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To: Distribution
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Subject: **Compilation of nuclear resonance fluorescence (NRF) data**

Nuclear resonance fluorescence (NRF) is a process of excitation of a specific resonance in nucleus (so called scissor dipole mode in deformed nuclei) by photon and having that state decay by prompt emission of gamma-ray to the ground or excited states.

First time such resonances in the actinide nuclei (^{238}U and ^{232}Th) were experimentally observed at excitation energies around 2 MeV by R.D. Heil and co-workers [1]. Due to small width and dependence of resonance energy on nucleus it was recently recognised that NFR could be used as a novel nondestructive method for detecting clandestine nuclear, toxic and explosive materials [2,3]. This stimulated a series of new measurements for actinides employing Bremsstrahlung (BRST) and Laser Compton back scattering (LCS) photon sources (see the survey of published experiments in Table below).

The energy integrated cross sections (some time denoted in publications as I_i), usually measured in experiment, is given by:

$$\sigma\left(E_x, E_i\right) = 2\left(\frac{\pi\hbar c}{E_x}\right)^2 g\,\frac{\Gamma_0\Gamma_i}{\Gamma_{\text{tot}}^2}, \text{where statisctical factor } g = \frac{2J_i+1}{2(2J_0+1)}$$

J_0 and J_i - spins of the ground and excited states,
Γ_0 and Γ_i: - gamma decay widths ground and excited states and Γ_{tot} is a sum of all them,
E_x = resonance (incident gamma) energy,
$E_\gamma = E_x - E_i$ – energy of decay gamma leading to the population of the *i*-th excited state.

The quantities reported by these experiments are (1) the energy integrated cross section (in units b-eV) corresponding to the emission of photon with energy E_γ and feeding the *i*-th excited state and/or (2) deduced from integrated cross sections the transition width $\Gamma_0\Gamma_i/\Gamma_{\text{tot}}$ or Γ_0 (in units meV):

$$\sigma\left(E_x, E_i\right) = 2\left(\frac{\pi\hbar c}{E_\gamma}\right)^2 g\,\frac{\Gamma_0\Gamma_i}{\Gamma_{\text{tot}}} \qquad (1)$$

$$\frac{\Gamma_0\Gamma_i}{\Gamma_{\text{tot}}} \text{ or } \Gamma_0 \qquad (2)$$

These quantities can be coded by REACTION codes in accordance with the current coding rule, e.g. for ^{235}U:

`(92-U-235(G,SCT),PAR,ARE)` or `92-U-235(G,EL),,ARE)` for (1)

`((92-U-235(G,EL),,WID)*(92-U-235(G,INL),PAR,WID))/`
`(92-U-235(G,TOT),,WID))` or `(92-U-235(G,EL),,WID)` for (2)

The incident photon energy should be coded as the end-point photon energy EN-RES-MAX (in the case of Bremsstrahlung source) or as resonance energy EN-RES (in the case of Laser Compton scattering source) and detected de-excitation (transition) photon energy under E.

The articles reporting these quantities are identified by NDS and summarized in the table.

References

1. R.D. Heil, H.H. Pitz, U.E.P. Berg et al., Observation of orbital magnetic dipole strength in the actinide nuclei 232Th and 238U, Nucl. Phys. **A476** (1988) 39
2. W. Bertozzi S.E. Korbly et al., Nucl. Instrum. and Meth. B **61** (2007) 33
3. T. Hayakawa et al., Nucl. Instrum. Meth. A**621** (2010) 695

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Experimental nuclear resonance fluorescence data for actinide

(Compilation of G0027 and G0028 is completed after approval of the new modifier code NG)

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Targ.	Proj.	γ-source	Eres,min (MeV)	Eres,max (MeV)	Lab.	Author	Publication	Vol	Page	Year	Source	Entry/Centre	Remarks
U238	g	BRST	2.043	2.468	2GERIFS	R.D. Heil+	J,NP/A	476	39	1988	Table	G0028.005-007	In EXFOR
U236	g	BRST	1.791	3.143	2GERIFS	J. Margraf+	J,PR/C	42	771	1990	Table	G0027.002-004	In EXFOR
U235	g	BRST	1.782	1.846	2GERIFS	A. Zilges+	J,PR/C	52	468	1995	Table	G0026.002-004	In EXFOR
U235	g	BRST	1.687	1.862	2GERTHD	O. Yevetska+	J,PR/C	81	044309	2010	Table	G0024.002-003	In EXFOR
U235	g	BRST	1.656	2.006	1USAMIT	W. Bertozzi+	J,PR/C	78	041601	2008	Table	L0139.002	In EXFOR
Pu239	g	BRST	2.040	2.471	1USAMIT	W. Bertozzi+	J,PR/C	78	041601	2008	Table	L0139.003	In EXFOR
Mn55	g	BRST	1.884		1USAMIT	W. Bertozzi+	J,PR/C	78	041601	2008	Table	L0139.004	In EXFOR
Np237	g	BRST	1.698	2.506	1USAMIT	C.T. Angell+	J,PR/C	82	054310	2010	Table	L0155.002	In EXFOR
Th232	g	LCS	2.044	4.002	1USATNL	A.S. Adekola+	J,PR/C	83	034615	2011	Table	L0159.002	In EXFOR
U235	g	LCS	1.656	2.755	1USATNL	E. Kwan+	J,PR/C	83	041601	2011	Table	L0161.002-004	PRELIM.L016