Los Alamos
NATIONAL LABORATORY
memorandum
The Applied Theoretical Physics Division
XTM: Transport Methods Group

To/MS: Distribution
From/MS: A. A. Adams
Phone/FAX: 5-4925 / 5-5538
Symbol: XTM-RN(U)97-010
Date: April 4, 1997

SUBJECT: Assessment of Photon Production Data for Thermal Neutron Capture in Chromium Isotopes

I. Introduction

This purpose of this research note is to assess the modified photon production data at incident thermal neutron energies for the four stable isotopes of chromium. This work is motivated primarily by the Multispectral Logging Project[1-3] and the ACTI CRADA[4], each of which requires high-quality photon production data at thermal energies. For a more complete background on these projects and the motivation behind this work, see the research note XTM-RN(U)97-008.

Several sources of photon production data for chromium were considered for this research note; standard ENDF/B-VI[5], ENSDF[6], the preliminary data for the ACTI CRADA, and experimental papers. The Evaluated Nuclear Data File (ENDF/B-VI) photon production data for the chromium isotopes contain no discrete gamma-rays and does not meet the requirements of ACTI. Compilations such as Lone[7] were not considered since they contain only elemental information and were shown to be inferior to experimental papers in a similar analysis of chlorine (see XTM-RN(U)97-008). The preliminary ACTI library for the chromium isotopes was created by T-2 using the information contained in the Evaluated Nuclear Structure Data File (ENSDF). This library will be referred to as the "ACTI" library. This research note compares the ACTI library, the ENSDF data, and experimental papers to determine which source is best. The comparisons show that the original ENSDF data is equivalent to the best available experimental data. The ACTI data is *almost* identical to the ENSDF data, suggesting the method used to extract the thermal-neutron capture data from ENSDF can be improved.

The ENSDF spectra were obtained from Dr. Jagdish Tuli of the National Nuclear Data Center (NNDC). Dr. Tuli provided the thermal-neutron capture spectra (extracted from ENSDF) for all four stable isotopes of chromium. He was also kind enough to provide references for the spectra.

The ACTI spectra for ^{50}Cr, ^{52}Cr, and ^{53}Cr were obtained from links given by the "Nuclear Data for ACTI CRADA" web page (URL "http://t2.lanl.gov/acti/acti.html"). A spectrum for thermal-neutron capture in ^{54}Cr was not produced by T-2.

The experimental papers compared in this research note were obtained through a painstaking search process. First, searches employing many different series of keywords were performed using LANL's SciSearch. All available years (1977-1997) were repeatedly searched. Second, the "Recent References" sections of all volumes of Nuclear Data Sheets from the present back to 1966 were combed. Third, the Nuclear Science References (NSR) section of the National Nuclear Data Center's online data service was extensively searched. (A telnet link to this online data service can be found at the URL "http://www.nndc.bnl.gov/~burrows/nndconl.html"). Finally, the approximately 50 papers found were in turn searched for additional references. While many papers were found, very few contained appreciable amounts of data, and most were quite old (published before 1973), suggesting that the thermal-neutron capture data for the chromium isotopes could be improved.

The natural abundances, thermal-neutron radiative capture cross-sections (σ^{th}), contributions to the gamma-ray spectrum of natural chromium, and Q-values for thermal neutron capture are listed in Table 1 for the stable chromium isotopes. Each isotope will now be discussed in turn.

Table 1: The stable isotopes of chromium

Isotope	Natural Abundance (Atom Fraction)	σ^{th} (barns)	Contribution to Natural Spectrum (%)	Q-Value for Neutron Capture (keV)[a]
^{50}Cr	0.0435	15.80	22.34	9261.62
^{52}Cr	0.8379	0.80	21.79	7939.17
^{53}Cr	0.0950	18.00	55.59	9719.01
^{54}Cr	0.0236	0.36	0.28	6246.30

[a]Values taken from Audi [8].

II. ^{50}Cr

The search for experimental data resulted in seven papers containing thermal-neutron capture spectra for ^{50}Cr. Brief information for each data set is listed in Table 2, including the total gamma-ray yield observed per neutron capture, and the designation that will be used to refer to the paper. Note that only the most recent paper (Kop74) contains an appreciable amount of data, and most of the papers are quite old. Only Kop74 observed a reasonable fraction of the neutron separation energy for ^{51}Cr (9261.62 keV).

Table 2: Summary of experimental papers for ^{50}Cr

Author(s)	Designation	Year	Number of gamma-rays Observed	Total Yield Observed (keV)
J. Kopecky[9]	Kop74	1974	71	9235.77
G. Bartholomew et al.[10]	Bar66	1966	7	6959.35
D. Broder et al.[11]	Bro71	1971	17	8113.57
G. Loper and G. Thomas[12]	Lop72	1972	9	6165.90
J. Kopecky et al.[13]	Kop72	1972	10	6626.22
R. Knerr and H. Vonach[14]	Kne71	1971	4	6098.48
E. Rudak and E. Firsov[15]	Rud65	1965	19	8819.42

These data sets were compared, but the results were not very illuminating. With so few gamma-rays observed in the older data sets, there were very few “matching” lines to compare. For the few matches that could be made, there was either good agreement between all the sets or very little agreement. However, there were no gamma-rays for which the majority of the older sets agreed well with each other but disagreed substantially with Kop74. We therefore conclude that Kop74 is the best source of data.

A detailed comparison between Kop74, ACTI, and ENSDF revealed that the data from Kop74 is identical to the original ENSDF spectrum obtained from the NNDC. The ENSDF data thus represents the best available experimental data for ^{50}Cr. As will be shown later, this is also true for the other stable isotopes of chromium.

When the ACTI spectrum was compared to ENSDF or Kop74, differences were found. In most cases the differences were due to slight rounding in the ACTI spectrum, but for the 3764.4 keV line the ACTI intensity was much greater than the value measured by Kop74. Since the ACTI spectrum should be very similar to the ENSDF spectrum, this suggests there may be a problem with the method used to create the ACTI spectrum, or else this may be a simple typographical error.

The ACTI, Kop74 and ENSDF spectra are presented in Table 3, with the 3764.4 keV line **highlighted**. The intensities from Kop74 / ENSDF were normalized to the neutron separation energy for ^{51}Cr (see Table 1), and these normalized intensities are also included in Table 3. Note that the intensity given is per 100 neutron capture reactions. Based on the best currently available experimental data, this is the thermal-neutron photon production spectrum that should be used for ^{50}Cr.

Table 3: Comparison of thermal-neutron capture spectra for ^{50}Cr

ACTI Spectrum (ENSDF-based)		J. Kopecky 1974 and ENSDF		Intensity from ENSDF Normalized to Q-value of Audi[8]
E γ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
603.3	0.76	603.3	0.76	0.762
749.0	80.00	749.0	80.00	80.224
826.9	0.28	826.9	0.28	0.281
834.1	0.31	834.1	0.31	0.311
845.2	0.36	845.2	0.36	0.361
857.1	0.05	857.1	0.05	0.050
862.3	0.07	862.3	0.07	0.070
888.2	2.17	888.2	2.20	2.206
913.2	0.17	913.2	0.17	0.170
928.2	0.14	928.2	0.14	0.140
990.4	0.78	990.4	0.78	0.782
1002.1	0.15	1002.1	0.15	0.150
1106.5	0.14	1106.5	0.14	0.140
1124.0	1.28	1124.0	1.28	1.284
1149.4	4.50	1149.4	4.50	4.513
1353.5	0.16	1353.5	0.16	0.160
1537.2	1.90	1537.2	1.90	1.905
1808.8	0.17	1808.8	0.17	0.170
1899.3	12.30	1899.3	12.30	12.334
2001.1	2.10	2001.1	2.10	2.106
2013.3	0.80	2013.3	0.80	0.802
2052.9	0.09	2052.9	0.09	0.090
2080.1	0.30	2080.1	0.30	0.301
2113.4	1.10	2113.4	1.10	1.103
2141.3	0.35	2141.3	0.35	0.351
2159.0	0.07	2159.0	0.07	0.070
2279.2	0.28	2279.2	0.28	0.281
2348.9	2.30	2349.0	2.30	2.306
2376.7	5.40	2376.7	5.40	5.415
2579.1	0.07	2579.1	0.07	0.070
2598.9	0.09	2599.0	0.09	0.090
2890.9	0.19	2890.9	0.19	0.191
2990.0	1.00	2990.1	1.00	1.003
3017.3	1.10	3017.4	1.10	1.103
3021.3	1.50	3021.4	1.50	1.504

Table 3: Comparison of thermal-neutron capture spectra for ^{50}Cr

ACTI Spectrum (ENSDF-based)		J. Kopecky 1974 and ENSDF		Intensity from ENSDF Normalized to Q-value of Audi[8]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
3262.8	1.60	3262.9	1.60	1.604
3276.8	0.16	3276.9	0.16	0.160
3284.2	0.14	3284.3	0.14	0.140
3290.8	0.56	3290.9	0.56	0.562
3305.8	0.07	3305.9	0.07	0.070
3512.2	0.60	3512.3	0.60	0.602
3593.4	0.90	3593.5	0.90	0.903
3764.4	**10.24**	**3764.4**	**0.24**	**0.241**
3859.8	0.73	3860.0	0.73	0.732
3898.9	0.26	3898.9	0.26	0.261
4020.5	0.54	4020.7	0.54	0.542
4057.4	0.14	4057.6	0.14	0.140
4133.1	0.10	4133.1	0.10	0.100
4400.1	0.24	4400.1	0.24	0.241
4491.4	0.64	4491.7	0.64	0.642
4625.0	1.10	4625.2	1.10	1.103
4833.2	0.25	4833.4	0.25	0.251
4891.5	0.25	4891.7	0.25	0.251
4971.6	0.42	4971.9	0.42	0.421
5126.4	0.24	5126.4	0.24	0.241
5151.7	0.17	5151.7	0.17	0.170
5206.1	0.20	5206.4	0.20	0.201
5221.9	2.30	5222.3	2.30	2.306
5491.4	1.76	5490.6	1.76	1.765
5494.5	2.00	5494.6	2.00	2.006
5990.0	0.20	5990.0	0.20	0.201
6135.7	7.60	6136.3	7.60	7.621
6206.3	0.21	6206.7	0.21	0.211
6370.9	4.00	6372.0	4.00	4.011
6433.7	0.10	6434.1	0.10	0.100
6643.7	0.24	6643.7	0.24	0.241
6710.5	0.06	6710.5	0.06	0.060
7362.0	13.70	7363.2	13.70	13.738
8484.0	26.00	8485.0	26.00	26.073
8512.1	37.00	8513.0	37.00	37.104
Total Yield (keV)	9611.07	9235.76		9261.66

[a]Number of photons per 100 neutron captures.

III. ^{52}Cr

The search for thermal-neutron capture data for ^{52}Cr resulted in six experimental papers. As before, most of the papers were rather old, and very few gamma-rays were identified. A brief summary of each paper is given in Table 4.

Table 4: Summary of experimental papers for ^{52}Cr

Author(s)	Designation	Year	Number of gamma-rays Observed	Total Yield Observed (keV)
D. Broder et al.[11]	Bro71	1971	13	7624.89
G. Loper and G. Thomas[12]	Lop72	1972	6	8010.5
J. Kopecky et al.[13]	Kop72	1972	5	6300.43
R. Knerr and H. Vonach[14]	Kne71	1971	2	5011.96
E. Rudak and E. Firsov[15]	Rud65	1965	11	6382.84
J. Kopecky et al.[16]	Kop80	1980	6	6735.83

The neutron separation energy for ^{53}Cr given by Audi[8] is 7939.17 keV. The yield observed by Lop72 is closest to this value. However, the intensities listed in Lop72 are consistently higher than the intensities listed in all the other papers. If Lop72 is excluded, the yield observed by Bro71 is closest to the neutron separation energy of Audi. However, most of the lines observed by Bro71 were not seen by any other experimenter. If these unconfirmed lines are removed, the yield from Bro71 drops to 6400.638 keV. If both Lop72 and Bro71 are excluded, the yields of Kop80 and Rud65 are the closest to Audi's Q-value, suggesting they are better sources of data.

The spectra from each experiment are listed in Table 5. In Table 6 the ACTI spectrum and the ENSDF spectrum are compared. Also listed in Table 6 are the ENSDF intensities normalized to Audi's[8] Q-value. The ENSDF spectrum includes all values from Kop80 (the most recent experimental data). For the five lines in the ENSDF spectrum *not* taken directly from Kop80, it appears an averaging scheme was used. Since not all of the over thirty references quoted in the ENSDF evaluation were obtained for this comparison, it is unclear from Table 5 how some of these ENSDF values were obtained. However, the energies and intensities of all five of these lines are in good agreement with Rud65, which appears to be one of the better sources of data based on its observed yield. We therefore conclude that the ENSDF evaluation is in good agreement with the best available experimental data for ^{52}Cr.

Table 5: Comparison of thermal-neutron capture spectra for ^{52}Cr

Broder 1971		Loper & Thomas 1972		Rudak & Firsov		Kopecky 1980		Kopecky 1972		Knerr & Vonach 1971	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
559	12			560	16.5						
804	4.0										
1261	2.4										
1353	7.5										
1549	0.5										
				1750	1.0						
				2120	2.4						
2163	6.5										
		2320.9	20.7	2320	13.5						
				2680	4.2						
3300	16										
		3616.7	4.0	3600	4.0						
3673	4.1										
4244	5.5										
4306	5.5	4322.7	4.1	4330	5.0	4322.1	3.1	4323.6	2.7		
				4800	1.0						
						5231.6	0.4				
				5260	7.0	5269.0	5.6	5270.4	5.1		
5595	21	5618.4	18.8	5610	16.0	5618.2	14.4	5619.3	13.9		
7356	13	7375.0	12.8			7374.6	11.4	7375.4	10.4	7364	12
7931	50	7938.9	65.6	7930	52.0	7938.6	58.4	7939.6	55	7939	52

[a]Number of photons per 100 neutron captures.

Table 6: Comparison of ENSDF and ACTI spectra for thermal-neutron capture in ^{52}Cr

ENSDF		ACTI (ENSDF-based)		ENSDF Intensity Normalized to Audi's[8] Q-Value
Eγ (keV)	Iγ (Number / 100 Captures)	Eγ (keV)	Iγ (Number / 100 Captures)	Iγ (Number / 100 Captures)
564.03	16	564.0	16	17.01
2120.0	2.4	***	***	2.55
2320.9	15	2320.9	15	15.95
2670.8	4.2	2670.8	4.2	4.47
3616.6	3.6	3616.6	3.6	3.83
4322.13	3.1	4322.1	3.1	3.30
5231.6	0.4	***	***	0.43
5269.0	5.6	5269.0	5.6	5.95
5618.23	14.4	5618.2	14.4	15.31
7374.58	11.4	7374.6	11.4	12.12
7938.58	58.4	7938.6	58.4	62.09
Total Yield (keV)	7467.47	7395.66		7939.74

A comparison of the ACTI and ENSDF data (see Table 6) show that the ACTI spectrum is almost identical to the original ENSDF spectrum. However, two weak lines are missing from the ACTI spectrum; the 2120 keV and 5231.6 keV lines. The documentation on the ACTI CRADA web site does not indicate why these two lines were omitted.

IV. ^{53}Cr

Five sources of experimental data were obtained for ^{53}Cr. Brief summaries of each experimental source are listed in Table 7. The latest paper, Hof89,[17] clearly represents the best source of data. Hofmeyr's yield is by far the closest to Audi's[8] neutron separation energy of 9719.01 keV and he lists more than four times the number of lines of any other experimenter. The gamma-rays observed by at least two authors are listed in Table 8. For most matching gamma-rays there is good agreement with Hofmeyr.

Table 7: Summary of experimental papers for ^{53}Cr

Author(s)	Designation	Year	Number of gamma-rays Observed	Total Yield Observed (keV)
D. Broder et al.[11]	Bro71	1971	19	8702.44
G. Loper and G. Thomas[12]	Lop72	1972	14	7925.64
R. Knerr and H. Vonach[14]	Kne71	1971	4	6250.82
E. Rudak and E. Firsov[15]	Rud65	1965	19	8890.90
C. Hofmeyr[17]	Hof89	1989	89	9398.81

When the ENSDF data were compared to Hof89, the ENSDF spectrum was found to be identical except for the absence of one line (at 2614.77 keV) which Hof89 indicates may be from ^{208}Pb. Since Hof89 represents the best available experimental data for ^{53}Cr, this ENSDF data is once again of the highest possible quality.

The ACTI and ENSDF spectra are compared in Table 9. As with the other isotopes, the ENSDF intensities normalized to Audi's[8] Q-value are also given. Note that there are again small differences between the ACTI and ENSDF spectra. The ACTI spectrum is missing four weak lines listed in ENSDF and Hof89. Except for these omissions and occasional rounding, the two spectra are equivalent. The documentation on the ACTI CRADA web site does not indicate why these lines were omitted.

Table 8: Gamma-rays from thermal-neutron capture in ^{53}Cr observed by two or more authors

Hof89		Bro71		Lop72		Kne71		Rud65	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
834.87	78.60	835	73					840	79.0
1100.38	0.64	1100	1.9						
1784.69	9.91	1783	8.4					1770	7.2
1994.56	2.93							2000	3.0
2239.07	10.98	2239	7.8	2238.8	10.2			2230	10.0
2601.91	2.31	2603	1.0	2601.8	2.4			2590	2.7
3026.05	0.47							3000	0.3
3177.93	1.40							3170	1.5
3403.55	0.17							3410	1.0
3719.84	3.98	3720	3.3	3719.6	3.6			3720	3.5
4433.43	0.20							4430	1.0
4847.54	1.96	4846	1.2	4846.8	1.5				
4872.27	1.06	4873	0.5	4872.3	0.7			4860	1.6
5707.09	1.35	5706	0.9	5705.8	1.3				
5858.98	1.21	5860	1.0	5857.9	1.1			5800	2.5
5999.95	4.79	5997	3.4	5998.8	4.3	6002	1.8	6000	4.0
6283.02	2.03	6287	1.3	6281.6	1.8			6290	3.3
6326.41	1.19	6322	1.0						
6645.64	10.29	6642	7.1	6644.8	9.5	6646	9	6640	9.0
6890.16	2.35	6886	1.6	6889.1	2.0			6890	2.0
7100.11	8.20	7101	5.9	7098.9	7.8			7110	7.5
8884.81	44.00	8884	44	8883.3	46.2	8884	46	8880	46.0
9719.79	14.65	9717	22	9717.7	15.0	9720	15	9720	15.0

[a]Number of photons per 100 neutron captures.

Table 9: Comparison of ENSDF and ACTI spectra for thermal-neutron capture in ^{53}Cr

ACTI		ENSDF		ENSDF Normalized to Audi's[8] Q-Value
Energy (keV)	Iγ [a]	Energy (keV)	Iγ [a]	Iγ [a]
205.6	0.05	205.62	0.05	0.052
745.4	0.06	745.37	0.06	0.062
789.2	0.07	789.22	0.07	0.072
817.2	0.07	817.20	0.07	0.072
834.9	79.00	834.87	78.60	81.278
845.6	0.17	845.57	0.17	0.176
847.9	0.08	847.90	0.08	0.083
890.4	0.43	890.41	0.43	0.445
944.6	0.03	944.57	0.03	0.031
946.8	0.05	946.80	0.05	0.052
989.1	0.76	989.08	0.76	0.786
1100.4	0.64	1100.38	0.64	0.662
1106.4	0.02	1106.38	0.02	0.021
1205.3	0.05	1205.33	0.05	0.052
1241.4	0.78	1241.36	0.78	0.807
***	***	1335.26	0.06	0.062
1340.8	0.12	1340.81	0.12	0.124
1435.5	0.23	1435.49	0.23	0.238
***	***	1460.10	0.04	0.041
1463.3	0.07	1463.33	0.07	0.072
1503.6	0.06	1503.62	0.06	0.062
1508.6	0.06	1508.24	0.06	0.062
1597.7	0.03	1597.72	0.03	0.031
1619.2	0.09	1619.17	0.09	0.093
1784.7	9.91	1784.69	9.91	10.248
1798.2	0.25	1798.22	0.25	0.259
1804.0	0.24	1804.00	0.24	0.248
1831.3	0.04	1831.34	0.03	0.031
1994.6	2.93	1994.56	2.93	3.030
2067.0	0.04	2066.99	0.04	0.041

Table 9: Comparison of ENSDF and ACTI spectra for thermal-neutron capture in ^{53}Cr

ACTI		ENSDF		ENSDF Normalized to Audi's[8] Q-Value
Energy (keV)	Iγ[a]	Energy (keV)	Iγ[a]	Iγ[a]
2101.4	0.10	2101.43	0.10	0.103
2233.1	0.07	2233.09	0.07	0.072
2239.1	11.00	2239.07	10.98	11.354
2259.2	0.21	2259.22	0.21	0.217
2393.7	0.10	2393.70	0.10	0.103
***	***	2464.23	0.09	0.093
2558.5	1.15	2558.45	1.15	1.189
2601.9	2.31	2601.91	2.31	2.389
***	***	2619.57	0.42	0.434
2674.5	0.20	2674.49	0.20	0.207
2749.6	0.05	2749.56	0.05	0.052
2946.4	0.10	2946.36	0.10	0.103
2967.1	0.17	2967.05	0.17	0.176
3026.1	0.47	3026.05	0.47	0.486
3074.0	0.12	3073.95	0.12	0.124
3090.6	0.30	3090.63	0.30	0.310
3177.9	1.40	3177.93	1.40	1.448
3292.1	0.13	3292.11	0.13	0.134
3303.5	0.05	3303.51	0.05	0.052
3382.8	0.11	3382.81	0.11	0.114
3393.5	0.67	3393.35	0.67	0.693
3403.6	0.17	3403.55	0.17	0.176
3509.9	0.21	3509.86	0.21	0.217
3545.9	0.32	3545.92	0.32	0.331
3576.1	0.20	3576.08	0.20	0.207
3719.8	3.98	3719.84	3.98	4.116
3863.6	0.39	3863.64	0.39	0.403
3898.5	0.11	3898.51	0.11	0.114
3927.6	0.52	3927.57	0.52	0.538
4133.2	0.48	4133.15	0.48	0.496
4168.1	0.12	4168.06	0.12	0.124
4229.9	0.10	4229.93	0.10	0.103
4393.3	0.06	4393.28	0.06	0.062

Table 9: Comparison of ENSDF and ACTI spectra for thermal-neutron capture in ^{53}Cr

ACTI		ENSDF		ENSDF Normalized to Audi's[8] Q-Value
Energy (keV)	Iγ[a]	Energy (keV)	Iγ[a]	Iγ[a]
4425.6	0.50	4425.63	0.50	0.517
4433.4	0.20	4433.43	0.20	0.207
4451.5	0.45	4451.47	0.45	0.465
4459.3	0.38	4459.28	0.38	0.393
4494.0	0.13	4494.00	0.13	0.134
4530.4	0.19	4530.38	0.19	0.196
4751.8	0.18	4751.83	0.18	0.186
4847.5	1.96	4847.54	1.96	2.027
4872.3	1.06	4872.27	1.06	1.096
5021.3	0.16	5021.29	0.16	0.165
5086.4	0.23	5086.36	0.23	0.238
5339.3	0.29	5339.27	0.29	0.300
5501.8	0.13	5501.78	0.13	0.134
5636.9	0.13	5636.90	0.13	0.134
5707.1	1.35	5707.09	1.35	1.396
5792.2	0.46	5792.17	0.46	0.476
5794.3	0.17	5794.32	0.17	0.176
5859.0	1.21	5858.98	1.21	1.251
6000.0	4.80	5999.95	4.79	4.953
6283.0	2.03	6283.02	2.03	2.099
6326.4	1.19	6326.41	1.19	1.231
6645.6	10.30	6645.64	10.29	10.641
6890.2	2.35	6890.16	2.35	2.430
7100.1	8.20	7100.11	8.20	8.479
8884.2	44.00	8884.81	44.00	45.499
9718.9	14.60	9719.79	14.65	15.149
Total Yield (keV)	9384.21	9398.81		9718.92

[a]Number of photons per 100 neutron captures.

V. ^{54}Cr

Of all the stable isotopes of chromium, ^{54}Cr contributes the least (0.28%) to the total photon production spectrum of natural chromium at thermal energies. For this reason, T-2 did not produce ACTI data for ^{54}Cr. However, as with the other chromium isotopes, Dr. Tuli of the NNDC was kind enough to produce a file from ENSDF containing the thermal-neutron capture spectrum for ^{54}Cr.

The search for experimental data resulted in only one paper with an appreciable amount of thermal-neutron capture data for ^{54}Cr. This paper by White and Howe[18] is also the main reference cited in the ENSDF file provided by Dr. Tuli. Except for occasional instances of rounding, the two spectra are equivalent. They are compared in Table 10. Also listed are the ENSDF intensities normalized to Audi's[8] Q-value. Once again we find that the thermal-neutron capture spectrum from ENSDF is equivalent to the best available experimental data.

Table 10: Comparison of thermal-neutron capture spectra for ^{54}Cr

ENSDF		White and Howe (1972)		ENSDF Intensities Normalized to Audi's[8] Q-Value
Energy (keV)	$I\gamma^a$	Energy (keV)	$I\gamma^a$	$I\gamma^a$
104.75	0.09	104.75	0.09	0.092
211.66	0.07	211.66	0.07	0.071
241.85	22.10	241.85	22.10	22.546
324.03	1.57	324.03	1.57	1.602
351.65	0.12	351.65	0.12	0.122
517.68	0.70	517.68	0.70	0.714
565.89	11.80	565.89	11.80	12.038
575.60	0.11	575.63	0.11	0.112
651.05	0.09	651.05	0.09	0.092
840.93	3.06	840.93	3.06	3.122
846.51	0.32	846.51	0.32	0.326
880.74	0.65	880.74	0.65	0.663
908.27	7.90	908.27	7.93	8.090
1086.74	0.09	1086.74	0.09	0.092
1197.23	0.59	1197.23	0.59	0.602
1209.45	0.07	1209.45	0.07	0.071
1232.21	0.88	1232.21	0.88	0.898
1283.21	0.07	1283.21	0.07	0.071

Table 10: Comparison of thermal-neutron capture spectra for ^{54}Cr

ENSDF		White and Howe (1972)		ENSDF Intensities Normalized to Audi's[8] Q-Value
Energy (keV)	Iγ[a]	Energy (keV)	Iγ[a]	Iγ[a]
1298.69	0.13	1298.69	0.13	0.133
1340.22	0.09	1340.22	0.09	0.092
1343.56	0.12	1343.56	0.12	0.122
1399.86	0.12	1399.86	0.12	0.122
1419.55	0.11	1419.55	0.11	0.112
1435.60	0.27	1435.60	0.27	0.275
1474.28	7.00	1474.28	6.99	7.131
1630.56	0.10	1630.56	0.10	0.102
1647.03	0.13	1647.03	0.13	0.133
1660.10	0.03	1660.10	0.03	0.031
1664.87	0.08	1664.87	0.08	0.082
1689.14	0.12	1689.14	0.12	0.122
1695.90	0.06	1695.90	0.06	0.061
1703.19	0.18	1703.19	0.18	0.184
1803.70	0.26	1803. 65	0.26	0.265
1816.40	0.15	1816.40	0.15	0.153
1842.05	0.21	1842.05	0.21	0.214
1873.30	0.18	1873.30	0.18	0.184
1908.30	0.12	1908.30	0.12	0.122
2078.29	0.41	2078.29	0.41	0.418
2083.70	0.36	2083.70	0.36	0.367
2120.97	0.31	2120.97	0.31	0.316
2143.61	0.39	2143.61	0.39	0.398
2202.00	0.69	2202.00	0.69	0.704
2269.40	0.18	2269.40	0.18	0.184
2328.66	0.52	2328.66	0.52	0.530
2379.48	1.59	2379.48	1.59	1.622
2408.60	0.08	2408.60	0.08	0.082
2444.90	0.31	2444.90	0.31	0.316
2454.86	0.33	2454.86	0.33	0.337
2457.80	0.59	2457.80	0.59	0.602
2463.90	0.10	2463.90	0.10	0.102
2576.50	0.10	2576.50	0.10	0.102
2652.40	0.83	2652.40	0.83	0.847
2687.00	0.90	2687.00	0.90	0.918
2697.40	0.28	2697.40	0.28	0.286
2718.00	0.08	2718.00	0.08	0.082
2782.00	0.07	2782.00	0.07	0.071

Table 10: Comparison of thermal-neutron capture spectra for ^{54}Cr

ENSDF		White and Howe (1972)		ENSDF Intensities Normalized to Audi's[8] Q-Value
Energy (keV)	Iγ[a]	Energy (keV)	Iγ[a]	Iγ[a]
2894.30	1.45	2894.30	1.45	1.479
2912.30	0.07	2912.30	0.07	0.071
2930.60	0.63	2930.60	0.63	0.643
3019.00	0.08	3019.00	0.08	0.082
3221.10	1.86	3221.10	1.86	1.898
3267.10	0.04	3267.10	0.04	0.041
3351.50	2.72	3351.50	2.72	2.775
3478.10	0.09	3478.10	0.09	0.092
3506.00	0.05	3506.00	0.05	0.051
3524.50	0.05	3524.50	0.05	0.051
3548.50	0.90	3548.50	0.90	0.918
3558.60	1.43	3558.60	1.43	1.459
3659.50	0.06	3659.50	0.06	0.061
3791.20	0.05	3791.17	0.05	0.051
3801.60	0.12	3801.60	0.12	0.122
3977.00	0.35	3977.00	0.35	0.357
4044.10	0.31	4044.10	0.31	0.316
4162.20	0.46	4162.20	0.46	0.469
4219.50	0.08	4219.50	0.08	0.082
4466.30	0.15	4466.30	0.15	0.153
4771.80	13.10	4771.80	13.10	13.364
4868.80	0.21	4868.80	0.21	0.214
5047.30	0.11	5047.30	0.11	0.112
5421.30	2.11	5421.30	2.11	2.153
5586.10	0.07	5586.10	0.07	0.071
5594.10	0.06	5594.06	0.06	0.061
5680.40	2.14	5680.40	2.14	2.183
6004.40	13.40	6004.40	13.40	13.671
6246.40	55.50	6246.40	55.50	56.621
Total Yield (keV)	6122.55	6122.68		6246.30

[a]Number of photons per 100 neutron captures.

VI. Summary

Several sources of thermal-neutron capture data for the stable chromium isotopes have been compared. Thermal-neutron capture spectra from ENSDF were obtained through Dr. Tuli of the National Nuclear Data Center and compared to experimental data. The ENSDF spectra are equivalent to the best available experimental data for each isotope of chromium. Thermal-neutron capture spectra derived from ENSDF by T-2 (the ACTI spectra) were then compared to the NNDC data. Other than a few differences, the ACTI spectra are equivalent to the ENSDF spectra. The noted differences may be the results of typographical errors or errors in the method used to create the ACTI spectra.

The ACTI spectra for nickel will be evaluated next. As with chromium, the ACTI spectra for the nickel isotopes were based on ENSDF. However, a preliminary analysis of the spectra has revealed significant differences between ACTI and ENSDF. A more thorough analysis, including comparisons to experimental data, is being performed.

Acknowledgments

I owe many thanks to Dr. Jagdish Tuli of the National Nuclear Data Center for providing both the ENSDF spectra and the ENSDF references. Dr. Tuli was also kind enough to promptly answer several questions concerning ENSDF and the NNDC web site. The significant efforts of Robert MacFarlane in creating the ACTI spectra that form the foundation of these comparisons is greatly appreciated. Thanks also to Phil Young of T-2 for providing the NNDC collection of experimental data on chromium. Finally, I thank Stephanie Frankle and Bob Little for many useful discussions, and for helping edit this research note.

References

1 J. G. Conaway and S. C. Frankle (1993), ``Summary Report for Fiscal Year 1993: Multispectral Nuclear Logging,'' Los Alamos National Laboratory Release, LA-UR-93-4538.

2 J. G. Conaway and J. Duray, ed. (1994), ``Contaminant Detection Thresholds for the Multispectral Neutron Borehole Logging Method: Preliminary Report,'' Department of Energy report DOE/ID/12534-188 and Los Alamos National Laboratory Release LA-CP-94-183.

3 S. C. Frankle and J. G. Conaway, ``MCNP™ Simulations for Identifying Environmental Contaminants Using Prompt Gamma-rays from Thermal Neutron Capture Reactions,'' submitted to the proceedings for the Third Topical Meeting on Industrial Radiation and Radioisotopes Measurements and Applications, LA-UR-97-692 (1996).

4 Joint Work Statement No. LA95J10236-A001, CRADA No. LA95C10236-A001, Computer Simulation in Support of Nuclear Well-Logging.

5 V. McLane, C. L. Dunford, P. F. Rose, Editors, ``ENDF-102 Data Formats and Procedures for the Evaluated Nuclear Data File, ENDF-6,'' Brookhaven National Laboratory report BNL-NCS-44945 (ENDF 102) (ENDF/B-VI) (Nov. 1995).

6 J. K. Tuli, ``The Evaluated Nuclear Structure Data File, A Manual for Preparation of Data Sets,'' Brookhaven National Laboratory report BNL-NCS-51655-Rev.87, (April 1987).

7 M. A. Lone et al., “Prompt Gamma Rays from Thermal-Neutron Capture,” Atomic Data and Nuclear Data Tables **26**, 511, (1981).

8 G. Audi and A. H. Wapstra, “Experimental Mass Data,” Nuclear Physics **A565**, 1 (1993).

9 J. Kopecky, “Investigation of the Reaction $^{50}Cr(n,\gamma)^{51}Cr$,” Reactor Centrum Nederland Report #214, Petten, the Netherlands (1974).

10 G. A. Bartholomew, E. D. Earle, and M. R. Gunye, “Neutron-Capture γ-Ray Studies in $^{50}Cr(n,\gamma)^{51}Cr$,“ Canadian Journal of Physics, **44** (1966).

11 D. L. Broder et al., “γ Radiation in the Capture of Thermal Neutrons by Cr Isotopes,” Soviet Journal of Nuclear Physics **13**, 233 (1971).

12 G. D. Loper and G. E. Thomas, “Gamma-Ray Intensity Standards: The Reactions $^{14}N(n,\gamma)^{15}N$, $^{35}Cl(n,\gamma)^{36}Cl$ and $^{53}Cr(n,\gamma)^{54}Cr$,” Nuclear Instruments and Methods **105**, 453 (1972).

13 J. Kopecky, K. Abrahams, and F. Stecher-Rasmussen, “Study of the (n,γ) Reaction in the Mass Region A=50-63,” Nuclear Physics **A188**, 535 (1972).

14 R. Knerr and H. Vonach, “Spinbestimmung der angeregten Zustande verschiedener Kerne aus der Gammazirkularpolarisation nach dem Einfang polarisierter Neutronen,” Zeitschrift fur Physik **246**, 151 (1971).

15 E. A. Rudak and E. I. Firsov, “Gamma-Ray Spectra from the (n,γ) Reaction in ^{50}Cr, ^{52}Cr, and ^{53}Cr,” Soviet Journal of Nuclear Physics **1**, 235 (1965).

16 J. Kopecky, R. E. Chrien, and H. I. Liou, "Resonance Neutron Capture in ^{52}Cr," Nuclear Physics **A334**, 35 (1980).

17 C. Hofmeyr, "$^{53}Cr(n,\gamma)$; Transition Energies and Levels Excited in Thermal Neutron Capture," Nuclear Physics **A500**, 111 (1980).

18 D. H. White and R. E. Howe, "Gamma-Ray Spectra and Level Structure of ^{55}Cr from Thermal Neutron Capture in ^{54}Cr," Nuclear Physics **A187**, 12 (1972).

MCNP is a trademark of the Regents of the University of California, Los Alamos National Laboratory.