^{242m}Am isomer yield in ^{243}Am(n,2n) reaction

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Collaboration

- **ADVANCED EVALUATION OF 237Np and 243Am NEUTRON DATA'**
- **COLLABORATION**
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SCOPE

Reaction chain ^{243}Am(n,2n)^{242g}Am(β^{-}(ε) ^{242}Cm(^{242}Pu) defines α- & n-activity of n spent fuel.

- The half-life of ^{242g}Am is 16 h
- The half-life of ^{242m}Am is 141 y
- ^{242m}Am $\sigma(n,f) \gtrsim$ 6000 barn may influence the core neutronics.
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^{243}Am(n,2n)^{242g}Am, E_n=15 MeV, measured by TL Norris, AJ Gancartz et al., 1982

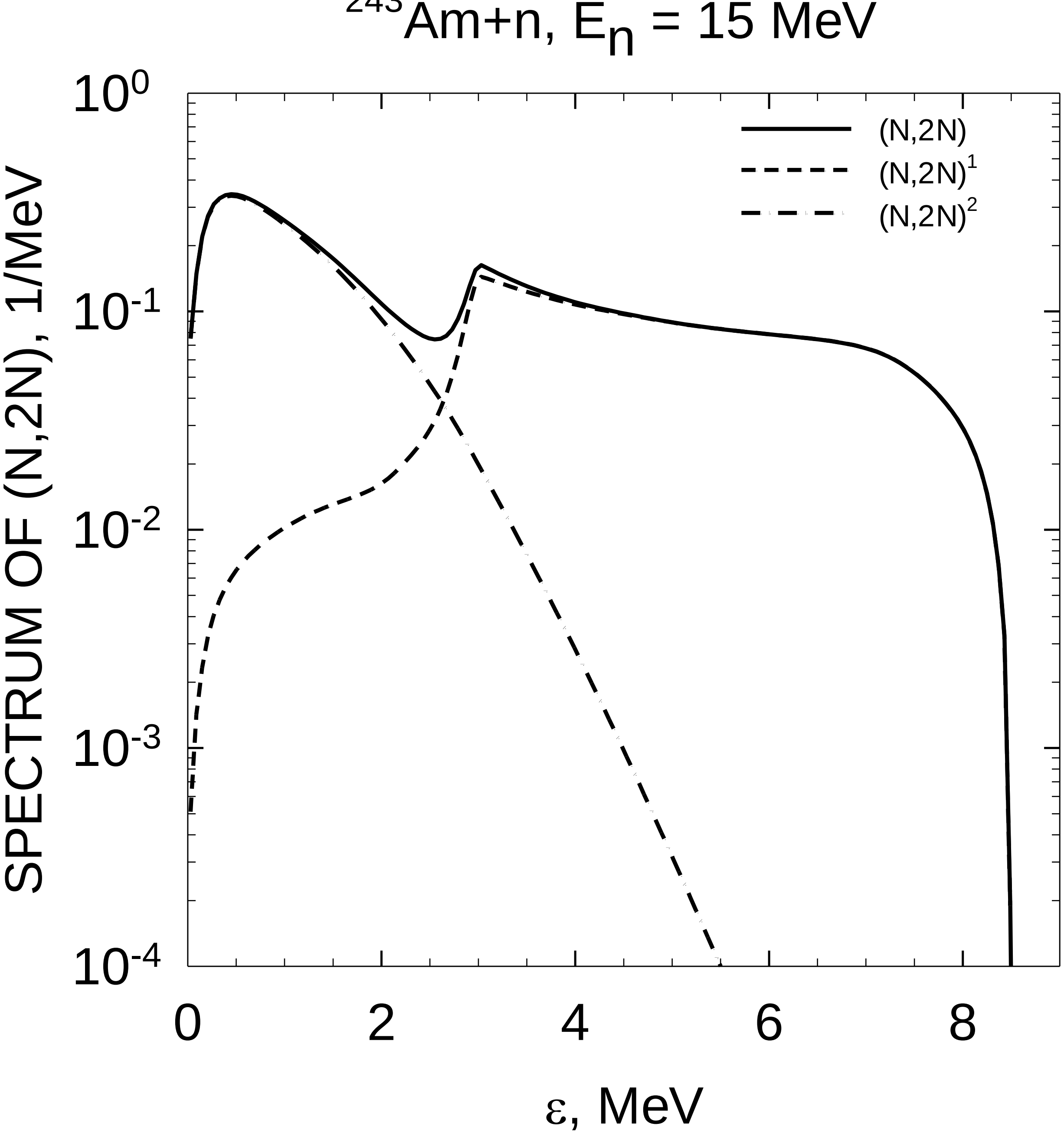
- ^{243}Am(n,2n) populates $T_{1/2}$ =16h ^{242g}Am, $J^{\pi}=1^{-}$ & $T_{1/2}$ =141y ^{242m}Am with $J^{\pi}=5^{-}$
- Forbidden β^{-}decay of ^{242m}Am
- ^{243}Am(n,2n)^{242g}Am(β^{-}(ε)^{242}Cm(^{242}Pu)
- Forbidden β^{-}decay of ^{242m}Am
- ^{242m}Am(n,γ)^{243}Am(n,γ)^{244m}Am(β^{-}(ε))^{244}Cm(^{244}Pu)
- ^{242m}Am(n,γ)^{243}Am(n,γ)^{244g}Am(β^{-}) ^{244}Cm

$$\frac{d\sigma^{1}_{n2nx}}{d\varepsilon}=\frac{d\sigma^{1}_{nnx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A}_{n}(E_{n}-\varepsilon)}{\Gamma^{A}(E_{n}-\varepsilon)}$$

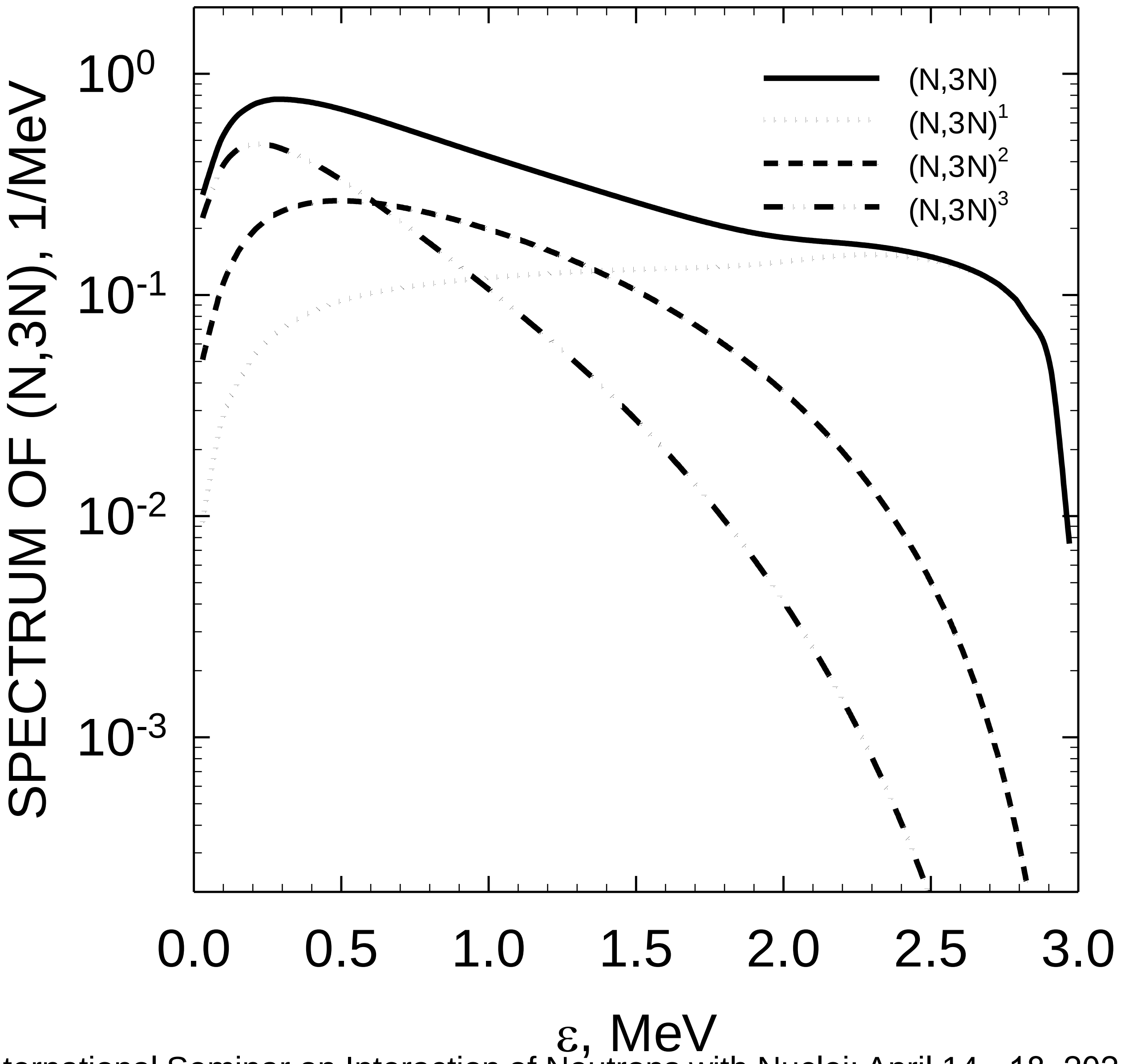
$$\frac{d\sigma^{1}_{n2n}}{d\varepsilon}=\int_{0}^{E_{n}-B_{n}^{A}}\frac{d\sigma^{1}_{n2nx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A-1}_{n}(E_{n}-B_{n}^{A}-\varepsilon-\varepsilon_{1})}{\Gamma^{A-1}(E_{n}-B_{n}^{A}-\varepsilon-\varepsilon_{1})}d\varepsilon_{1}$$

$$\frac{d\sigma^{2}_{n2nx}}{d\varepsilon}=\int_{0}^{E\ -B_{n}^{A}-\varepsilon}\frac{d\sigma^{1}_{n2nx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A}_{n}(E_{n}-B_{n}^{A}-\varepsilon-\varepsilon_{1})}{\Gamma^{A}(E_{n}-B_{n}^{A}-\varepsilon-\varepsilon_{1})}d\varepsilon_{1}$$

$$\frac{d\sigma^{2}_{n2n}}{d\varepsilon}=\int_{0}^{E\ -B_{n}}\frac{d\sigma^{2}_{n2nx}(\varepsilon)}{d\varepsilon}\,\frac{\Gamma^{A-1}_{n}(E_{n}-B_{n}^{A}-\varepsilon_{1}-\varepsilon_{2})}{\Gamma^{A-1}(E_{n}-B_{n}^{A}-\varepsilon_{1}-\varepsilon_{2})}d\varepsilon_{1}$$


^{243}Am+n, E_n = 15 MeV
SPECTRUM OF (N,2N), 1/MeV
ε, MeV
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
2
4
6
8
(N,2N)
$(N,2N)^1$
$(N,2N)^2$

^{243}Am, E_n = 15 MeV



The γ-decay of the excited nucleus is described
by the kinetic equation n

$$\frac{\partial\omega_k(U,J^\pi,t)}{\partial t}=\sum_{J'\pi'}\int_0^{U_g}\omega_{k-1}(U',J^\pi{}',t)\frac{\Gamma_\gamma(U',J^\pi{}',U,J^\pi)}{\Gamma(U',J^\pi{}')}dt-\omega_k(U,J^\pi,t)\frac{\Gamma_\gamma(U,J^\pi)}{\Gamma(U,J^\pi)}$$

$\omega_k(U,J^\pi)$ is the population of $(\mathrm{J}\pi)$at U after emission of k $\gamma-$quanta

Integrating over t , in the long run, one gets W(U,Jπ) after emission of k γ-quanta

$$\omega_k(U,J^\pi,\infty)-\omega_k(U,J^\pi,0)=\sum_{J'\pi'}\int_U^{U_g}\frac{\Gamma_\gamma(U',J^\pi{}',U,J^\pi)}{\Gamma(U',J^\pi{}')}\int_0^\infty\omega_{k-1}(U',J^\pi{}',t)dtdU'-$$

$$\frac{\Gamma_\gamma(U,J^\pi)}{\Gamma(U,J^\pi)}\int_0^\infty\omega_k(U,J^\pi,t)dt$$

$$\frac{\partial \omega_k(U, J^{\pi}, t)}{\partial t} = \sum_{J'\pi'} \int_0^{U_g} \omega_{k-1}(U', J^{\pi}{}', t) \frac{\Gamma_{\gamma}(U', J^{\pi}{}', U, J^{\pi})}{\Gamma\,(U', J^{\pi}{}')} dt - \omega_k(U, J^{\pi}, t) \frac{\Gamma_{\gamma}(U, J^{\pi})}{\Gamma\,(U, J^{\pi})}$$

$$\omega_k(U, J^{\pi}, t = 0) = \delta_{ko} \omega_0(U, J^{\pi})$$

$$\begin{aligned}\omega_k(U, J^{\pi}, \infty) - \omega_k(U, J^{\pi}, 0) = \sum_{J'\pi'} \int_U^{U_g} \frac{\Gamma_{\gamma}(U', J^{\pi}{}', U, J^{\pi})}{\Gamma\,(U', J^{\pi}{}')} \int_0^{\infty} \omega_{k-1}(U', J^{\pi}{}', t) dt dU' - \\ \frac{\Gamma_{\gamma}(U, J^{\pi})}{\Gamma\,(U, J^{\pi})} \int_0^{\infty} \omega_k(U, J^{\pi}, t) dt\end{aligned}$$

$$W_k(U, J^{\pi}) = \frac{\Gamma_{\gamma}(U, J^{\pi})}{\Gamma\,(U, J^{\pi})} \int_0^{\infty} \omega_k(U, J^{\pi}, t) dt$$

$W_k(U, J^\pi)$ population of state after emission of k gamma-quanta

$$W_k(U, J^\pi) = \sum_{J'\pi'} \int_U^{U_g} \frac{\Gamma_\gamma(U', J^\pi{}', U, J^\pi)}{\Gamma(U', J^\pi{}')} W_{k-1}(U', J^\pi{}') dU' + \omega_k(U, J^\pi, 0)$$

$$W(U, J^\pi) = \sum_k W_k(U, J^\pi)$$

$$W(U, J^\pi) = \sum_{J'\pi'} \int_U^{U_g} \frac{\Gamma_\gamma(U', J^\pi{}', U, J^\pi)}{\Gamma(U', J^\pi{}')} W(U', J^\pi{}') dU' + W_0(U, J^\pi)$$

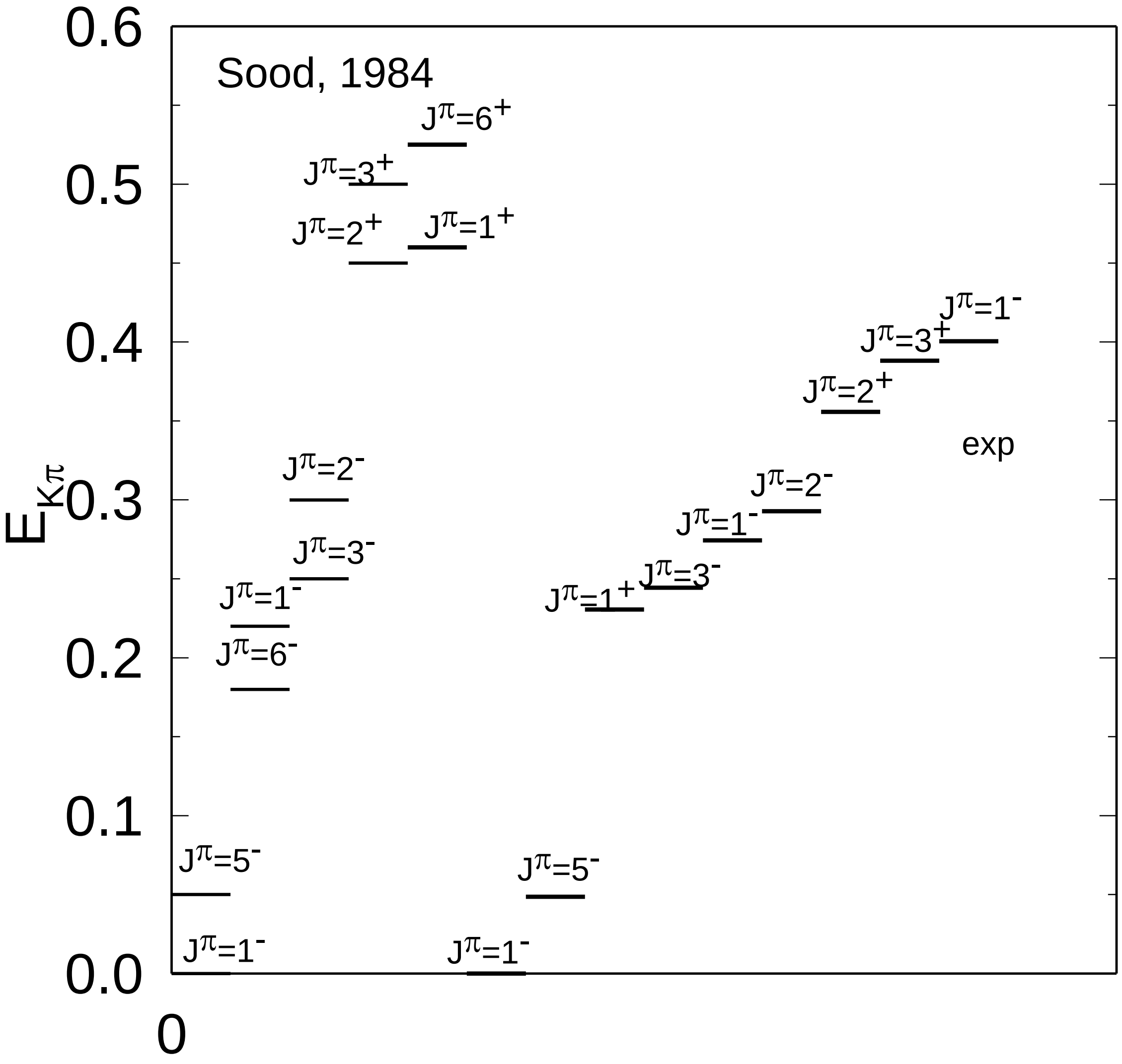
$$r(E_n) = \frac{\sum\limits_{J>(J_l+J_s)/2} W(U, J^{\pi})}{\sum\limits_{J\le(J_l+J_s)/2} W(U, J^{\pi})}$$

$$r(E_n) = \sigma^{m}_{\mathrm{n2n}}\left(E_n\right) / \sigma^{g}_{\mathrm{n2n}}\left(E_n\right)$$

^{242m}Am $$\sigma^{m}_{\mathrm{n2n}}\left(E_n\right) = \sigma_{\mathrm{n2n}}\left(E_n\right) r(E_n)\,/(1+r(E_n))$$

^{242g}Am $$\sigma^{g}_{\mathrm{n2n}}\left(E_n\right) = \sigma_{\mathrm{n2n}}\left(E_n\right)/(1+r(E_n))$$

^{242}Am levels



Splitted Gallaher-Moshkowski doublets

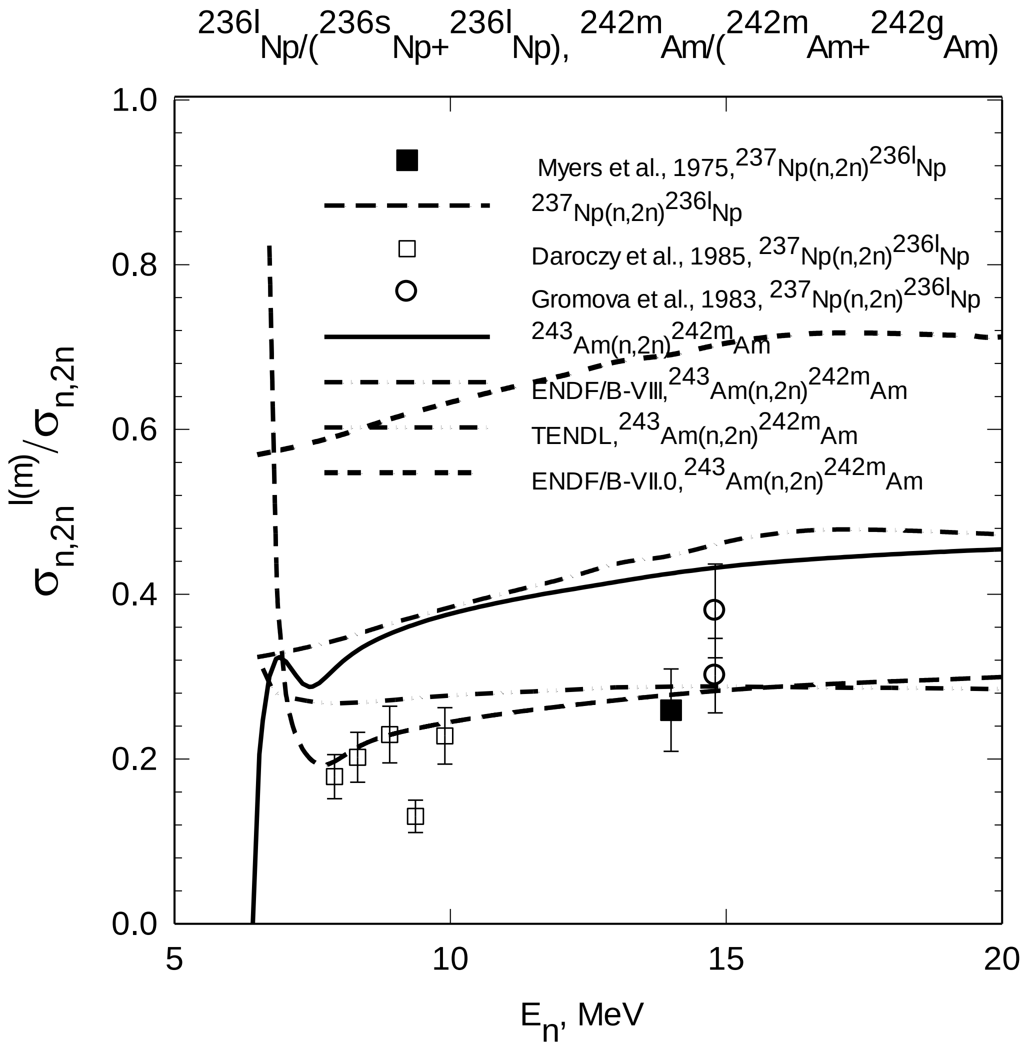
$$K^{+} = \left| K_n + K_p \right| \qquad K^{-} = \left| K_n - K_p \right|$$

Rotational bands are build on two-quasiparticle states

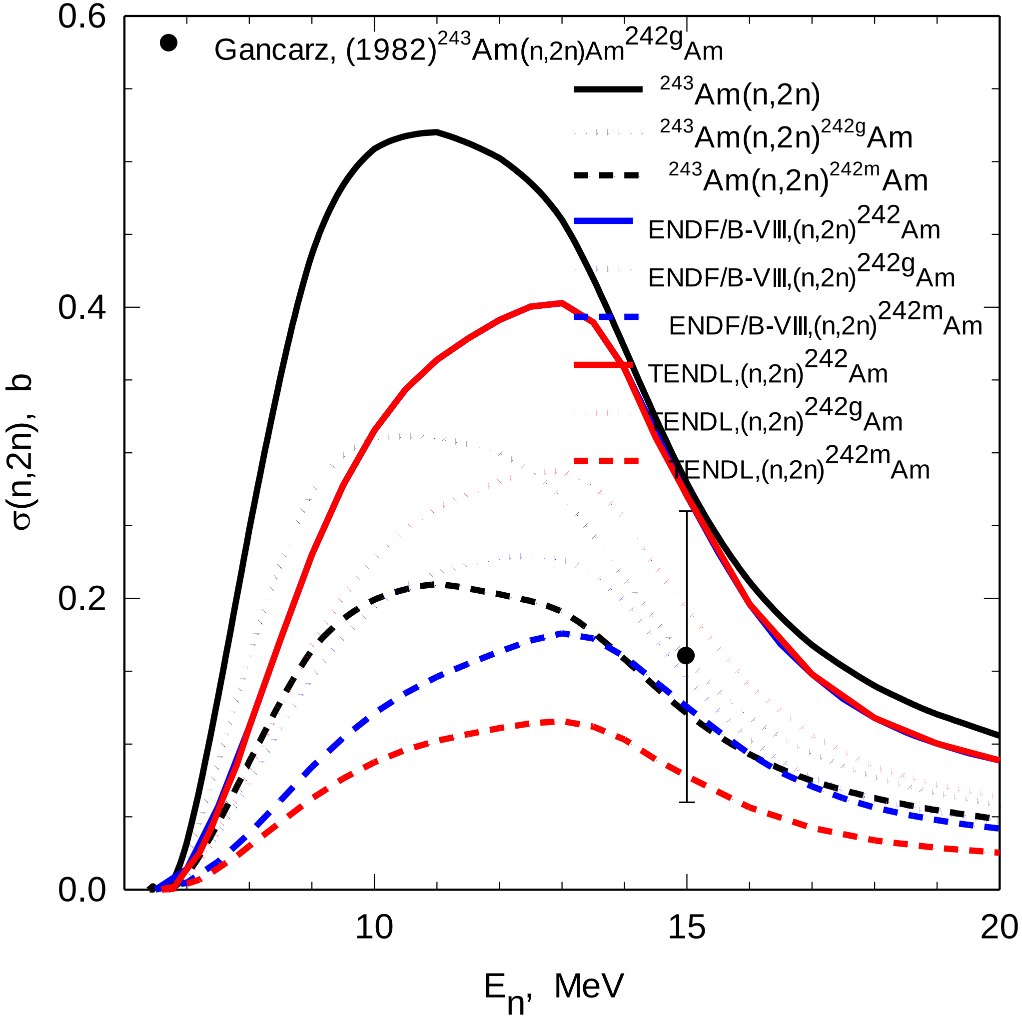
$$E_{JK\pi} = E_{JK} + 5.5\left[J(J+1) - K(K+1) \right]$$

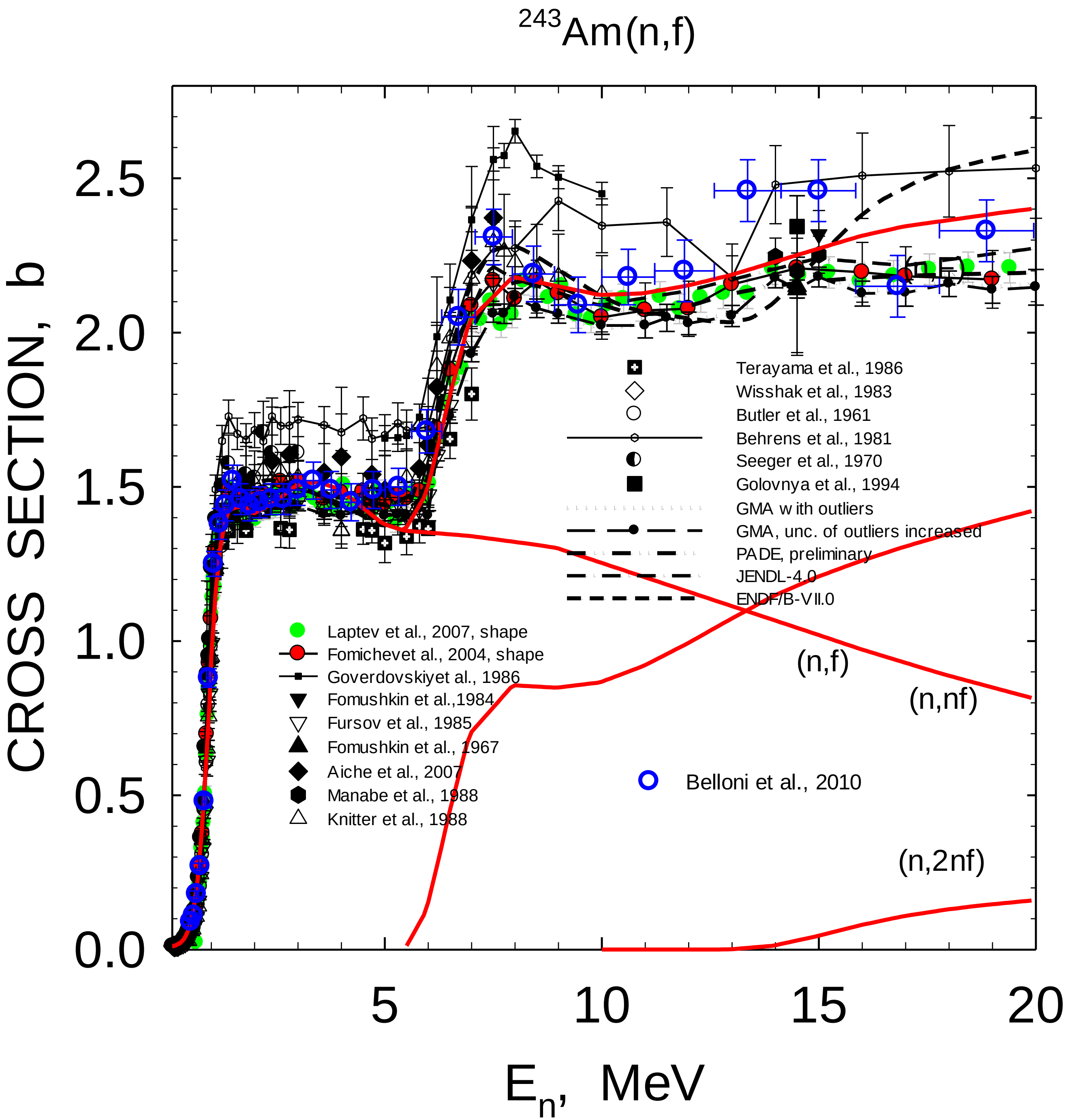
$$N(U) = e^{2\Delta_0 / T}\left(e^{U / T} - 1\right)$$

^{236l}Np/(^{236s}Np+^{236l}Np) ^{242m}Am/(^{242m}Am+^{242g}Am)

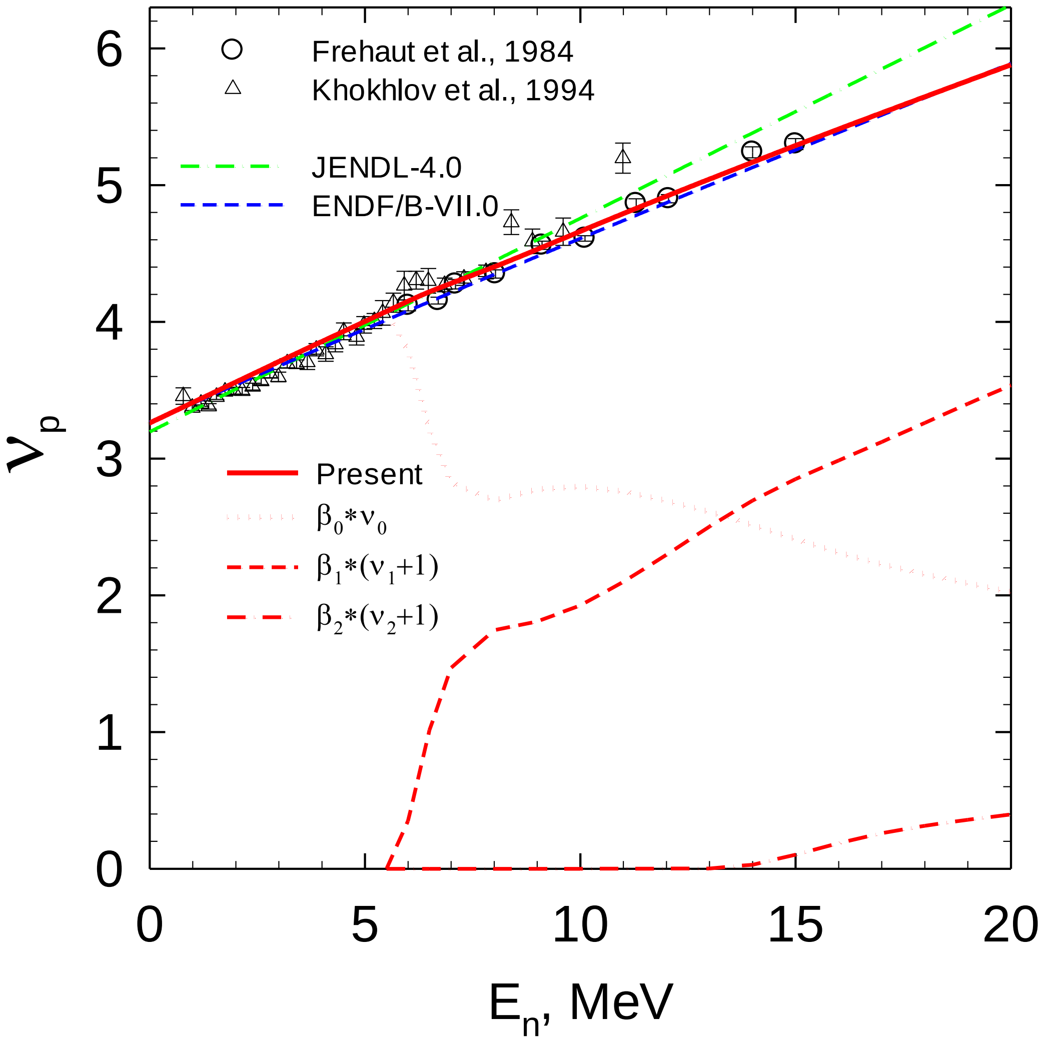


^{243}Am(n,2n) ^{243}Am(n,2n)^{242m}Am ^{243}Am(n,2n)^{242g}Am

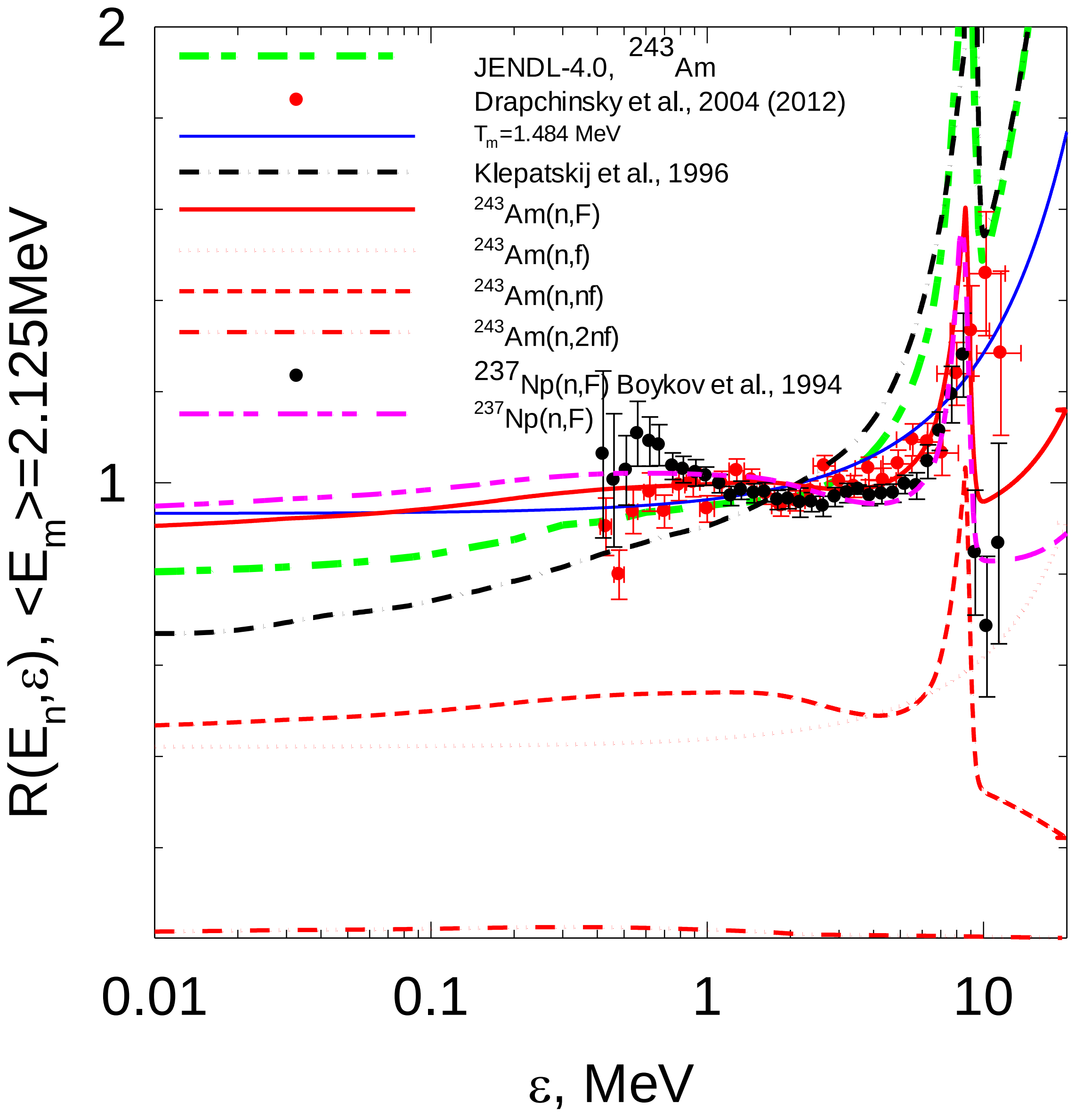



^{243}Am(n,f)
CROSS SECTION, b
0.0
0.5
1.0
1.5
2.0
2.5
5
10
15
20
E_n, MeV
Terayama et al., 1986
Wisshak et al., 1983
Butler et al., 1961
Behrens et al., 1981
Seeger et al., 1970
Golovnya et al., 1994
GMA w ith outliers
GMA, unc. of outliers increased
PADE, preliminary
JENDL-4.0
ENDF/B-VII.0
Laptev et al., 2007, shape
Fomichevet al., 2004, shape
Goverdovskiyet al., 1986
Fomushkin et al.,1984
Fursov et al., 1985
Fomushkin et al., 1967
Aiche et al., 2007
Manabe et al., 1988
Knitter et al., 1988
Belloni et al., 2010
(n,F)
(n,f)
(n,nf)
(n,2nf)

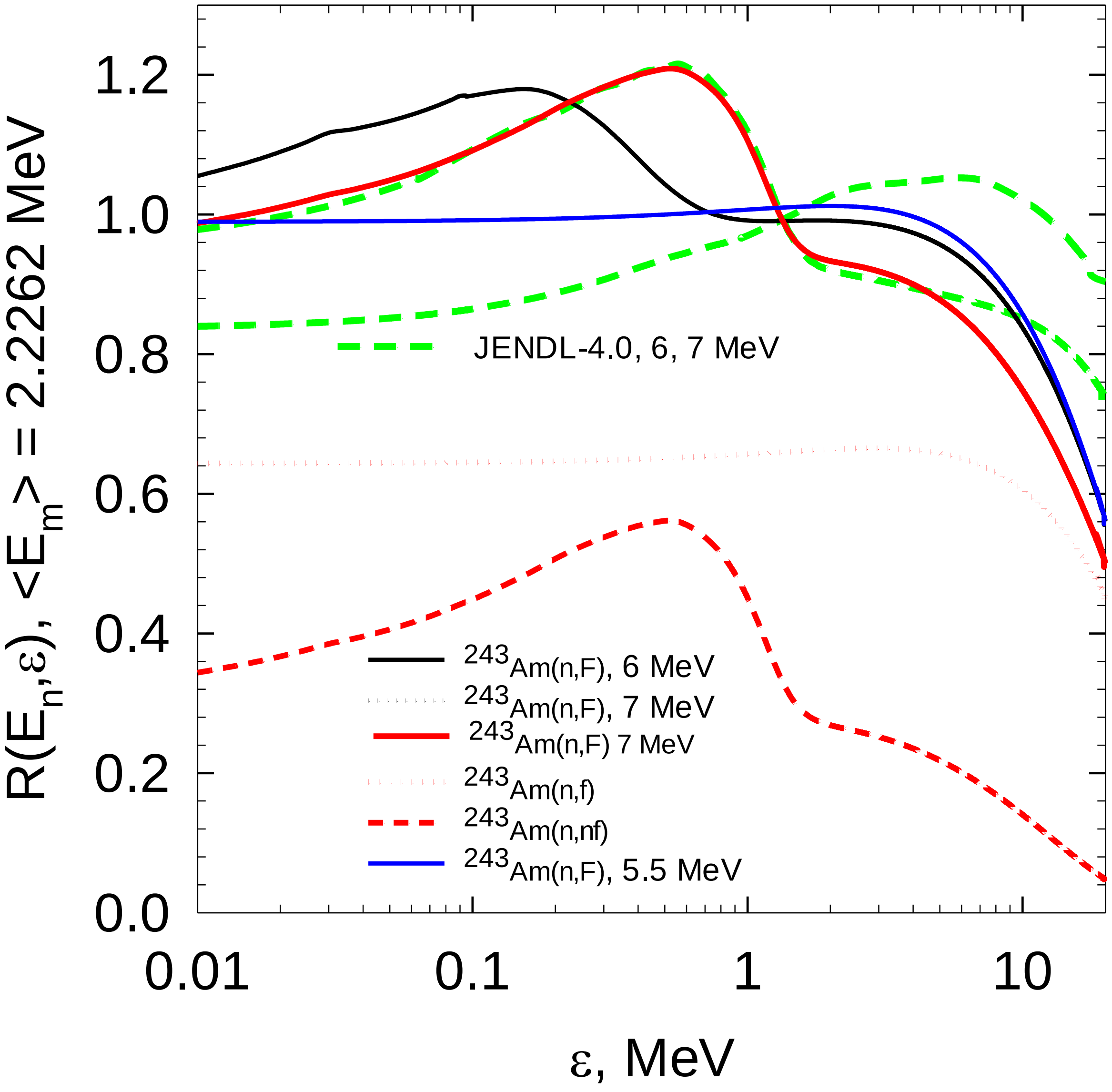
^{243}Am(n,F) PROMPT FISSION NEUTRON MULTIPLICITY



^{243}Am PFNS, E_n=15 MeV



^{243}Am(n,F) PFNS E_n = 6 MeV



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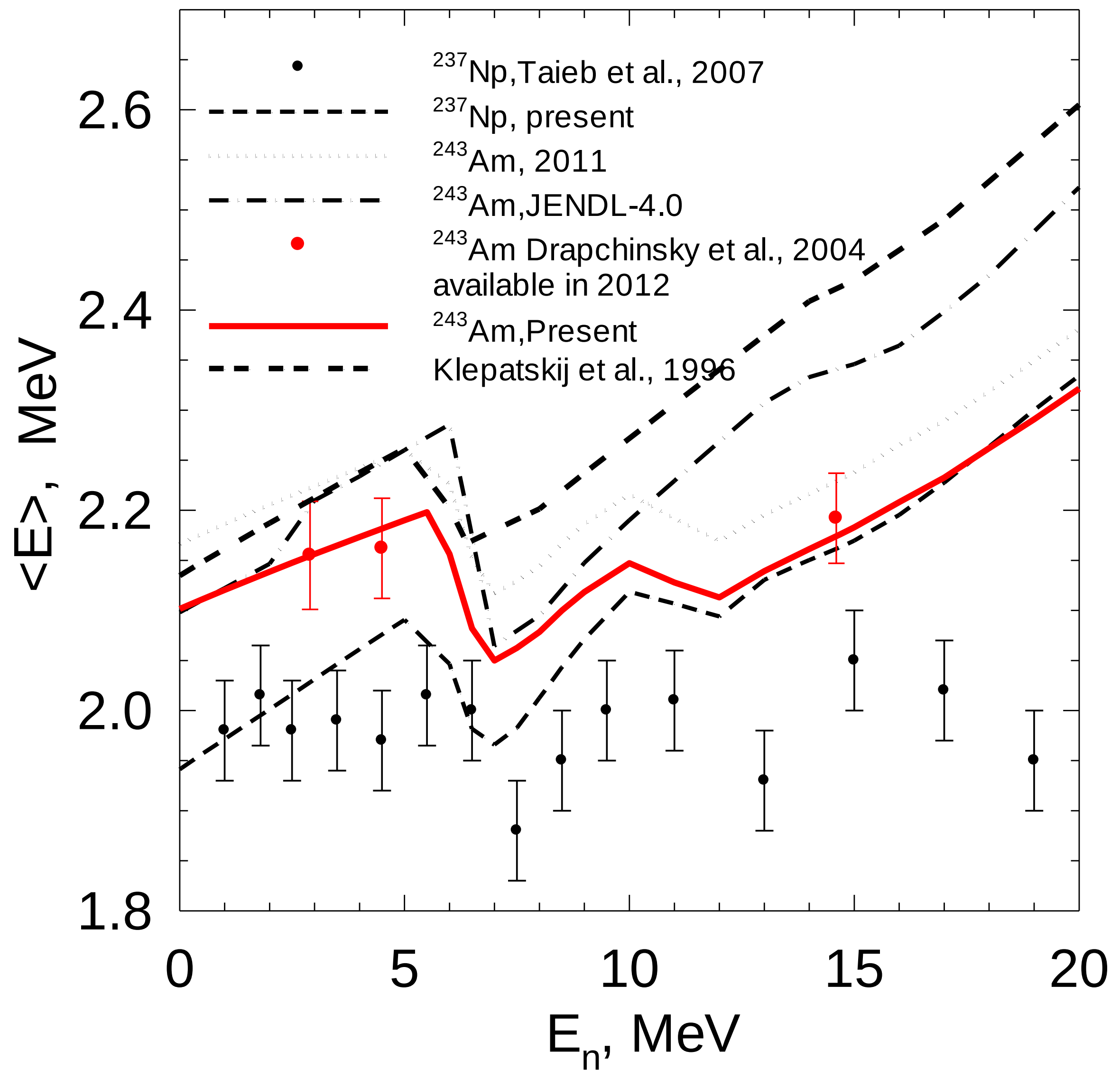
^{243}Am(n,F), <E> of PFNS



CONCLUSIONS

- Calculated yields of ^{242g}Am and isomer ^{242m}Am states of the residual ^{242}Am nuclide predict the branching ratio
- The branching ratio defined by the ratio of the populations of the lowest states. These populations defined by the γ-decay of the excited states, described by the standard kinetic equation. The absolute yield of ^{242g}Am is compatible with the measured data on ^{243}Am(n,2n)^{242g}Am, En=15 MeV by Norris et al., 1982.
- The ordering of the low and high spin states is different in case of ^{236}Np and ^{242}Am, that explains different shapes of $r(E_n)$ near the (n,2n) reaction threshold, excitation energy dependences are similar.
- ^{243}Am(n,F) PFNS data at 14.7 MeV by Drapchinsky (2004, released in 2012) support ^{243}Am(n,xnf) distribution and exclusive neutron spectra of ^{243}Am(n,2n) [1,2]