is described as: "A strong murderous beast, jaws as powerful as a steel trap, has ***ravenous appetite***, eats tigers, lions, elephants, buffaloes, donkeys, giraffes, octopuses, rhinoceroses, and moose." **Similar to our TAS detector**

Contaminants: background, isobaric contaminants

Source of systematic uncertainty. In the neutron rich side it is not possible to use the EC process to clean the spectra.

Posible solutions:

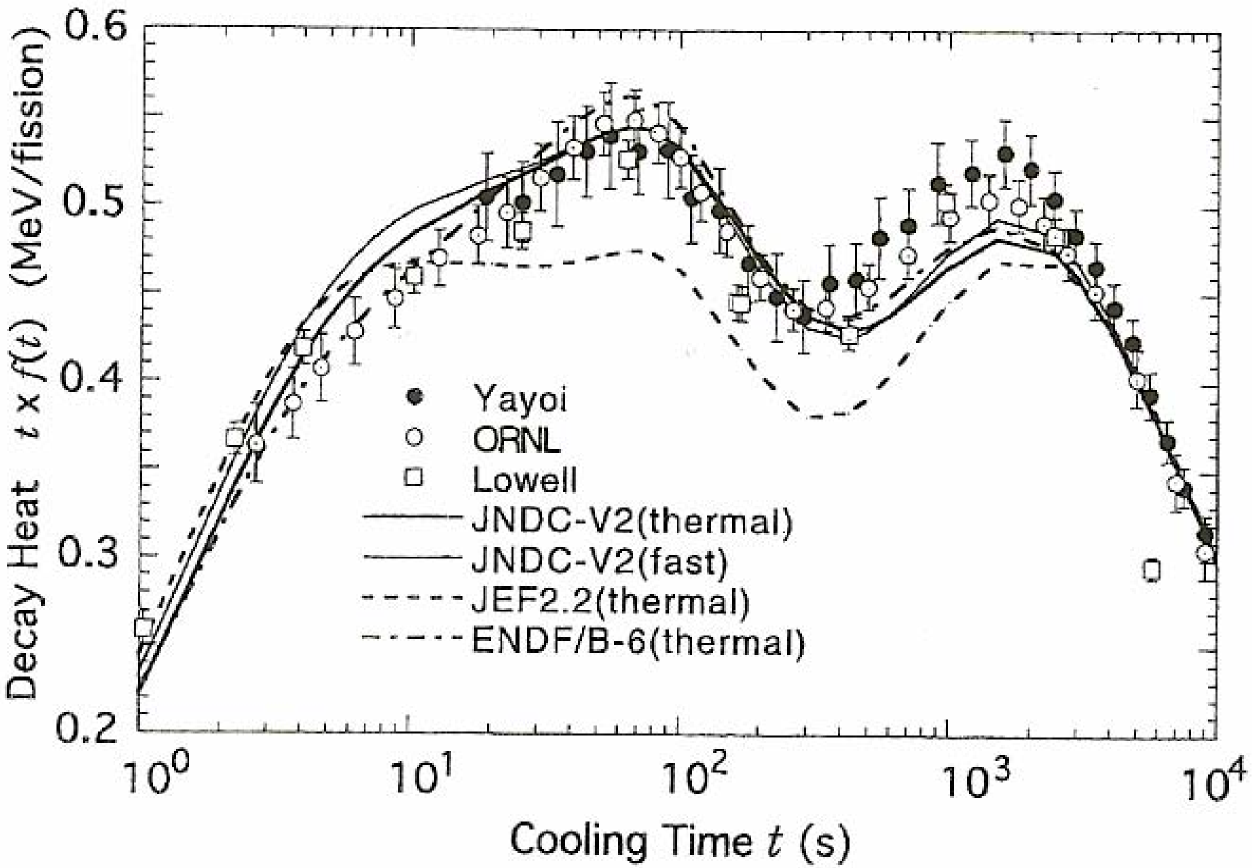
- Separation using cycles that exploit half-life knowledge of the nucleus of interest and contaminants
- Use of chemical selectivity at the ion source
- Use of laser ionization schemes, to ionize only the species of interest

Example: measurement of the beta decay of $^{104,105}Tc$

The main motivation of this work was the study of Yoshida and co-workers (Journ. of Nucl. Sc. and Tech. 36 (1999) 135)

See ^{239}Pu example, similar situation for $^{235,238}U$

^{239}Pu example

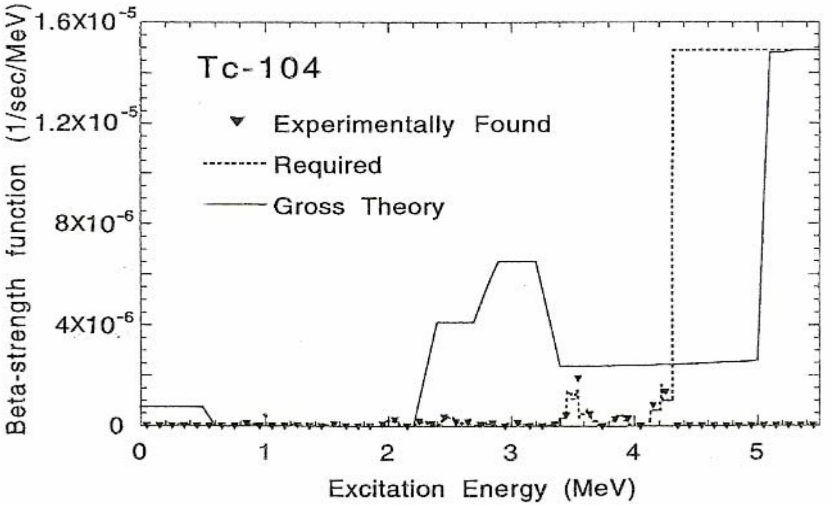


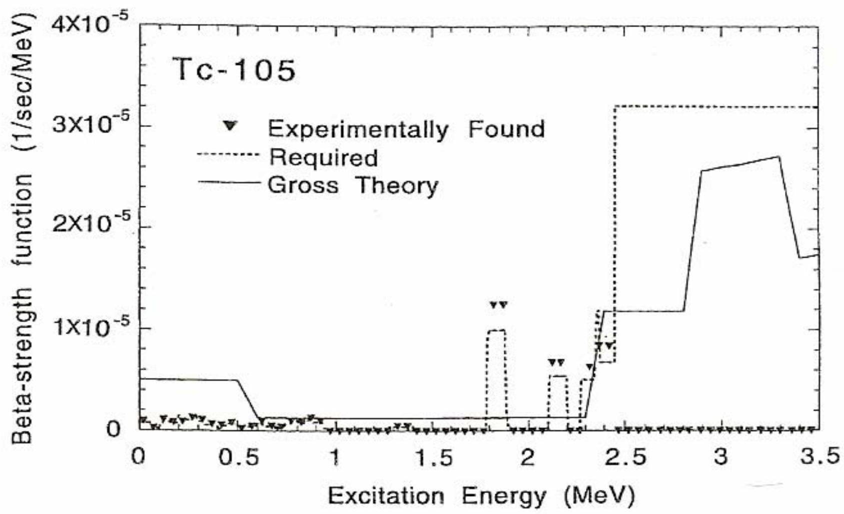
Motivations, original plans

In their work (detective work) Yoshida *et al.* identified some nuclei that may be responsible for the under-estimation of the E_ν component.

Possible nuclei that may be blamed for the anomaly were ^{102,104,105}Tc

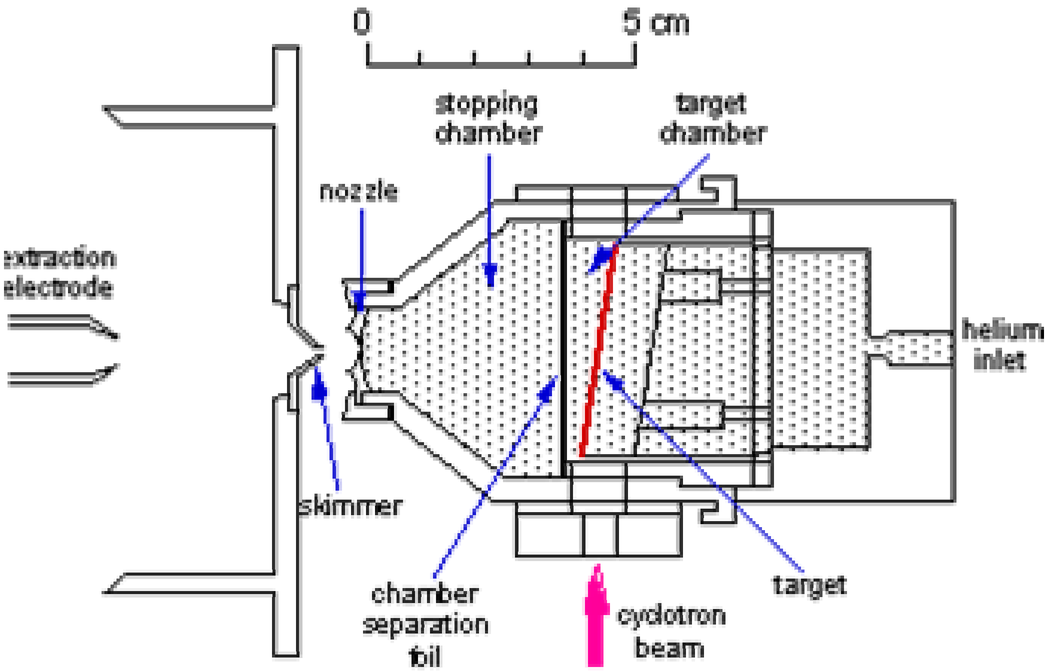
Explanation: certainly suffer from the Pandemonium effect, their half lives are in the range needed, and their fission yields are also correlated in the way required to solve the discrepancy





The IGISOL technique

Fission ion guide: 2700 ions/s per mb, eff. of $1.6x10^{-4}$ relative to the production in the target



Details of our experiment:

Beam: 30 MeV proton (5microA)

Target: natural U

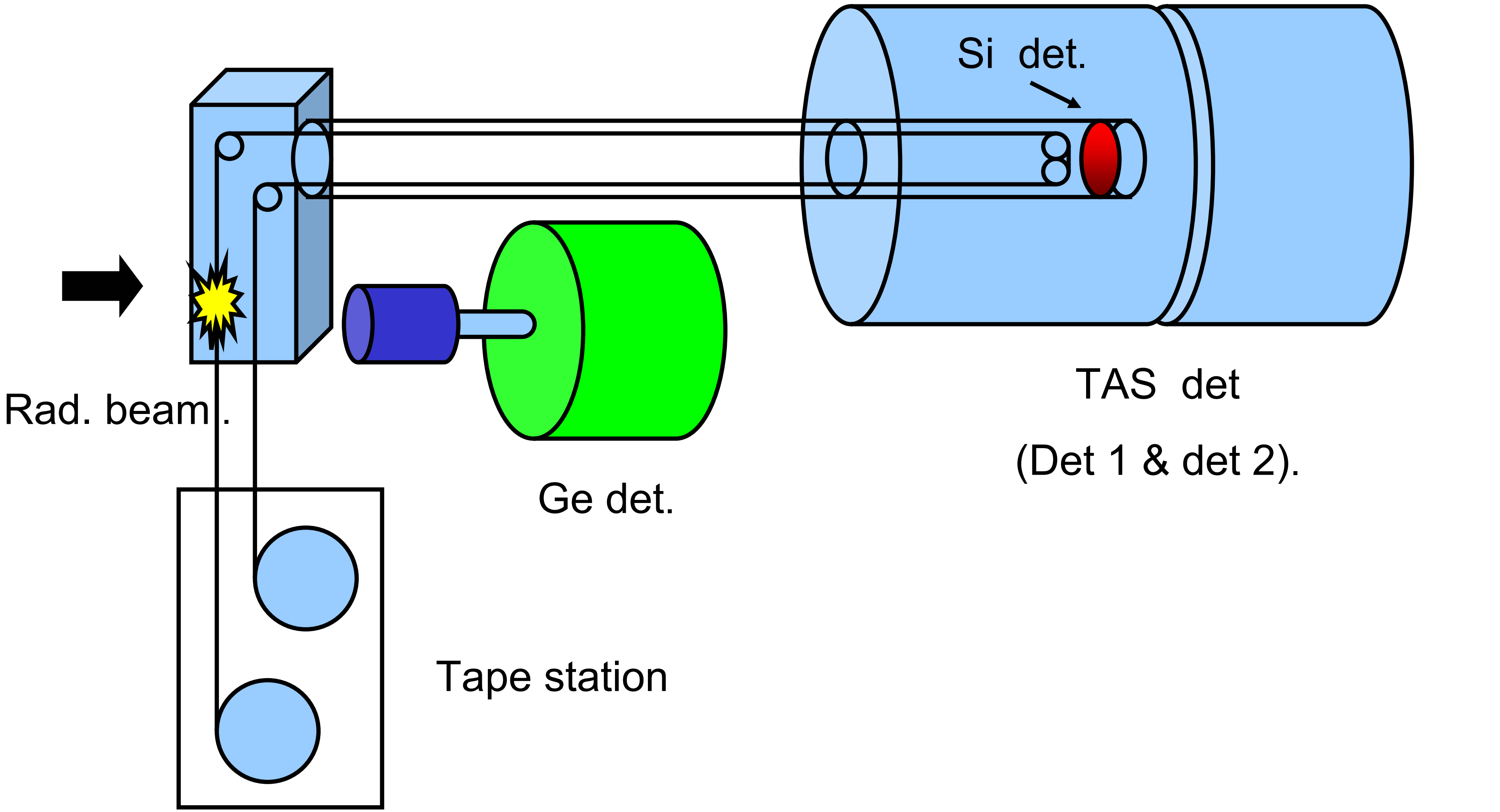
Target thickness: 15 mg/cm^2

Target dimensions: 10x50 mm, tilted 7 degrees

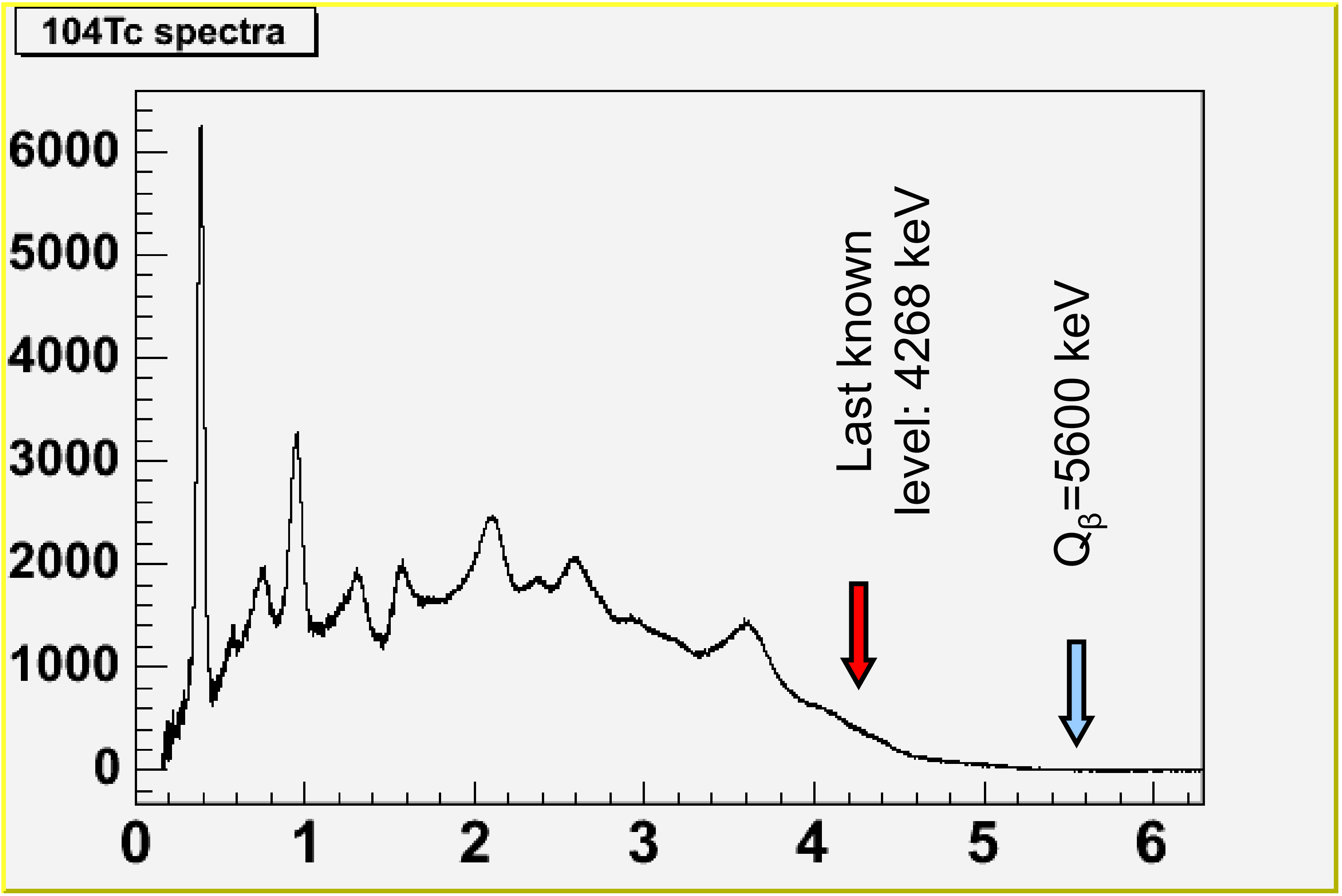
Yield of ^{112}Rh: 3500 atoms/microC

Tight collimation scheme to avoid contamination of neighbour mases (losses of 25%)

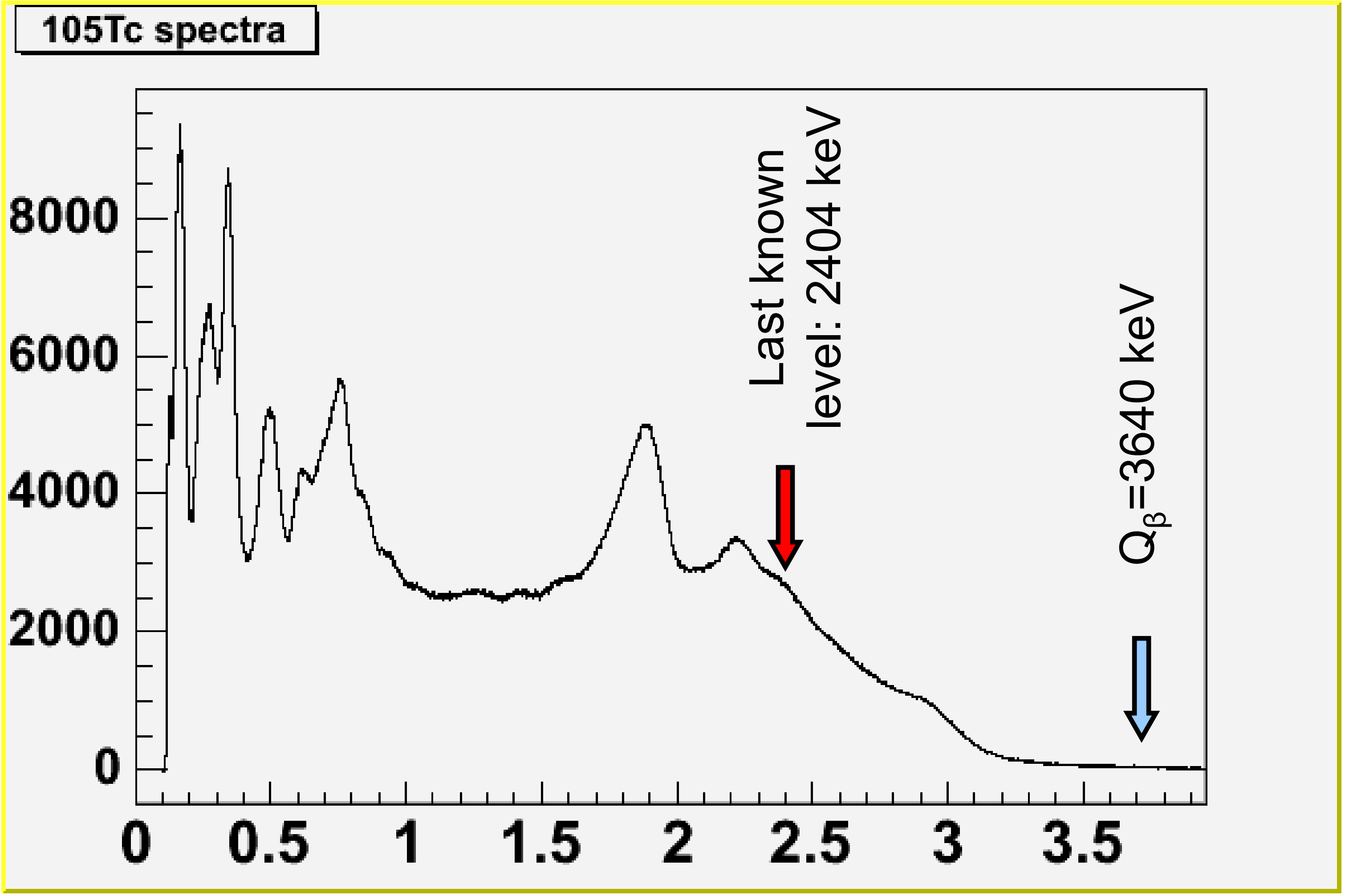
Experimental setup at Jyväskylä



^{104}Tc TAS spectrum



^{105}Tc TAS spectrum



Analysis of ^{104}Tc

Expectation Maximization (EM) method:
• modify knowledge on causes from effects

$$P(f_j | d_i) = \frac{P(d_i | f_j) P(f_j)}{\sum_j P(d_i | f_j) P(f_j)}$$

Algorithm:

$$f_j^{(s+1)} = \frac{1}{\sum_i R_{ij}} \sum_i \frac{R_{ij} f_j^{(s)} d_i}{\sum_k R_{ik} f_k^{(s)}}$$

Some details (d=Rf)

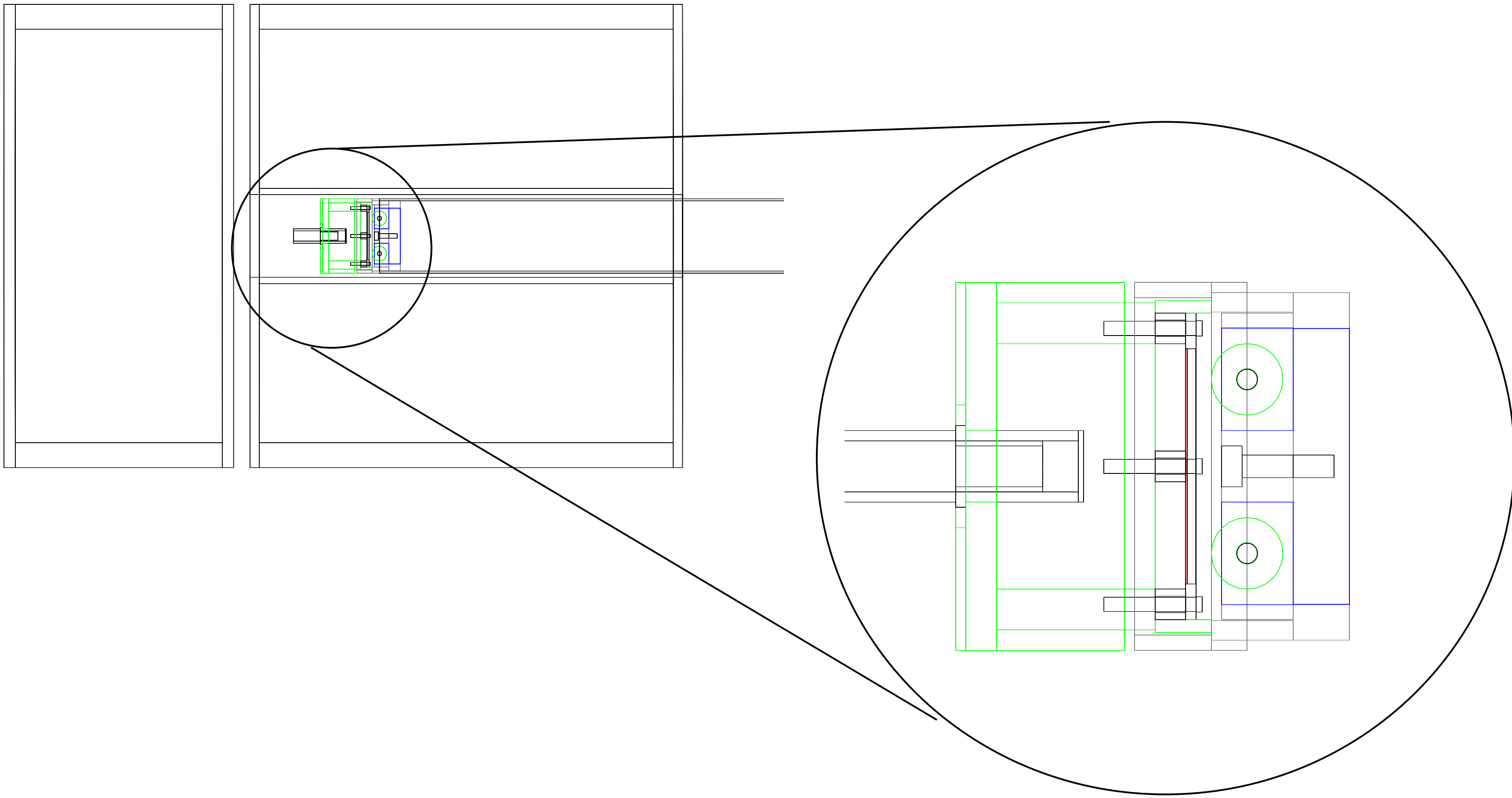
Known levels up to: 1515 keV excitation

From that level up to the Q_β value we use an statistical model

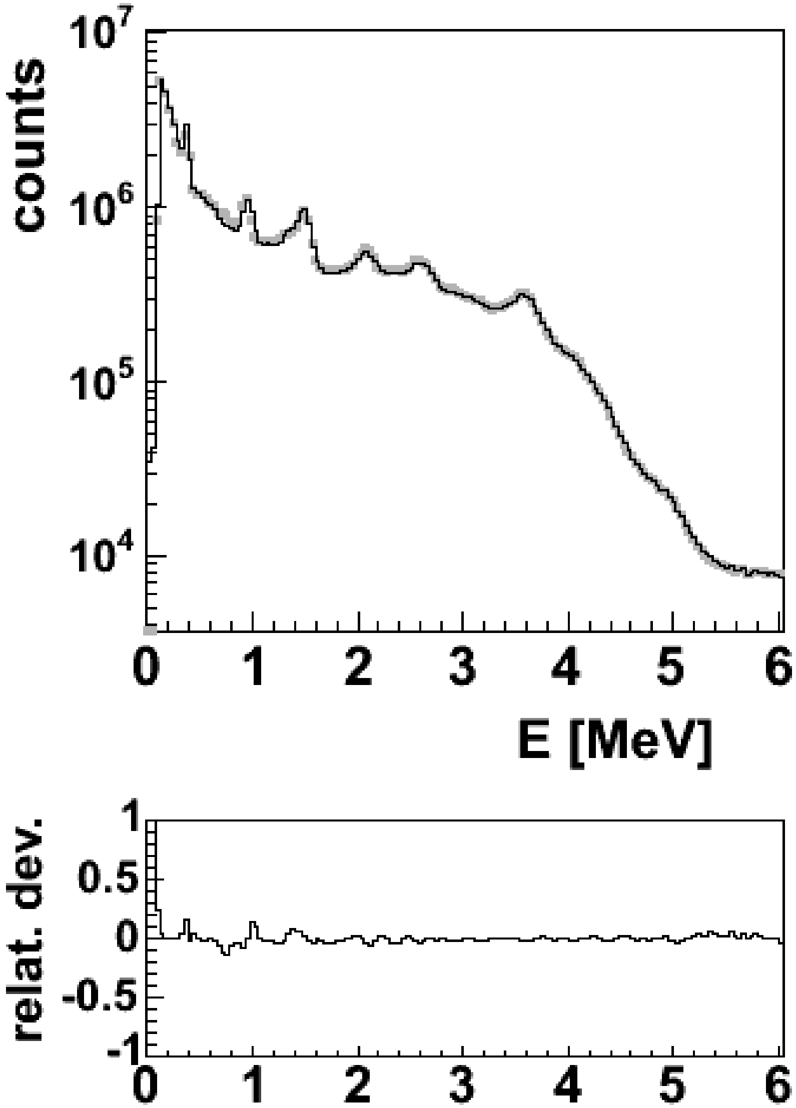
(Back Shifted Fermi formula for the level density with parameters taken from the RIPL database (^{102}Ru,^{106}Pd)

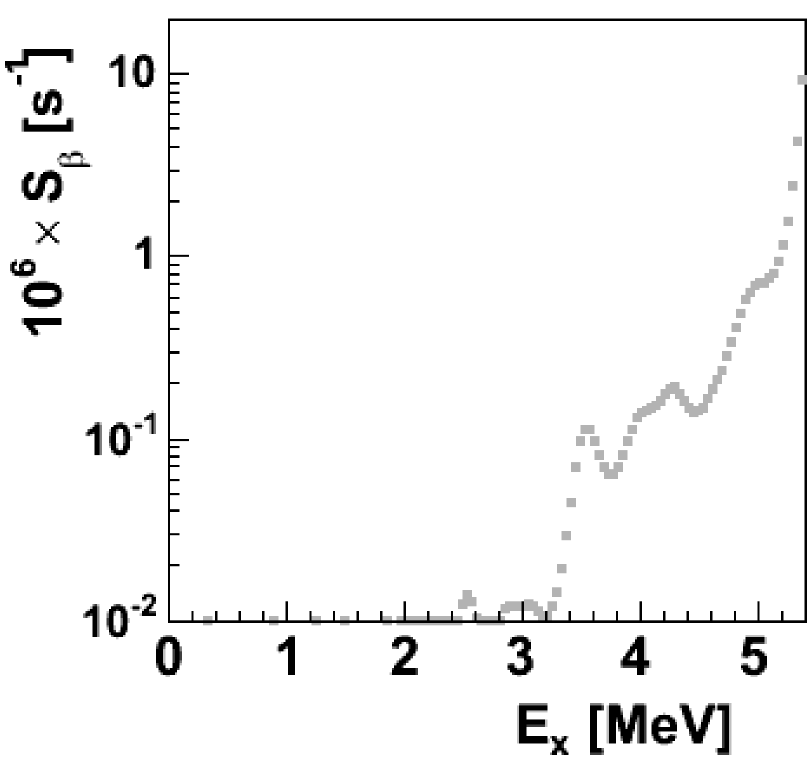
Branching ratios

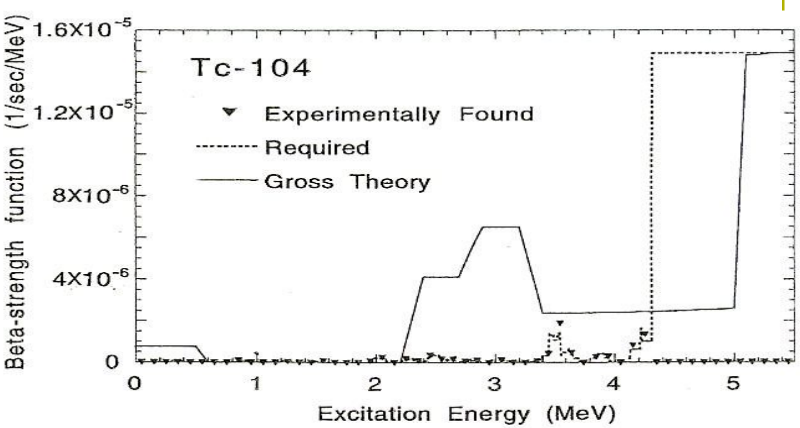
Monte Carlo simulations of the setup: geometry



Results of the analysis for ^{104}Tc







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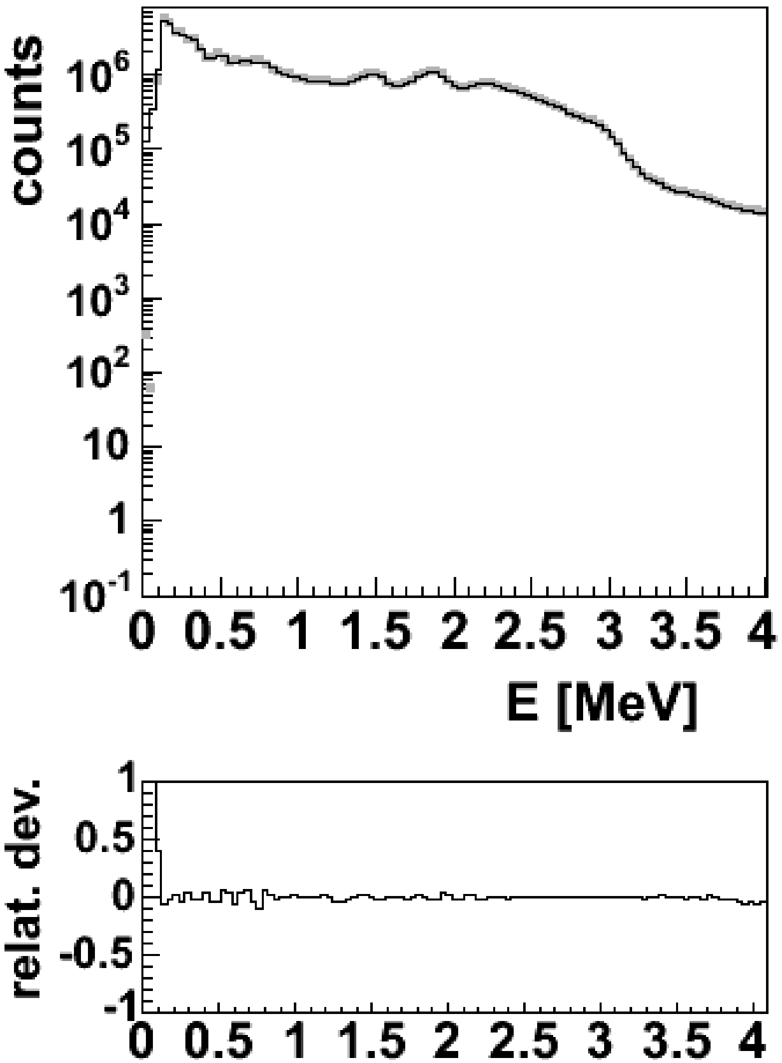
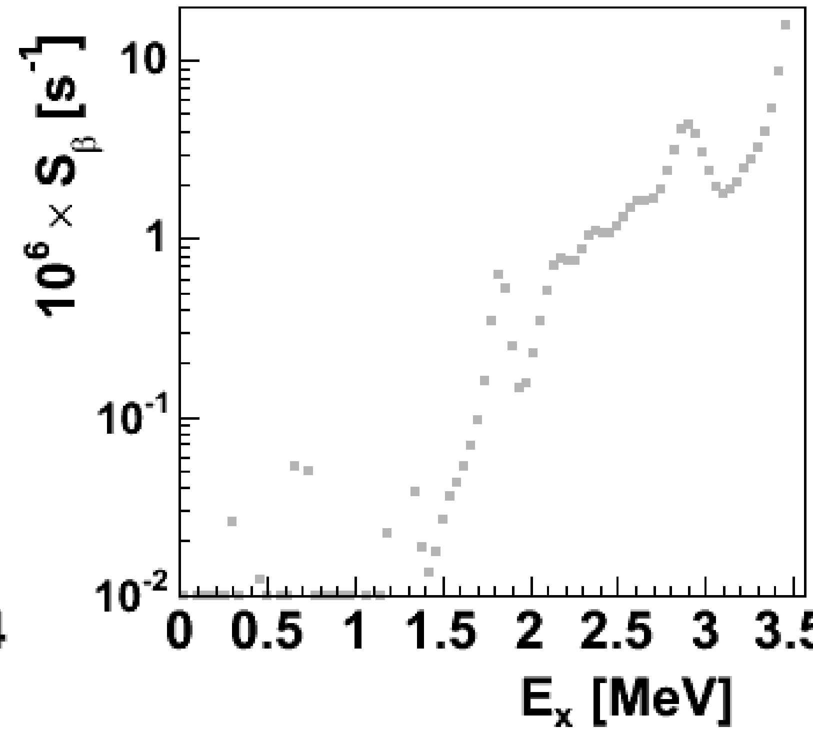
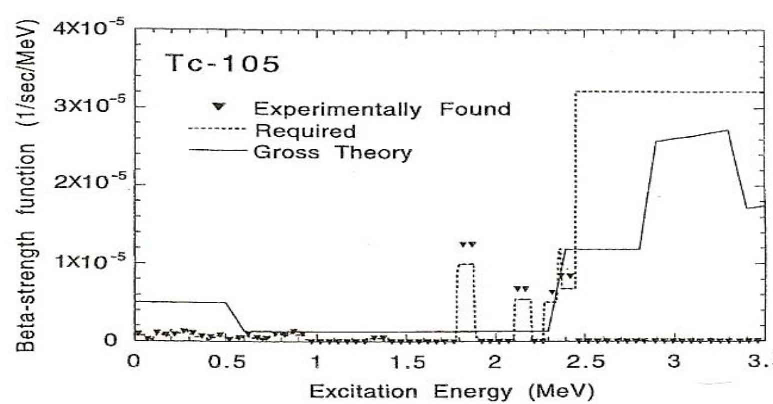
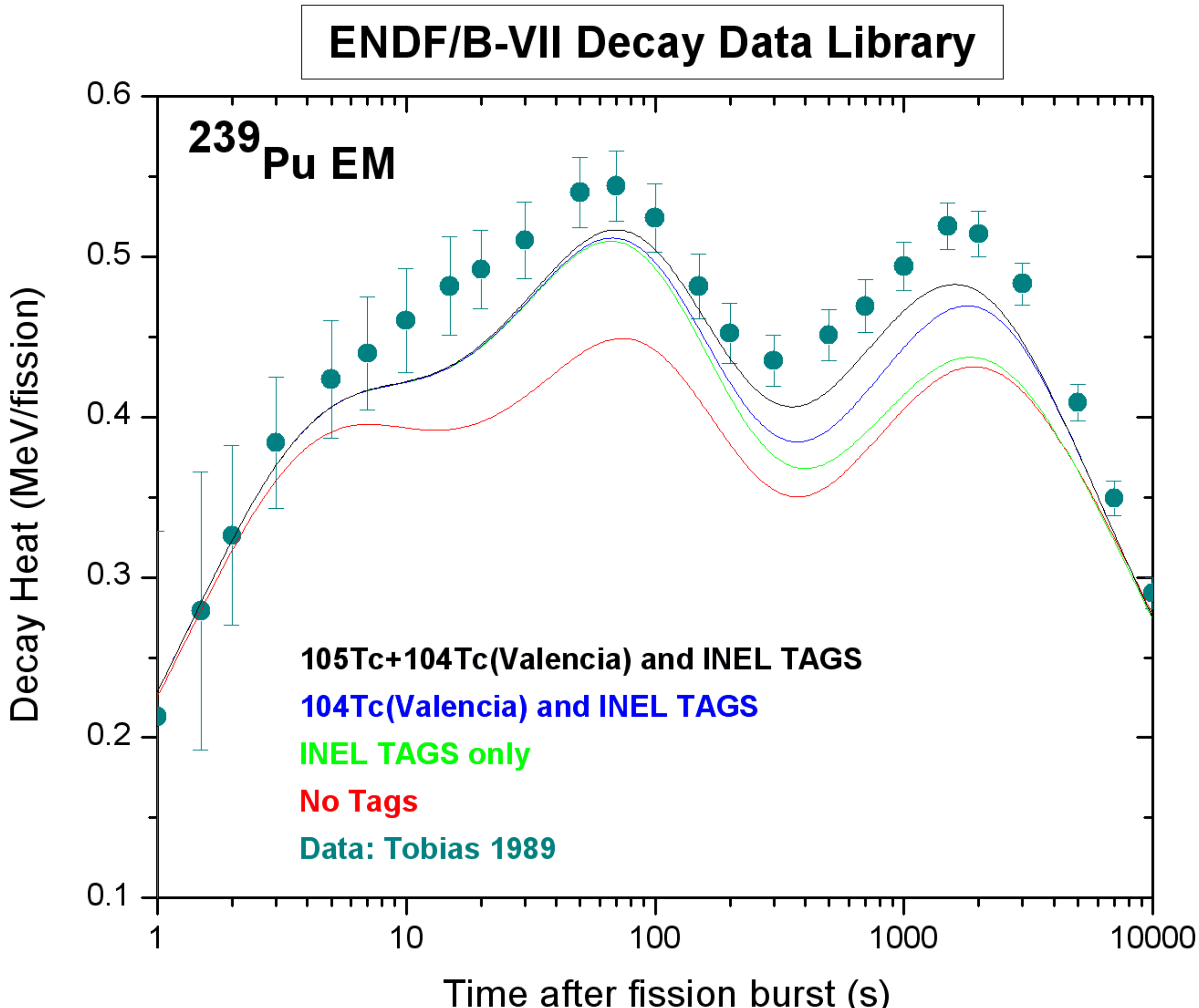






Impact of the results for $^{104,105}Tc$



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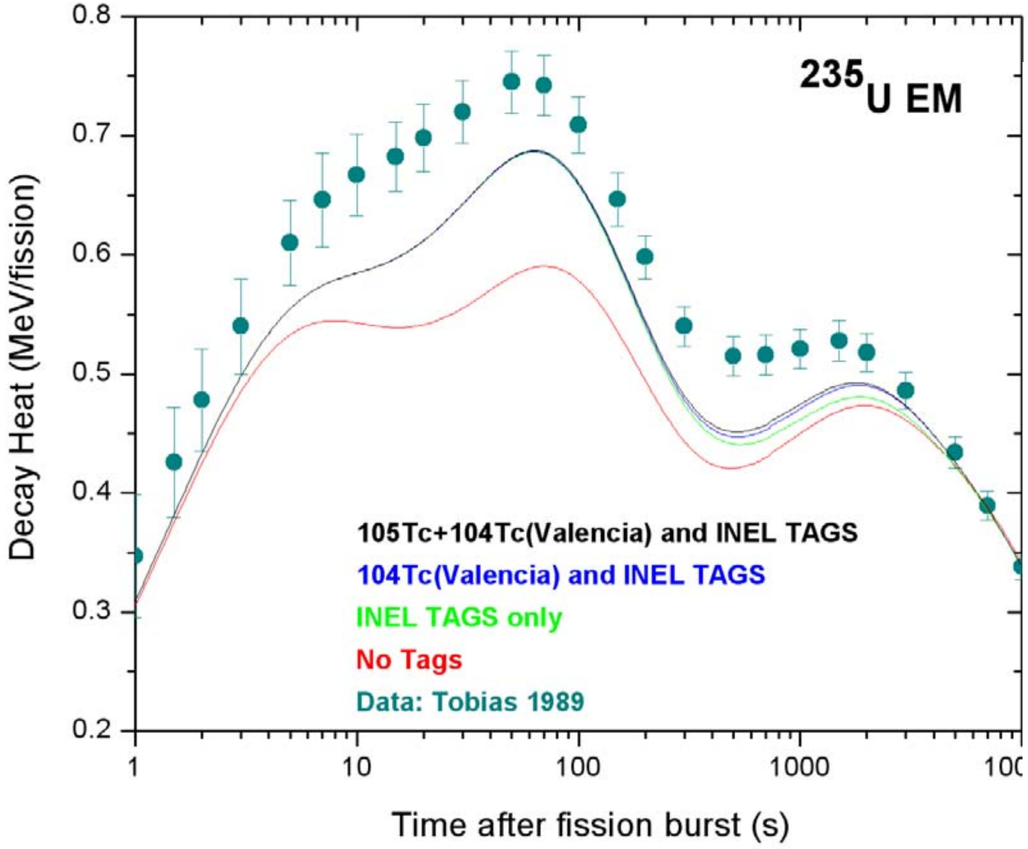

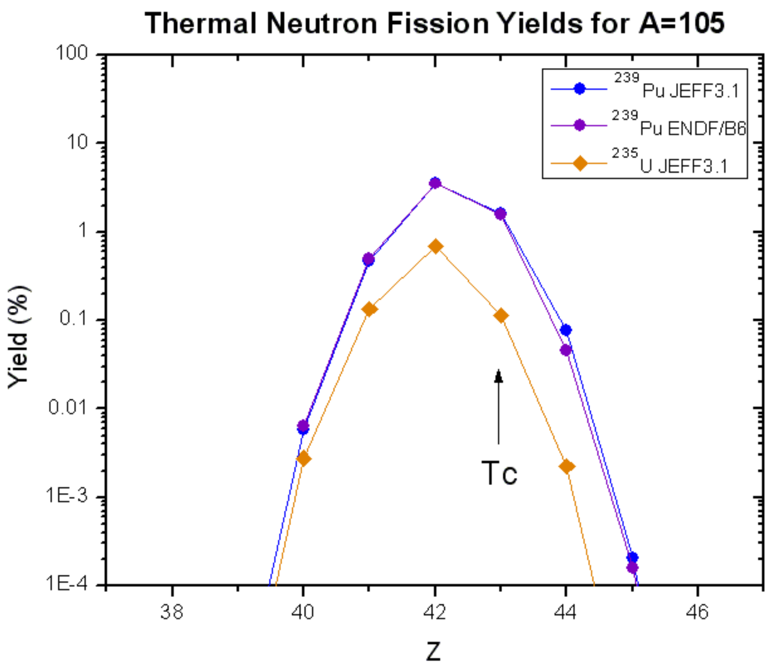

Possible measurements at ALTO

There are several advantages of having a stable setup for these kind of measurements:

- The possibility of doing systematic studies in a controlled way, provided on the availability of beamtime
- Very cost effective, since we are not forced to mount and dismount the setup, with a large amount of effort. There is also the advantage of the reduction of the time required for the analysis.
- The possibility of instructing people (students, and not only students) in the use of the TAS technique

Possible cases: Yoshida's list

Nucl	$T_{1/2}$	Q_β	E_{last}	S_n	$N_\%$	Comments
^{92}Rb	4.5s	8105	7363	7342	0.0107	Diff. sep. with $T_{1/2}$
^{89}Sr	50.5d	1497	909		-	Why in the list?
^{97}Sr	426ms	7467	2558	5979	0.005	Diff. sep. with $T_{1/2}$
^{96}Y	5.3s 9.6s	7087 " +X	6231 5899	7854	-	Diff. sep. with $T_{1/2}$, the two isomers are sim.
^{100}Zr	7.1s	3335	703	5680	-	Daugther $T_{1/2}$=1.5 s
^{99}Nb	15s 2.6m	3639 3974	235 2944	5925	-	Looks ok
^{102}Nb	4.3s 1.3s	7210 " +X	2480 ???	8117	-	High resol. meas. needed, clean beam needed

Possible cases: Yoshida's list II

Nucl	$T_{1/2}$	Q_β	E_{last}	S_n	$N_{\%}$	Comments
^{135}Te	19s	5960	4773	7900	-	☺
^{145}Ba	4.31s	4930	2566	6150	-	Greenwood case
^{145}La	24.8s	4120	2607	4730	-	Greenwood case
^{87}Br	55.6s	6853	5821	5514	2.57	Case study, Nichols list
^{142}Cs	1.7s	7306	5280	6170	0.091	Diff. $T_{1/2}$ cleaning.
^{143}La	14.2m	3425	2825	5145	-	☺

Other possible cases: Nichols

Nucl	$T_{1/2}$	Q_β	E_{last}	S_n	$N_{\%}$	Comments
^{87}Br	55.6s	6853	5821	5514	2.57	Case study, good $T_{1/2}$ sep
^{88}Br	7.1s	8960	7000	7053	6.4	Case study, good $T_{1/2}$ sep
^{90}Br	1.92s	10350	5730	6310	24.6	More diff. case
^{137}I	24.5s	5880	5170	4025	6.97	Separable using $T_{1/2}$
^{138}I	6.49s	7820	5341	5810	5.5	Still possible sep. with $T_{1/2}$

Conclusions

- From the available information (databases) it is clear that there is a huge amount of work to be done. It requires close collaboration with the experts of the field in order to determine priorities.

- The work requires the installation of a new TAS setup, and counting on the availability of beam time. In other words large support from the laboratory.

- There are specific issues that need to be addressed for each case of interest: purity of the beam, beta delayed neutron emission, etc.