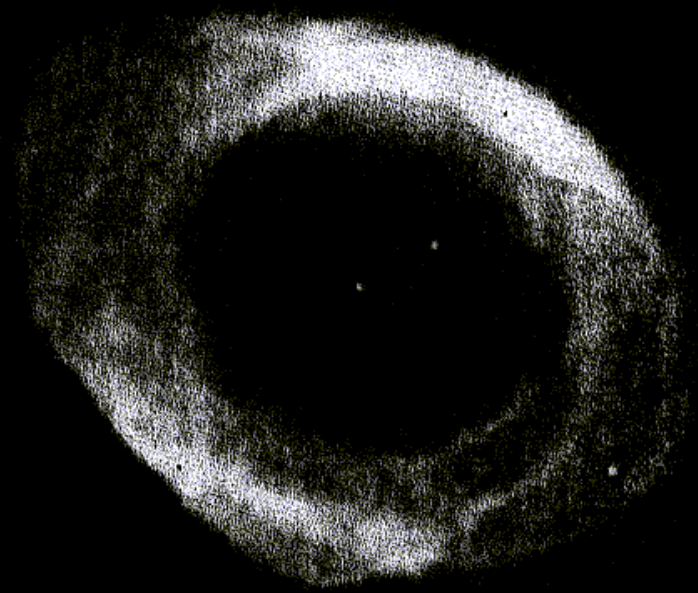
Stellar s–process rates of radioactive isotopes: Impact, measurements, and prospectives

F. Käppeler

F. Käppeler

s-process rates of radioactive isotopes: impact, recent measurements, future perspectives

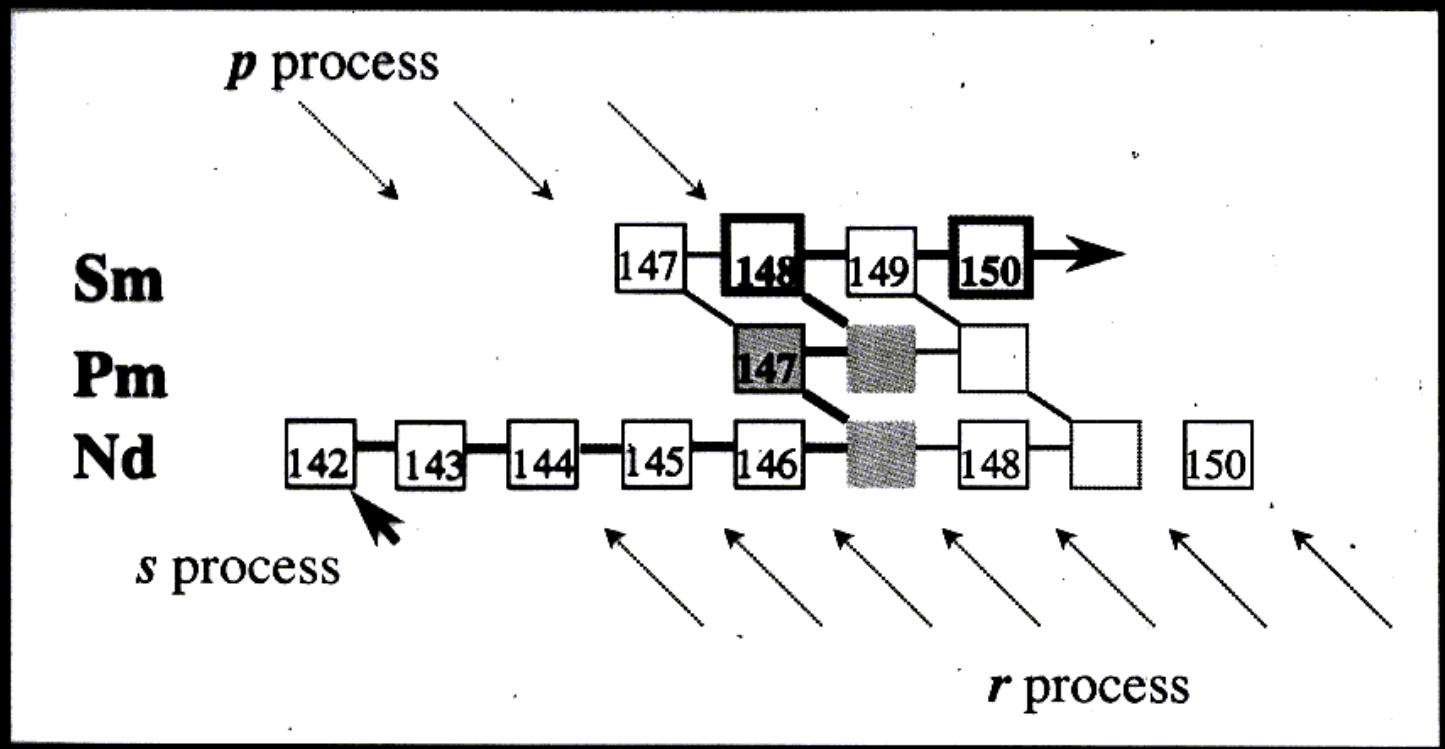


relevance and present status

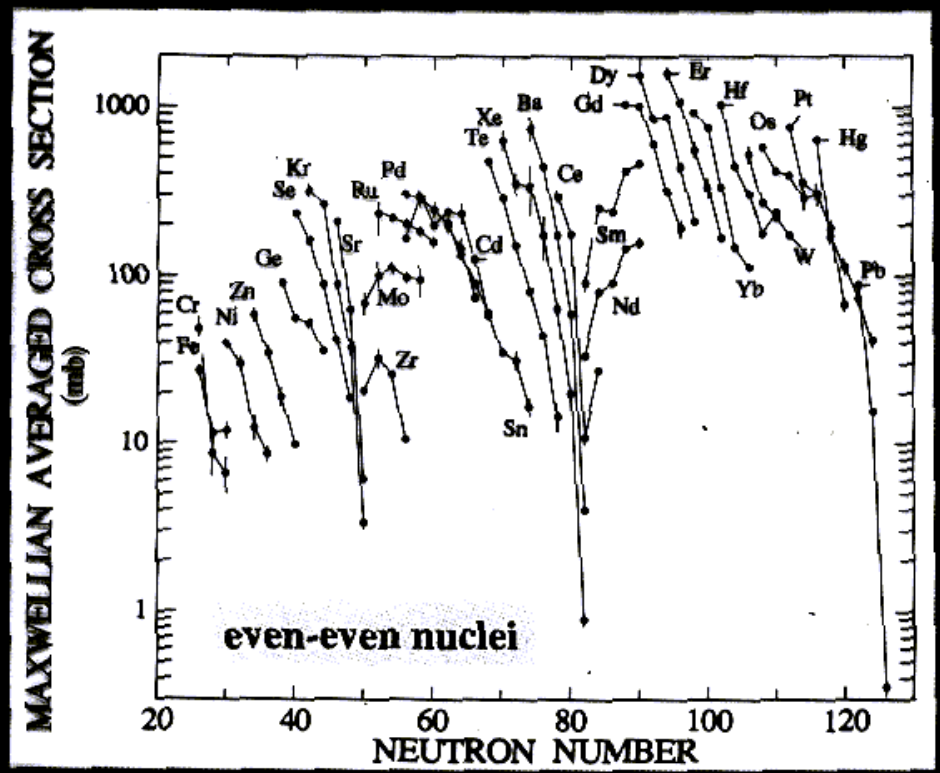
experimental possibilities

new results: ^{147}Pm and ^{171}Tm

branchings in the s-process path



status of *s*-process (n,γ) cross sections



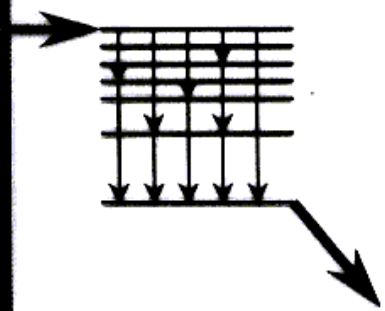
branch point	status $\frac{\langle\sigma v\rangle}{v_T}$
^{59}Fe	●
^{63}Ni	●
^{79}Se	●
^{81}Kr	●
^{85}Kr	●
^{147}Nd	●
^{147}Pm	● ←
^{148}Pm	●
^{151}Sm	●
^{154}Eu	●
^{155}Eu	●
^{153}Gd	●
^{160}Tb	●
^{163}Ho	●
^{170}Tm	●
^{171}Tm	● ←
^{179}Ta	●
^{185}W	●
^{204}Tl	●

status of (n,γ) cross sections for explosive scenarios

- **no** experimental data on unstable isotopes
- **few** measurements outside *s*-process path
- so far, **all** r- and p-process calculations rely on HF calculations

detection of neutron capture events

(n,γ):



prompt γ–rays + TOF-method

single γ´s	* Moxon-Rae	$\varepsilon_\gamma \sim 1\%$
	* PH-weighting	$\sim 20\%$
	* Ge, NaI	$< 1\%$
all cascade γ´s	* $4\pi BaF_2$	$\sim 100\%$

activation in quasi-stellar spectrum

most sensitive	* small cross sections, 10^{14} atoms sufficient
selective	* natural samples or low enrichment

sample requirements

VdG and e-linac:

TOF 0.05 - 5 g separated isotopes

→ too much for short-lived samples

activation 100 **ng** **"natural"** samples

→ limited to special cases

spallation neutron source:

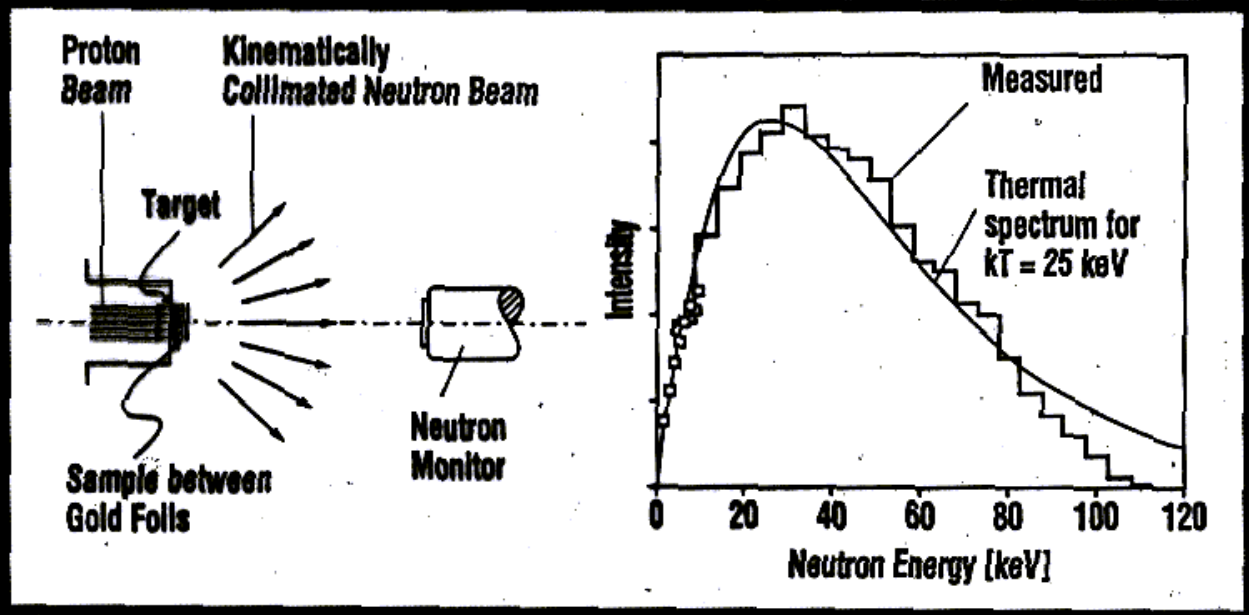
TOF/10-200m 0.5 - 5 **mg** separated isotopes

(if scaled with neutron flux)

→ measurements on radioactive samples

activation technique using quasi-stellar spectrum at kT=25 keV

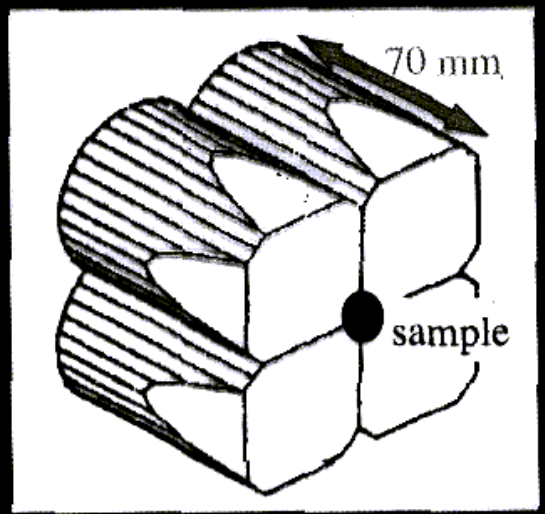
Beer & Käppeler, Phys. Rev. C 21 (1980) 534

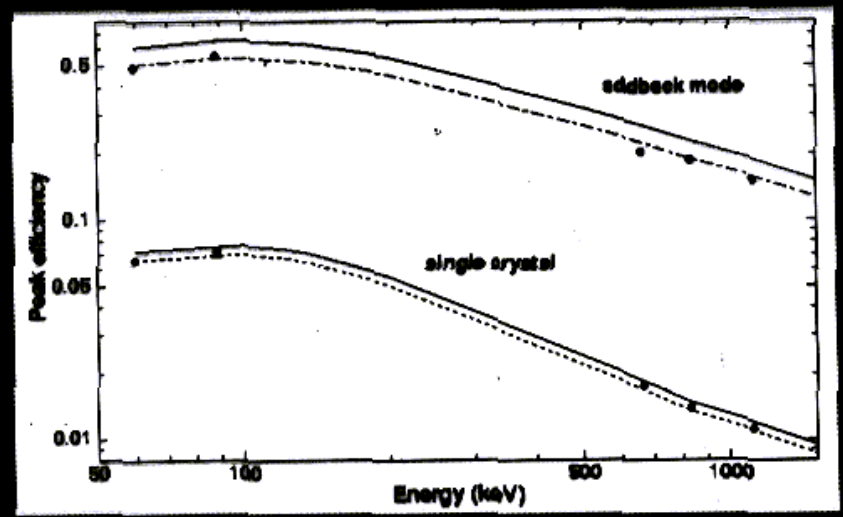


$^{7}Li(p,n)^{7}Be$ reaction, proton energy 1912 keV, $\Phi_n = 3\ 10^9$ n/s

measurements with samples of 28 ng ^{147}Pm and 800 ng ^{171}Tm

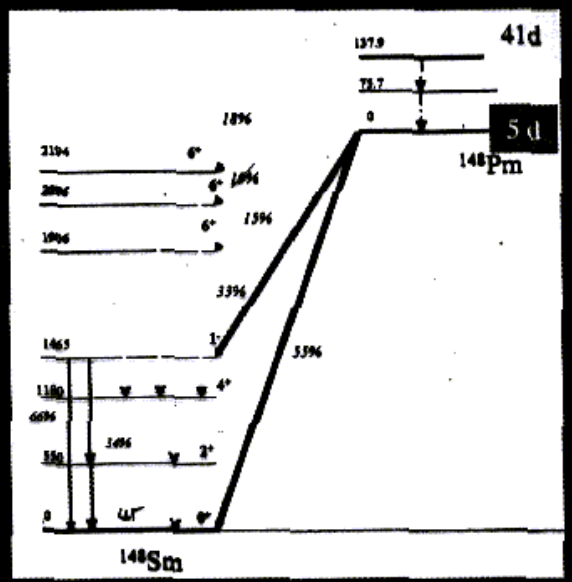
efficient γ-counting: 2 Ge Clovers face to face

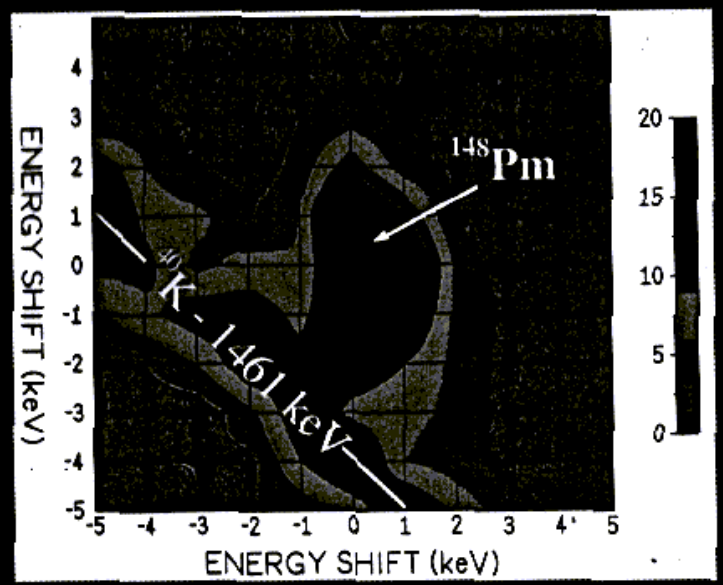




^{147}Pm sample irradiated for 12 d, induced activity counted for 20 d
individual γ-transitions from ^{148}Pm decay buried in background

improved sensitivity by coincident detection of γ-cascades





experimental results: $\sigma^g = 303 \pm 30$ mbarn, $\sigma^m = 382 \pm 40$ mbarn

$\sigma^{tot} = 685 \pm 60$ mbarn

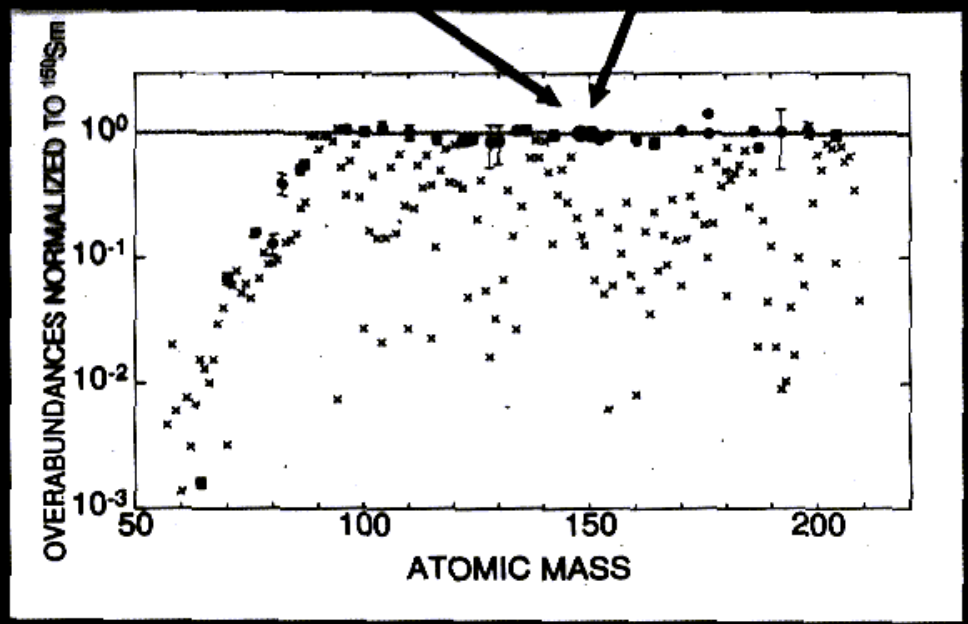
theoretical predictions (1976-2000): 938 - 2000 mbarn

consequences for branchings at A=147/148

before:
$^{148}Sm/^{150}Sm = 1.03$

now:
$^{148}Sm/^{150}Sm = 0.97$

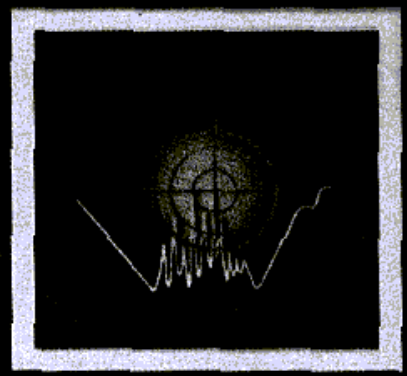
***p* yield (^{148}Sm) = 1 - 6%**



spallation sources for TOF measurements of stellar (n,γ) rates

operating

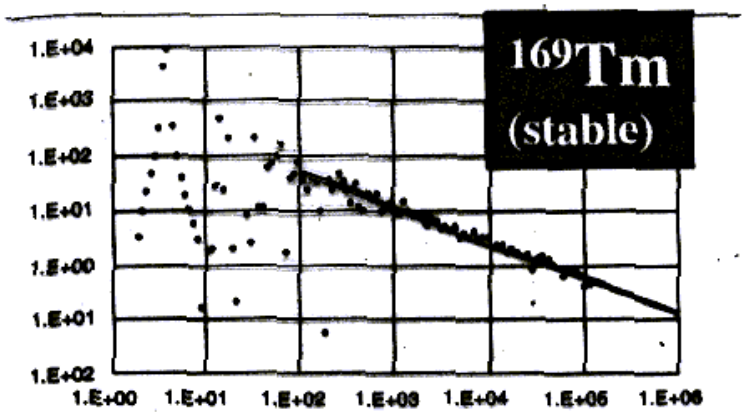
starting 10/2000

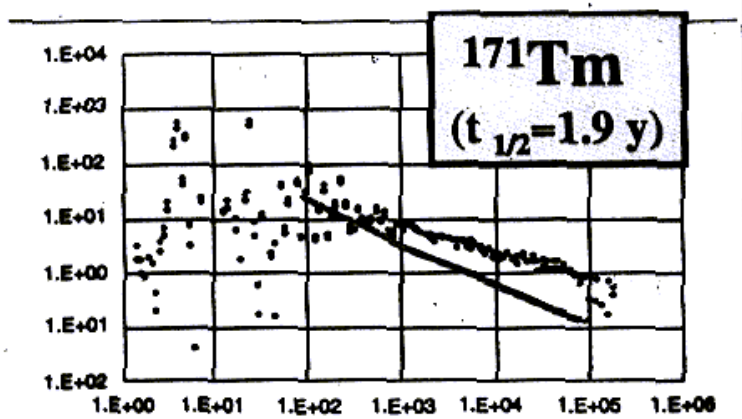


0.8	proton energy (GeV)	24
20	repetition rate (Hz)	0.4
250	pulse width (ns)	5
20	flight path (m)	185
200	average proton current (μA)	2
20	neutrons per proton	760

first TOF measurement at

[redacted]



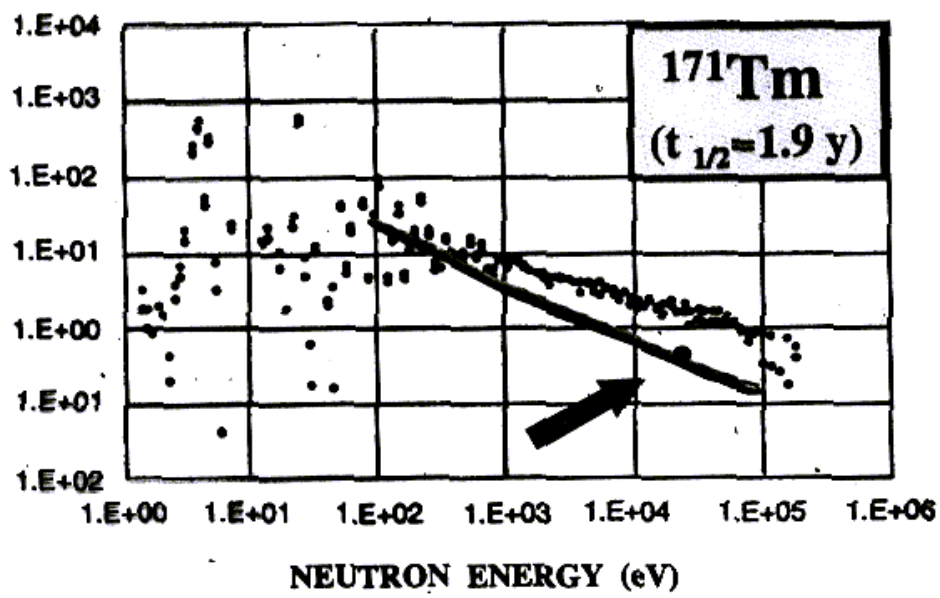


NEUTRON ENERGY (eV)

calculated with statistical model code GNASH

preliminary result of activation measurement

possibly unrecognized backgrounds in TOF experiment due to small radioactive sample ?



feasible at spallation source

s process

branch point	status $\underline{<\sigma>}$
^{63}Ni	●
^{79}Se	●
^{81}Kr	●
^{85}Kr	●
^{147}Nd	●
^{147}Pm	●
^{148}Pm	●
^{151}Sm	●
^{154}Eu	●
^{155}Eu	●
^{153}Gd	●
^{160}Tb	●
^{163}Ho	●
^{170}Tm	●
^{171}Tm	●
^{179}Ta	●
^{185}W	●
^{204}Tl	●

r and *p* processes

(n,γ) cross sections for a variety of selected unstable isotopes

- for direct use in reaction networks
- to derive rates of inverse reactions
- to test and assist statistical models

such data are important to follow the abundance yields during the freeze-out phase of explosive scenarios

summary

- **(n,γ) cross sections essential for analyzing and testing neutron capture scenarios, e.g. via branchings**
- **existing experimental possibilities in some cases suited for measurements on unstable isotopes, but many branching points not accessible**
- **high flux at spallation source opens new possibilities for a variety of measurements on important unstable isotopes, for stellar and explosive nucleosynthesis scenarios**

collaborators

- C. Arlandini
- B. Haight
- M. Heil
- A. Mengoni
- G. Miller
- R. Reifarth
- B. Rundberg
- P. Sedychev
- J. Ullmann
- J. Wilhelmy

- University of Milano
- Los Alamos National Lab.
- ENEA Bologna
- JINR Dubna
- FZKarlsruhe