Activation Cross-Sections for Short-Lived Reaction Products on Hafnium Isotopes Induced by 1 – 20 MeV Neutrons

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Content

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- Experimental procedure
- Comparison of the present results with the EXFOR data base and TENDL-2017
- Conclusions

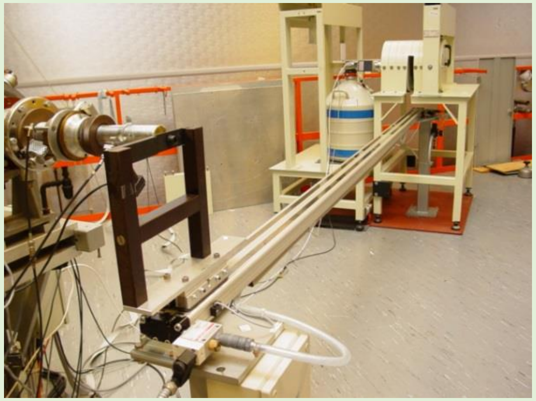
Aim and scope of this work

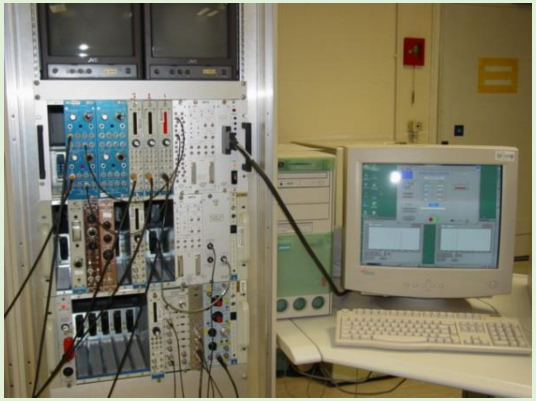
- Nuclear data for applications
  - Nuclear reactors.
  - Fusion technology. Hafnium is alloying element of the low activation materials that are under development for use in ITER and DEMO reactors.
- Data for nuclear models' development. The elemental hafnium is a mixture of add and even isotopes. All are highly deformed collective rotors with complex exited structure.
- The experimental data for the neutron-induced cross sections on studied reactions are scarce.

Experimental procedure - I

- Neutron source: 7 MV Van de Graaff accelerator at JRC-Geel
  - $^{3}H(p,n)^{3}He$ reaction at E_p = 2.2, 2.8, 3.8 and solid-state Ti/T target for production of neutrons in 1.3 – 3.0 MeV energy range
  - $^{2}H(d,n)^{3}He$ reaction at E_d = 2.5, 3.3 and D_2 gas target for production of neutrons in 5.0 – 6.0 MeV energy range
  - $^{3}H(d,n)^{4}He$ reaction at E_d = 1, 2, 3 and solid-state Ti/T target for production of quasi-monoenergetic neutrons in 13.3 - 20 MeV energy range
- Irradiation geometry: pneumatic transport system

  Time for the sample transfer from the irradiation to the gamma-ray measurement position: 3.5 s.





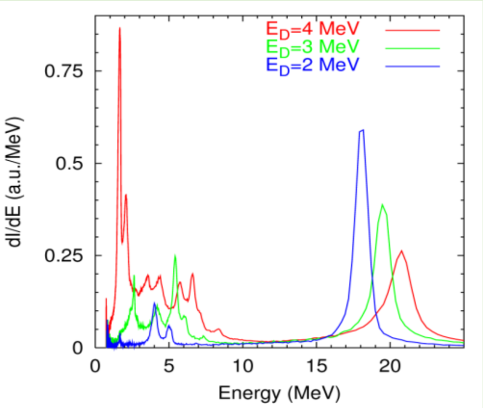
Samples

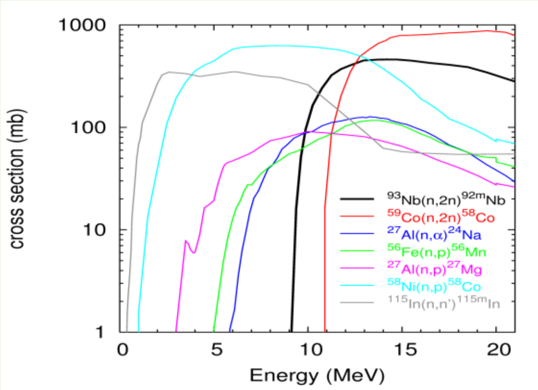
72	173Hf 23.6 H ε: 100.00%	174Hf 2.0E+15 Y 0.16% α: 100.00%	175Hf 70 D ε: 100.00%	176Hf STABLE 5.26%	177Hf STABLE 18.60%	178Hf STABLE 27.28%	179Hf STABLE 13.62%	180Hf STABLE 35.08%	181Hf 42.39 D β-: 100.00%

	Natural	$^{178}HfO_2$	$^{179}HfO_2$
^{174}Hf	0.16(1)	<0.05	<0.05
^{176}Hf	5.26(7)	0.8	0.2
^{177}Hf	18.60(9)	1.9	1.3
^{178}Hf	27.28(7)	92.4	4.1
^{179}Hf	13.62(2)	3.3	72.1
^{180}Hf	35.08(16)	1.6	22.3

Experimental procedure - II

- Neutron spectrum unfolding: Mean neutron energy and energy distribution for the irradiation geometry were determined by EnergySet program, spectrum unfolding by time-of-flight measurements in combination with threshold activation unfolding procedure were used in order to determine contribution of the low energy neutrons.

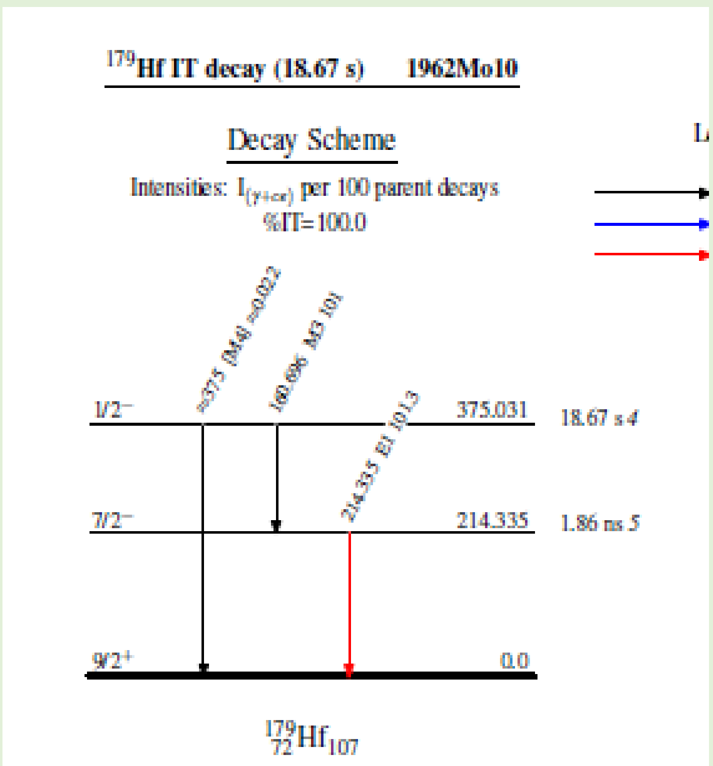


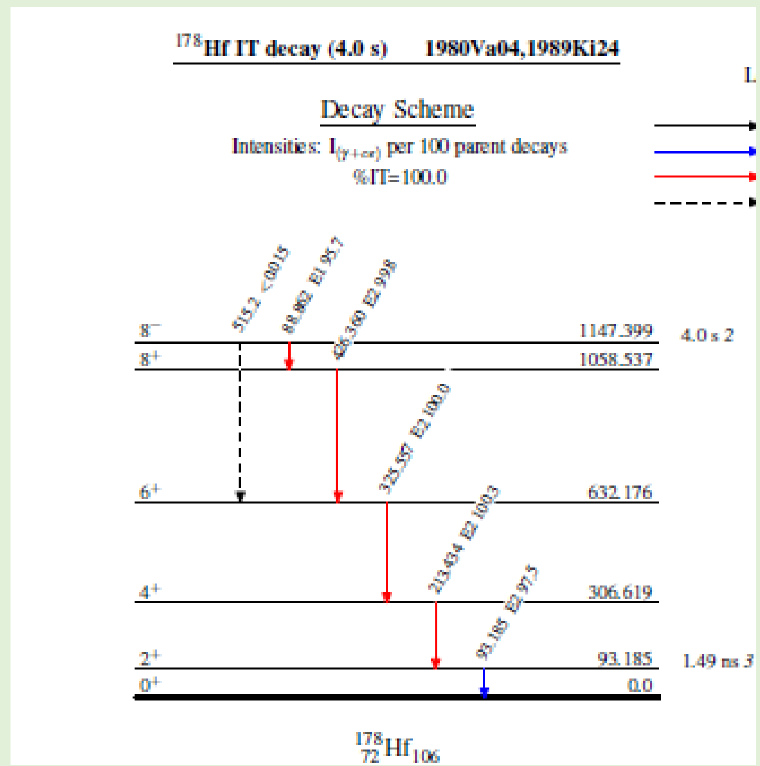


- The radioactivity of the reaction products was determined by γ-ray spectrometry using HPGe detector.
- The neutron fluence rate was determined by the $^{27}Al(n,\alpha)^{24}Na$ standard cross section. A BF_3 neutron counter used for the normalization of the neutron fluence rate during the sort-lived reaction cross section measurements.
- Corrections were applied for the neutron source intensity variation during irradiation, low energy neutrons, coincidence summing effects, gamma-ray self-attenuation, interference between reactions leading to the same reaction product.

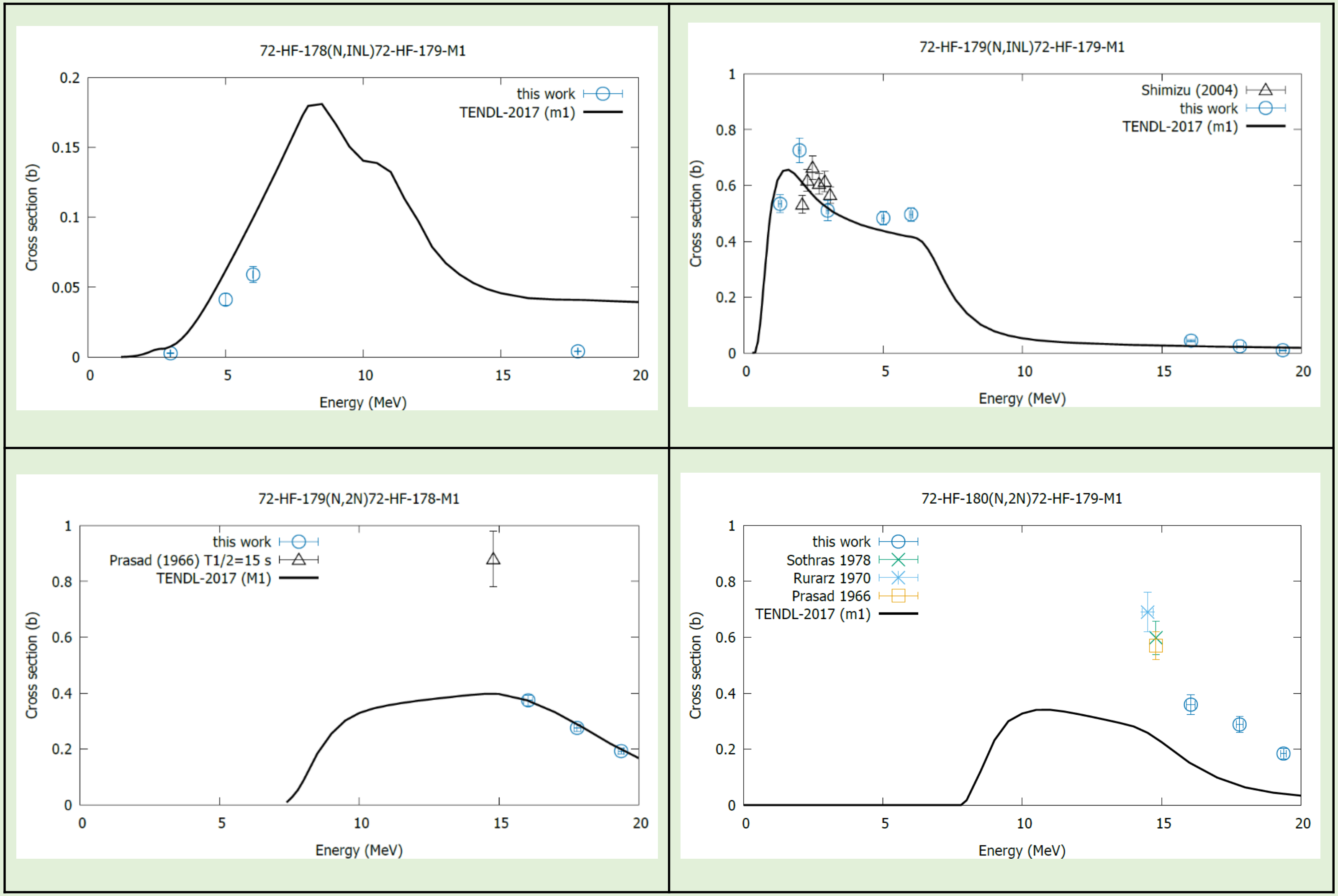
Decay data

Isotope	E(level) (MeV)	Jπ	Δ(MeV)	$T_{1/2}$	Abundance	Decay Modes
^{178}Hf	**0.0**	**0+**	**-52.4443**	**STABLE**	**27.28% *7***	
	1.1474	**8-**	**-51.2968**	**4.0 s *2***		**IT : 100 %**
	2.4461	**16+**	**-49.9982**	**31 y *1***		**IT : 100 %**
^{179}Hf	**0.0**	**9/2+**	**-50.4710**	**STABLE**	**13.62% *2***	
	0.3750	**1/2-**	**-50.0960**	**18.67 s *4***		**IT : 100 %**
	1.1058	**25/2-**	**-49.3652**	**25.05 d**		**IT : 100 %**
^{180}Hf	**0.0**	**0+**	**-49.7884**	**STABLE**	**35.08% *16***	
	1.1415	**8-**	**-48.6469**	**5.47 h *4***		**IT: 99.70%, b-: 0.30%**





Results


72-HF-178(N,INL)72-HF-179-M1
this work
TENDL-2017 (m1)
Cross section (b)
Energy (MeV)
72-HF-179(N,INL)72-HF-179-M1
Shimizu (2004)
this work
TENDL-2017 (m1)
Cross section (b)
Energy (MeV)
72-HF-179(N,2N)72-HF-178-M1
this work
Prasad (1966) T1/2=15 s
TENDL-2017 (M1)
Cross section (b)
Energy (MeV)
72-HF-180(N,2N)72-HF-179-M1
this work
Sothras 1978
Rurarz 1970
Prasad 1966
TENDL-2017 (m1)
Cross section (b)
Energy (MeV)

Conclusions

New measurements are being carried out for the following reactions:

$^{178}Hf(n,n'g)^{178}Hf^{m1}$, $^{179}Hf(n,n'g)^{179}Hf^{m1}$,

$^{179}Hf(n,2n)\ ^{178}Hf^{m1}$, $^{180}Hf(n,2n)\ ^{179}Hf^{m1}$

The new experimental data improve the knowledge of the excitation functions of the investigated reactions and one of the studied reactions was measured for the first time.