Neutron-induced cross sections of actinides via de surrogate reaction method

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Neutron-induced cross sections of short-lived nuclei in reactor physics

- Incineration of minor actinides
  - Fission and capture cross of e.g. $^{241,243}\text{Am},^{243}\text{Cm}(29.1\text{y}),^{244}\text{Cm}(18.1\text{y}),^{245}\text{Cm} (8500\text{y})$

- $^{232}\text{Th}/^{233}\text{U}$ cycle
  - Fission and capture cross sections of e.g. $^{232}\text{U}(69\text{y}),^{231}\text{Th} (26\text{h}),^{233}\text{Th}(22\text{m})$

The data are missing (in particular for capture) due to the high radio-toxicity of the targets involved!
Indirect \((n,f)\) and \((n,\gamma)\) measurements: the surrogate method

Neutron-induced reaction

Surrogate reaction

Cramer and Britt (Los Alamos 1970...!!)

\[
\sigma^A_{(n,\chi)}(E^*) = \sigma^{A+1}(E^*)P^{A+1}_\chi(E^*)
\]

\(\text{Calculated} \quad \text{(Optical model calculations CEA/Bruyeres le Chatel)}\)

\(\text{Measured}\)
Surrogate method and fission cross sections

**243Am(3He,4He)242Am**


How about radiative capture??
Surrogate method applied to capture in rare-earth region

Results for 174Yb(3He,p)176Lu

175Lu(n,γ)

Spin distributions


Very important discrepancies!
Why do we obtain such big differences?

Due to the high spin of the decaying nucleus, neutron emission to the ground- and first excited states is highly improbable and gamma emission is highly enhanced! Things should get better when the level density of the nucleus after neutron emission increases --> better for actinides
Surrogate method applied to capture in actinide region
Experiment at the Oslo cyclotron:
Reactions studied

Good quality neutron-induced data exist!
(d,p) interesting for inverse kinematics

3He (24 MeV)

238U+n

239U

238U

237U

(d,p)

(d,t)

(d,d)

238U+n

236U+n

237Np+n

(3He,p)

(3He,d)

(3He,t)

(3He,4He)

238Np

239Np

237Np

240Np

237U

236U+n

Surrogate method applied to capture in actinide region
Experiment at the Oslo cyclotron:
Reactions studied

Good quality neutron-induced data exist!
(d,p) interesting for inverse kinematics
Experimental set-up at the Oslo cyclotron

High efficiency
Simultaneous measurement of gamma and fission decay
Determination of decay probability

\[ P \left( E^* \right) = \frac{N_{\text{coin}} \left( E^* \right)}{N_{\text{CN}} \left( E^* \right) \cdot \text{Eff} \left( E^* \right)} \]

\[ E^* = \frac{A}{A+1} E_n + B_n \]
First preliminary results: Fission

**Fission Probability of 239U**

- ENDF-VII.1
- 238U(n,f)
- CENBG
- 238U(d,p) at 15 MeV
- Britt, Cramer
- 238U(d,p) at 18 MeV

Deuteron breakup!

The neutron is emitted before CN formation

(I. Thompson, 2012)
First very preliminary results: Fission
(Analysis with very low statistics, only 1 telescope strip!)

Fission Probability 237U*

- ENDF-VII.1 (neutron induced)
- 236U(n, f)
- CENBG (surrogate)
- 238U(3He, 4Hef)
First very preliminary results: Fission
(Analysis with very low statistics, only 1 telescope strip!)

Fission Probability 238Np*

- ENDF-VII.1 (neutron induced)
- 237Np(n,f)
- CENBG (surrogate)
- 238U(3He,tf)
First very preliminary results: gamma decay

This ratio needs to be corrected for the gamma-cascade detection efficiency to get $P_{\gamma}$!
Conclusions...

• Surrogate-reaction method:
  --> works well for fission
  --> important discrepancies for capture in rare-earth region due to spin selectivity of neutron emission

• New experiment to study capture in actinide region at the Oslo cyclotron
  → d+238U & 3He+238U
  → 238U(d,p): fission cross section 25% lower than 238U(n,f), d breakup!
  → Preliminary fission probabilities from 238U(3He,4He) & 238U(3He,t) agree well with n-induced data
  → Analysis on the way to extract gamma-decay probabilities

...Perspectives

• Further study of d-breakup involving theoreticians

• Gamma-decay probabilities to be extracted for:
  238U(d,p)239U <-> 238U(n,γ)
  238U(d,t)237U <-> 236U(n,γ)
  238U(3He,4He)237U <-> 236U(n,γ)
  238U(3He,t)238Np <-> 237Np(n,γ)

• Evaluate to which extent the surrogate method can be used to extract unknown capture cross sections of short-lived actinides