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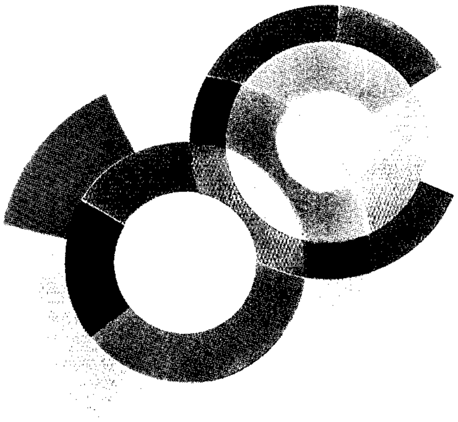

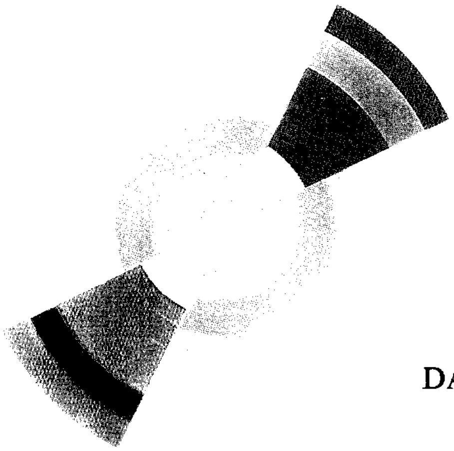

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MEASUREMENT OF THE NEUTRON TOTAL CROSS SECTION OF ^{99}Tc IN THE ENERGY RANGE FROM 3 TO 600 eV

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Abstract

Within the framework of a collaboration between the Institute for Reference Materials and Measurements (IRMM) and the Commissariat à l'Energie Atomique (CEA), a project has been started to measure neutron cross sections for nuclear waste transmutation purposes. We describe the measurements of the total neutron cross section of ^{99}Tc, performed at the pulsed white neutron source GELINA of the IRMM. We used the time-of-flight method to obtain neutron spectra in the energy range from 3 to 600 eV. Preliminary results of 69 resonance parameters derived with the resonance shape fitting program REFIT are presented here.

1 Introduction

The lack of reliable and sufficient data on neutron cross sections of long-living fission products and minor actinides is a major problem in the design of nuclear waste transmutation systems. Therefore in the past few years a renewed interest in neutron cross section measurements has arisen. One of the possible candidates for transmutation is ^{99}Tc. Several measurements of its resonance parameters have been performed in the past, see for example ref. [1, 2] and for a more complete evaluation ref. [3], but a demand for more precise parameters exists [4]. The resonance parameters of the $9/2^+$ nucleus ^{99}Tc may also contribute to the investigation of the neutron strength function in the mass $A = 100$ region, of interest for the development of nuclear models. Finally, a more detailed knowledge of the cross section of ^{99}Tc is also an important factor for nucleosynthesis models in astrophysics [5, 6].

2 Experimental Setup

The total cross section measurements of ^{99}Tc were performed at the pulsed neutron facility of the Geel Linear Electron Accelerator GELINA using the time-of-flight technique. Three ^{99}Tc samples with thicknesses of 0.16, 0.44 and 4.0 g/cm^2 have have been used for the transmission measurements. For the two smallest samples, the experiment was set up to cover the energy range from 3 to 600 eV, with the Geel linac operating to provide electron bursts of 100 MeV average energy and 15 ns width at a repetition frequency of 200 Hz and an average beam current of 20 μA. For the thickest sample, intended for a measurement from 20 eV to 100 keV, the linac was functioning at 800 Hz with an average beam current of 60 μA and a pulse width of 2 ns.

The neutrons produced via Bremsstrahlung by the electron beam hitting a rotating uranium target were moderated by two slabs of 4 cm thick water canned in beryllium. The partially moderated neutrons were collimated into the flight paths through evacuated aluminum pipes of 50 cm diameter with collimators consisting of either borated wax or copper. In order to absorb slow neutrons that otherwise overlap with the next machine cycle, a filter containing ^{10}B was placed in the neutron beam.

At a distance of 23 m from the neutron source the ^{99}Tc sample was placed in a automatic sample changer, also containing isotopes with large resonances filtering the neutron flux at specific energies in order to determine the background. The sample changer was driven by the data acquisition system, allowing to store data with the sample in and out of the beam as well as background measurements. In order to diminish systematic errors these measurement sequences were recorded alternatively within a cycle of four sequences lasting about one hour in total. The neutrons passing through the sample were further collimated and detected by a NE912 lithium-glass detector placed at a distance of 49.33 m. The timing signals of the photomultiplier, detecting the scintillation of the glass due to the ^{6}Li(n,α) reaction, were electronically processed and converted to a neutron time-of-flight and then stored by the data acquisition system for further analysis.

3 Analysis and Results

Data have been recorded during 70, 150 and 450 hours of effective beam time for the samples of 0.16, 0.44 and 4.0 g/cm^2 thickness respectively. The background on the time-of-flight spectra was estimated by means of several "black" resonances and subtracted from the spectra corresponding to the sample in and out of the beam respectively. The transmission factor was derived as the ratio of these spectra, normalized by the ratio of the number of incoming neutrons. The in-house developed data processing package AGS [7] was used to apply the various spectrum manipulations as dead time correction and background fitting on the recorded histograms in order to obtain the transmission factor together with the components allowing to construct the full covariance matrix.

The neutron resonance shape fitting program REFIT [8] was used in order to fit the resonance parameters E_0, the resonance energy, the radiative width Γ_γ and the neutron width Γ_n. Since the resonance spins are not known, in the table we rather give the statistical spin factor g multiplied by the neutron width Γ_n. The used spin values are also given assuming the orbital momentum $l = 0$. The energy scale was calibrated

Table 1: Preliminary parameters of 69 resonances of ^{99}Tc. The errors are only the standard deviations from the fit. For small resonances Γ_γ has been fixed at 200 meV.

E_0 (eV)		J	Γ_γ (meV)	error %	$g\Gamma_n$ (meV)	error %	$g\Gamma_n\Gamma_\gamma/\Gamma$ (meV)
5.584	±0.001	⟨5⟩	149.2	0.5	1.864	0.4	1.823
*14.596	±0.027	⟨4⟩	200.0		0.0035	12.9	0.004
20.274	±0.000	⟨4⟩	150.3	0.6	3.795	0.4	3.594
*22.371	±0.029	⟨4⟩	200.0		0.0052	9.8	0.005
39.841	±0.001	⟨5⟩	136.9	1.2	0.580	0.4	0.575
56.677	±0.001	⟨4⟩	154.6	1.0	1.703	0.4	1.662
*58.709	±0.038	⟨4⟩	200.0		0.010	11.3	0.010
61.430	±0.012	⟨5⟩	200.0		0.035	3.3	0.035
67.651	±0.010	⟨4⟩	200.0		0.045	2.9	0.045
80.951	±0.012	⟨5⟩	200.0		0.059	2.9	0.059
81.721	±0.012	⟨4⟩	200.0		0.055	3.1	0.055
*102.832	±0.059	⟨4⟩	200.0		0.020	12.3	0.020
*109.153	±0.042	⟨4⟩	200.0		0.031	7.8	0.031
111.218	±0.001	⟨5⟩	150.2	1.2	5.348	0.4	5.023
*114.204	±0.031	⟨5⟩	200.0		0.038	6.9	0.038
123.775	±0.001	⟨4⟩	170.2	1.5	1.829	0.3	1.787
148.336	±0.045	⟨5⟩	200.0		0.040	9.1	0.040
*161.289	±0.053	⟨5⟩	200.0		0.062	10.4	0.062
163.017	±0.001	⟨5⟩	143.0	1.3	32.401	0.5	22.947
173.126	±0.032	⟨4⟩	200.0		0.072	6.3	0.072
*177.461	±0.048	⟨4⟩	200.0		0.036	11.2	0.036
182.087	±0.001	⟨5⟩	183.7	1.0	29.563	0.5	22.871
191.721	±0.001	⟨4⟩	148.7	1.4	20.070	0.5	15.439
196.330	±0.023	⟨5⟩	200.0		0.145	4.0	0.145
206.406	±0.010	⟨4⟩	200.0		0.321	1.9	0.320
209.941	±0.014	⟨5⟩	200.0		0.229	2.7	0.228
214.834	±0.007	⟨4⟩	200.0		0.546	1.2	0.543
220.604	±0.013	⟨5⟩	200.0		0.275	2.4	0.274
225.982	±0.032	⟨5⟩	200.0		0.128	5.4	0.128
241.212	±0.001	⟨4⟩	208.5	1.4	15.768	0.4	13.499
261.630	±0.044	⟨5⟩	200.0		0.120	6.8	0.120
273.144	±0.018	⟨4⟩	200.0		0.354	2.7	0.352
279.979	±0.001	⟨5⟩	210.0	1.9	6.694	0.3	6.327
299.984	±0.001	⟨4⟩	217.0	1.5	15.660	0.3	13.496
*305.039	±0.026	⟨4⟩	200.0		0.294	4.3	0.293
306.811	±0.002	⟨5⟩	200.0		7.810	0.3	7.292
317.689	±0.021	⟨4⟩	200.0		0.365	3.2	0.364
324.609	±0.026	⟨5⟩	200.0		0.271	4.8	0.270
333.138	±0.048	⟨4⟩	200.0		0.162	6.6	0.162
343.209	±0.013	⟨5⟩	200.0		0.867	1.7	0.860
350.129	±0.029	⟨5⟩	200.0		0.425	3.7	0.423
*356.032	±0.052	⟨4⟩	200.0		0.211	6.6	0.210
358.651	±0.002	⟨4⟩	191.5	2.9	8.528	0.3	7.760
*362.158	±0.018	⟨4⟩	200.0		0.628	2.8	0.624
364.940	±0.001	⟨5⟩	282.1	1.7	66.275	0.6	46.439
379.856	±0.002	⟨4⟩	235.4	2.2	11.462	0.3	10.342
386.086	±0.032	⟨5⟩	200.0		0.385	4.4	0.383
398.104	±0.118	⟨4⟩	200.0		0.176	9.5	0.176
*402.710	±0.108	⟨5⟩	200.0		0.144	12.5	0.144
*412.916	±0.033	⟨5⟩	200.0		0.417	5.0	0.415
416.817	±0.001	⟨5⟩	242.8	1.4	26.912	0.4	22.398
426.552	±0.001	⟨4⟩	210.5	2.0	31.739	0.5	23.773
439.710	±0.107	⟨5⟩	200.0		0.150	14.7	0.150
447.713	±0.008	⟨5⟩	200.0		1.211	1.9	1.198
459.917	±0.002	⟨4⟩	226.5	2.2	18.144	0.3	15.402
465.465	±0.035	⟨5⟩	200.0		0.543	4.3	0.541
478.789	±0.005	⟨4⟩	266.4	4.9	5.904	0.7	5.627
486.585	±0.008	⟨5⟩	200.0		2.900	1.0	2.826
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E_0 (eV)		J	Γ_γ (meV)	error %	$g\Gamma_n$ (meV)	error %	$g\Gamma_n\Gamma_\gamma/\Gamma$ (meV)
...							
507.616	±0.087	⟨4⟩	200.0		0.270	9.8	0.269
516.443	±0.005	⟨5⟩	253.1	6.0	5.946	0.8	5.702
520.570	±0.002	⟨4⟩	249.7	2.7	16.187	0.4	14.148
527.397	±0.035	⟨5⟩	200.0		0.814	3.7	0.808
536.615	±0.003	⟨4⟩	287.8	2.7	13.869	0.4	12.527
563.237	±0.007	⟨5⟩	200.0		4.414	0.8	4.243
*567.037	±0.050	⟨5⟩	200.0		0.697	5.0	0.692
*588.720	±0.117	⟨5⟩	200.0		0.276	12.1	0.275
593.729	±0.013	⟨4⟩	200.0		2.629	1.4	2.555
598.261	±0.003	⟨5⟩	458.9	2.1	16.489	0.4	15.478
606.769	±0.003	⟨4⟩	263.5	3.2	16.929	0.4	14.814

using the well studied resonances of ^{238}U. The time resolution of the spectrometer was represented by an optimized resolution function for the used fligth path.

We used the input data only with their uncorrelated uncertainties in accordance with the possibilities of REFIT. The errors on the resonance parameters are the standard deviations resulting from the fit. Correlated or "systematic" uncertainties are under study. Where possible, a simultaneous fit of the experimental data sets have been performed. A number of 15 new resonances, not given in the JEF2 evaluation, have been found and are indicated in the table with an asterisk.

A simultaneous fit of the data of this transmission experiment and the capture experiment [9] may improve the resonance parameters. Data have been taken up to 100 keV, both for capture and transmission. These data are currently under analysis.

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