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

I. Introduction

This research note assesses the modified photon production data at incident thermal neutron energies for the five stable isotopes of nickel. 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 neutron energies. For a more complete background on these projects and the motivation behind this work, see the research note XTM-RN(U)97-008.

As discussed in XTM-RN(U)97-010, preliminary ACTI libraries for several isotopes have been created by T-2. The purpose of this research note is to compare the preliminary ACTI data for the stable nickel isotopes with other sources of data such as standard ENDF/B-VI[5], ENSDF[6], and experimental papers. Compilations such as Lone[7] were not considered in detail since they contain very few gamma-rays compared to experimental papers on nickel, provide only elemental information, and were shown to be vastly inferior to experimental papers in a similar analysis of chlorine (see XTM-RN(U)97-008). Since the photon production data in the Evaluated Nuclear Data File (ENDF/B-VI) contain no discrete gamma-rays for the nickel isotopes, ENDF/B-VI will also not be discussed. The sources of data meeting the high-quality requirements of ACTI (data from ENDSF, experimental papers, and the preliminary ACTI libraries from T-2) will be compared in this research note to determine which source is best.

The preliminary ACTI libraries for the nickel isotopes were created by T-2 using the information contained in the Evaluated Nuclear Structure Data File (ENSDF). The T-2 spectra for thermal-neutron capture in ^{58}Ni, ^{60}Ni, ^{62}Ni and ^{64}Ni 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 ^{61}Ni was not produced by T-2.

The thermal-neutron capture ENSDF data were obtained from Dr. Jagdish Tuli of the National Nuclear Data Center (NNDC). Dr. Tuli provided thermal-neutron capture spectra for all five stable isotopes of nickel, and also provided the complete set of ENSDF references for each isotope.

The experimental papers compared in this research note were obtained through an extensive 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 1976 were combed. Third, all of the pertinent ENSDF references provided by Dr. Tuli were obtained. Finally, the approximately 30 papers found were in turn searched for additional references, although papers published prior to 1966 were not sought.

The natural abundances, thermal-neutron radiative capture cross-sections (σ_{th}), contributions to the gamma-ray spectrum of natural nickel, and Q-values for thermal neutron capture are listed in Table 1 for the stable nickel isotopes. For three of the five isotopes, ^{58}Ni, ^{60}Ni, and ^{62}Ni, the search for experimental papers yielded good recent (1993) thermal-neutron capture data. For the other two isotopes the data found were considerably older (~1970's). Because ^{58}Ni, ^{60}Ni, and ^{62}Ni contribute over 99% of the total photon yield of natural nickel, the thermal-neutron capture data for nickel should be in good condition for ACTI applications.

Table 1: The stable isotopes of nickel

Isotope	Natural Abundance (Atom Fraction)	σ_{th} (barns)	Contribution to Natural Spectrum (%)	Q-Value for Neutron Capture (keV)[a]
^{58}Ni	0.6827	4.60	70.43	8999.44
^{60}Ni	0.2610	2.90	16.97	7820.04
^{61}Ni	0.0113	2.40	0.61	10597.23
^{62}Ni	0.0359	14.50	11.67	6837.85
^{64}Ni	0.0091	1.55	0.32	6098.01

[a]Values taken from Audi[8].

The comparisons between the T-2 and ENSDF data revealed significant differences between the two. Comparisons with experimental data gave mixed results. For ^{58}Ni, ^{61}Ni, and ^{64}Ni, ENSDF is equivalent to the best available experimental data. However, for ^{60}Ni and ^{62}Ni this is not true. Each isotope will now be discussed in turn.

II. ^{58}Ni

A. Comparison of Experimental Data

The search for experimental data resulted in eight papers containing thermal-neutron capture data for ^{58}Ni. Brief information for each data set is listed in Table 2, including the number of gamma-rays listed, the year the paper was published, the total gamma-ray yield per neutron capture, and the designation that will be used to refer to the paper.

Table 2: Summary of experimental papers for ^{58}Ni

Author(s)	Designation	Year	Number of Gamma-Rays Listed	Yield of Listed Spectrum (keV)
A. Harder et al.[9]	Har93	1993	241	8816.88
S. Ulbig et al.[10]	Ulb91	1991	7	188.84
A. Ishaq et al.[11]	Ish77	1977	59	8764.61
C. Hofmeyr[12]	Hof75	1975	139	9457.88[b]
W. Wilson et al.[13]	Wil75	1975	4	---[a]
R. Knerr and H. Vonach[14]	Kne71	1971	8	6867.72
F. Stecher-Rasmussen et al.[15]	Ste72	1972	8	6151.40
P. Treado and P. Chagnon[16]	Tre61	1961	11	8775.10

[a]Only relative intensities were given.
[b]The yield from gamma-rays with uncertain intensities was excluded.

According to the Q-value listed by Audi[8], the total radiated energy from thermal-neutron capture in ^{58}Ni should be 8999.44 keV. Of the eight papers in Table 2 only four (Har93, Ish77, Hof75, and Tre61) list yields close to this value. The other four papers (Ste72, Ulb91, Wil75, and Kne71) only list a few gamma-rays. However, a quick comparison of the papers reveals that the oldest paper, Tre61, lists several gamma-rays not observed by the other experimenters. The intensities in Tre61 are also considerably larger than the intensities found in the other papers, and have extremely large uncertainties (on the order of 50%). This explains why its yield is so high even though only 11 gamma-rays were observed.

If the five papers with only a few (< 12) listed gamma-rays are omitted, we are left with three sources of data; Har93, Ish77, and Hof75. Of these three, the data from Har93 appear to be the best for several reasons. First, Har93 represents the most recent (1993) and complete (241 gamma-rays) spectral measurement. Second, its yield is closest to the Audi and Wapstra Q-value for the $^{58}Ni(n,\gamma)^{59}Ni$ reaction (8999.44 keV). In contrast, the yield observed by Hof75 is about 5% *greater* than the available energy, even when the 27 gamma-rays with uncertain intensities are excluded. Clearly the Hof75 intensities are systematically inflated and/or gamma-rays from contaminant materials were included. Finally, the Har93 spectrum includes *all* measured gamma-rays, whereas Ish77 only lists gamma-rays with energies above 1949.7 keV. The spectra from these three sources are compared explicitly in Table 3.

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
8998.41	50.1	9001.0	52.7	8999.91	52.7
8533.36	23.8	8536.0	25.4	8534.14	25.6
8120.51	4.3	8123.1	4.5	8121.76	4.65
7697.12	1.25	7698.8	1.2	7698.40	1.28
7264.05	0.236	7265.5	0.5	7265.75	0.31
----------	-----	-----	-----	7244.9	0.11
-----	-----	-----	-----	7161.9	0.07
-----	-----	-----	-----	7059.39	0.14
-----	-----	6708.8	1.0	-----	-----
-----	-----	6674.5	0.4	-----	-----
-----	-----	6656.3	0.4	-----	-----
6597.67	0.098	6604.0	0.4	-----	-----
6583.85	2.61	6585.6	2.5	6584.61	2.74
-----	-----	6560.5	0.2	-----	-----
6391.93	0.034	-----	-----	-----	-----
6258.74	0.038	-----	-----	6260.9	0.06
6141.20	0.061	6140.6	0.2	6140.4	0.09
6105.28	2.35	6106.2	2.4	6106.03	2.39
6030.34	0.051	-----	-----	-----	-----
5993.84	0.029	-----	-----	-----	-----
5973.01	0.881	5975.2	0.8	5974.40	0.87
5956.75	0.058	-----	-----	-----	-----
-----	-----	5926.5	0.5	-----	-----
5817.19	3.60	5818.1	4.3	5817.99	3.70

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
-----	-----	5782.9	0.2	-----	-----
5754.36	0.018	-----	-----	-----	-----
5701.76	0.039	-----	-----	-----	-----
5676.80	0.014	-----	-----	-----	-----
5636.80	0.010	-----	-----	-----	-----
5631.99	0.016	-----	-----	-----	-----
5621.41	0.126	-----	-----	5621.0	0.16
5617.04	0.075	-----	-----	-----	-----
5590.0	0.005	-----	-----	-----	-----
5565.96	0.019	-----	-----	-----	-----
5546.62	0.066	-----	-----	-----	-----
-----	-----	-----	-----	5528.0	0.06
-----	-----	5491.0	0.2	-----	-----
5458.74	0.079	-----	-----	5459.1	0.09
-----	-----	5447.6	0.2	-----	-----
5435.77	0.631	5436.2	0.7	5436.72	0.72
5384.52	0.025	5381.5	0.2	-----	-----
5362.67	0.045	-----	-----	-----	-----
5312.64	1.74	5313.3	1.8	5313.18	1.74
5292.69	0.038	-----	-----	-----	-----
5277.35	0.021	5275.0	0.4	-----	-----
5268.56	0.337	-----	-----	5269.58	0.29
5237.0	0.003	-----	-----	-----	-----
5223.38	0.027	-----	-----	-----	-----
5167.55	0.007	-----	-----	-----	-----
5152.30	0.047	5151.1	0.2	-----	-----
5145.18	0.131	5142.0	0.2	5146.5	0.14
5140.76	0.026	-----	-----	-----	-----
5115.93	0.007	-----	-----	-----	-----
5109.06	0.108	5107.8	0.4	5111.5	0.11
5078.92	0.024	-----	-----	-----	-----
5068.63	0.109	-----	-----	5069.2	0.08
5044.89	0.030	-----	-----	-----	-----
4977.00	0.253	4974.4	0.3	4977.48	0.26
-----	-----	-----	-----	4967.7	0.10
4949.68	0.165	4951.6	0.3	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
4919.54	0.034	-----	-----	-----	-----
4912.78	0.005	-----	-----	-----	-----
4858.61	1.46	4859.3	1.5	4859.18	1.53
4841.20	0.012	-----	-----	-----	-----
4823.91	0.023	-----	-----	-----	-----
4805.10	0.059	-----	-----	-----	-----
4753.56	0.006	-----	-----	-----	-----
4745.96	0.117	4749.8	0.2	4746.1	0.15
4729.19	0.017	-----	-----	-----	-----
4715.04	0.284	4715.6	0.3	4715.31	0.25
-----	-----	4654.0	0.2	-----	-----
4646.44	0.120	4646.0	0.2	4646.8	0.15
-----	-----	4635.7	0.3	-----	-----
4629.20	0.019	-----	-----	-----	-----
4603.90	0.012	-----	-----	-----	-----
4565.99	0.009	-----	-----	-----	-----
4506.54	0.040	-----	-----	-----	-----
4503.57	0.049	-----	-----	-----	-----
4459.2	0.002	4462.4	0.2	-----	-----
4452.84	0.007	-----	-----	-----	-----
4442.54	0.008	-----	-----	-----	-----
4428.49	0.037	-----	-----	-----	-----
4426.3	0.007	-----	-----	-----	-----
4420.8	0.002	-----	-----	-----	-----
4406.5	0.003	-----	-----	-----	-----
4401.8	0.003	-----	-----	-----	-----
4375.83	0.063	4376.9	0.2	-----	-----
4352.19	0.060	-----	-----	-----	-----
4332.4	0.003	4327.9	0.2	-----	-----
4314.51	0.011	-----	-----	-----	-----
4295.55	0.019	-----	-----	-----	-----
4283.67	0.426	4284.5	0.5	4284.21	0.39
4253.05	0.072	-----	-----	-----	-----
4250.06	0.042	-----	-----	-----	-----
4244.70	0.009	-----	-----	-----	-----
4223.19	0.004	-----	-----	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
4190.96	0.110	-----	-----	4191.5	0.13
4140.05	0.218	4140.9	0.3	4140.63	0.29
4090.79	0.011	-----	-----	-----	-----
4083.23	0.016	-----	-----	-----	-----
4049.94	0.321	4049.7	0.4	4050.77	0.31
4030.17	0.497	4027.0	0.5	4030.79	0.46
4021.96	0.035	-----	-----	-----	-----
4019.88	0.028	-----	-----	-----	-----
-----	-----	4004.1	< 0.1	-----	-----
3952.24	0.032	3958.4	< 0.1	-----	-----
3937.49	0.010	-----	-----	-----	-----
3930.01	0.392	3933.4	0.2	3930.46	0.40
3913.23	0.006	-----	-----	-----	-----
3897.11	0.008	-----	-----	-----	-----
3889.53	0.058	3889.0	< 0.1	-----	-----
3880.10	0.005	3874.1	< 0.1	-----	-----
3858.04	0.025	-----	-----	-----	-----
3853.72	0.043	-----	-----	-----	-----
3818.5	0.005	-----	-----	-----	-----
3800.79	0.072	-----	-----	-----	-----
3787.85	0.040	-----	-----	-----	-----
3779.94	0.252	3778.3	0.2	3780.26	0.26
3767.43	0.032	-----	-----	-----	-----
3730.19	0.098	3730.4	0.2	-----	-----
3705.2	0.005	-----	-----	-----	-----
3685.97	0.368	3687.0	0.3	-----	-----
3675.23	0.957	3674.2	0.9	3674.94	0.96
3667.42	0.054	-----	-----	-----	-----
3648.3	0.002	-----	-----	-----	-----
3614.37	0.177	3618.4	0.2	3614.86	0.22
3585.2	0.004	-----	-----	-----	-----
3578.6	0.003	-----	-----	-----	-----
3562.91	0.241	3564.4	0.2	3563.06	0.23
-----	-----	-----	-----	3555.1	0.06
3526.66	0.014	-----	-----	-----	-----
3514.06	0.058	-----	-----	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
-----	-----	3504.6	0.2	-----	-----
-----	-----	3468.1	0.2	-----	-----
3452.37	0.046	-----	-----	-----	-----
3412.03	0.011	-----	-----	-----	-----
3391.23	0.038	-----	-----	-----	-----
3388.79	0.036	-----	-----	-----	-----
3381.89	0.228	3383.7	0.3	3381.86	0.31
3377.14	0.064	-----	-----	-----	-----
3367.05	0.260	-----	-----	3366.8	0.24
3346.65	0.227	-----	-----	3346.6	0.24
3334.59	0.007	-----	-----	-----	-----
3296.62	0.173	3297.1	0.3	3298.4	0.12
3265.31	0.190	3267.4	0.2	3265.8	0.22
3262.32	0.043	-----	-----	-----	-----
-----	-----	3251.0	0.2	-----	-----
3244.58	0.074	-----	-----	-----	-----
3234.08	0.011	3237.8	< 0.1	-----	-----
-----	-----	3226.4	0.1	-----	-----
3221.11	0.527	3219.5	0.6	3221.18	0.47
3200.46	0.123	-----	-----	3201.7	0.12
-----	-----	3192.2	0.1	-----	-----
3181.59	0.422	3182.2	0.3	3181.97	0.42
3163.55	0.017	-----	-----	-----	-----
3143.84	0.070	-----	-----	-----	-----
3136.75	0.025	-----	-----	-----	-----
3112.81	0.011	-----	-----	-----	-----
3063.63	0.068	-----	-----	-----	-----
3051.14	0.015	-----	-----	-----	-----
3041.77	0.155	-----	-----	-----	-----
3037.94	0.158	-----	-----	3039.2	0.27
3025.73	0.454	3025.8	0.3	3025.69	0.44
3012.08	0.006	3014.3	0.2	-----	-----
3004.84	0.112	-----	-----	-----	-----
2987.12	0.013	-----	-----	-----	-----
2980.59	0.011	-----	-----	-----	-----
2975.47	0.006	-----	-----	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
2968.520	0.320	2969.0	0.3	2968.3	0.21
2951.58	0.061	-----	-----	-----	-----
2912.28	0.018	-----	-----	-----	-----
-----	-----	2907.1	0.2	-----	-----
2897.70	0.119	-----	-----	-----	-----
2893.121	0.426	2894.2	0.3	2894.8	0.36
2857.564	0.127	2856.7	0.2	-----	-----
2842.102	1.77	2842.5	1.6	2842.14	1.58
2808.190	0.323	-----	-----	2808.9	0.17
2763.92	0.018	-----	-----	-----	-----
-----	-----	2758.2	0.1	-----	-----
2738.70	0.017	-----	-----	-----	-----
2723.93	0.011	-----	-----	-----	-----
2719.35	0.123	-----	-----	-----	-----
2716.62	0.092	-----	-----	-----	-----
2685.129	0.415	2686.8	0.3	2685.8	0.32
2661.38	0.009	-----	-----	-----	-----
2616.66	0.022	-----	-----	-----	-----
2574.62	0.032	-----	-----	-----	-----
2560.55	0.022	-----	-----	-----	-----
2554.142	1.61	2554.3	1.3	2554.67	1.62
2541.49	0.021	-----	-----	-----	-----
2517.8	0.004	-----	-----	-----	-----
2504.83	0.013	-----	-----	-----	-----
2497.465	0.216	2499.0	0.4	2499.3	0.27
-----	-----	2489.5	< 0.1	-----	-----
-----	-----	2486.7	< 0.1	-----	-----
2460.76	0.014	-----	-----	-----	-----
2450.52	0.012	-----	-----	-----	-----
2437.155	0.108	-----	-----	-----	-----
2428.570	0.280	2429.2	0.2	-----	-----
2422.138	0.140	-----	-----	-----	-----
2414.969	0.488	2415.3	0.3	-----	-----
2400.948	0.221	-----	-----	-----	-----
2384.80	0.261	2385.1	0.2	-----	-----
-----	-----	2344.3	0.2	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
2303.69	0.151	-----	-----	-----	-----
2300.75	0.024	-----	-----	-----	-----
2287.83	0.011	-----	-----	-----	-----
-----	-----	2263.1	0.1	-----	-----
2254.77	0.015	-----	-----	-----	-----
2248.08	0.011	-----	-----	-----	-----
2178.63	0.080	-----	-----	-----	-----
2147.91	0.429	2148.1	0.4	-----	-----
-----	-----	2105.5	0.1	-----	-----
2075.45	0.087	2075.7	0.1	-----	-----
2050.78	0.043	-----	-----	-----	-----
-----	-----	2041.7	0.2	-----	-----
2015.70	0.488	2015.7	0.4	-----	-----
1992.83	0.48	1993.2	0.5	1993.61	0.76
1950.05	1.66	1949.9	1.7	1949.72	1.92
1901.75	0.022	-----	-----	-----	-----
1880.26	0.131	1881.2	0.1	-----	-----
1865.29	0.012	-----	-----	-----	-----
1837.40	0.017	1836.8	0.1	-----	-----
-----	-----	1830.1	0.1	-----	-----
1816.76	0.049	-----	-----	-----	-----
1734.780	0.53	1735.1	0.5	-----	-----
1728.81	0.048	-----	-----	-----	-----
1724.625	0.217	1725.7	0.3	-----	-----
1717.33	0.009	-----	-----	-----	-----
1704.86	0.109	1703.5	0.1	-----	-----
1679.59	0.119	1680.1	0.1	-----	-----
1663.10	0.133	1663.3	0.1	-----	-----
1615.2	0.007	-----	-----	-----	-----
1604.95	0.012	-----	-----	-----	-----
1595.2	0.005	-----	-----	-----	-----
1592.22	0.040	-----	-----	-----	-----
1568.48	0.014	-----	-----	-----	-----
1536.948	0.63	1536.5	0.6	-----	-----
1501.881	0.49	1501.8	0.5	-----	-----
1446.902	0.34	1447.6	0.4	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
1395.282	0.155	1395.3	0.1	-----	-----
1392.922	0.105	-----	-----	-----	-----
1378.96	0.056	1378.8	0.1	-----	-----
1362.80	0.053	-----	-----	-----	-----
1340.303	0.64	1340.3	0.7	-----	-----
1301.473	1.79	1301.3	1.9	-----	-----
-----	-----	1276.5	< 0.1	-----	-----
1269.699	0.112	1269.5	0.1	-----	-----
-----	-----	1233.7	< 0.1	-----	-----
1226.109	0.41	1225.8	0.3	-----	-----
1213.923	0.073	1213.4	< 0.1	-----	-----
1210.15	0.005	1211.3	< 0.1	-----	-----
1188.797	1.79	1188.8	1.7	-----	-----
1158.75	0.006	-----	-----	-----	-----
1148.31	0.012	1147.0	< 0.1	-----	-----
1132.21	0.015	-----	-----	-----	-----
1114.00	0.031	-----	-----	-----	-----
1112.96	0.028	-----	-----	-----	-----
-----	-----	1027.9	0.1	-----	-----
-----	-----	999.2	0.1	-----	-----
-----	-----	989.0	< 0.1	-----	-----
-----	-----	975.7	< 0.1	-----	-----
934.596	0.190	-----	-----	-----	-----
-----	-----	916.0	< 0.1	-----	-----
877.971	7.6	877.7	7.9	-----	-----
857.75	0.011	862.4	< 0.1	-----	-----
849.369	0.081	849.9	0.1	-----	-----
846.819	0.137	-----	-----	-----	-----
843.57	0.017	-----	-----	-----	-----
840.99	0.010	-----	-----	-----	-----
836.458	0.30	836.3	0.3	-----	-----
828.26	0.010	-----	-----	-----	-----
801.81	0.013	803.8	< 0.1	-----	-----
766.613	0.086	767.3	0.1	-----	-----
723.85	0.018	-----	-----	-----	-----
712.75	0.043	-----	-----	-----	-----

Table 3: Comparison of ^{58}Ni spectra from Har93, Hof75, and Ish77

Harder 1993		Hofmeyr 1975		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
-----	-----	671.2	< 0.1	-----	-----
-----	-----	565.3	< 0.1	-----	-----
-----	-----	558.7	0.1	-----	-----
545.90	0.088	546.1	0.1	-----	-----
538.55	0.086	538.7	0.1	-----	-----
-----	-----	531.6	< 0.1	-----	-----
-----	-----	485.3	< 0.1	-----	-----
465.00	23.0	465.2	28.9	-----	-----
423.465	-----[b]	423.7	0.3	-----	-----
-----	-----	373.0	< 0.1	-----	-----
-----	-----	352.6	0.1	-----	-----
339.418	-----[b]	339.5	7.1	-----	-----
-----	-----	311.0	< 0.1	-----	-----
-----	-----	289.6	< 0.1	-----	-----
-----	-----	217.0	< 0.1	-----	-----
-----	-----	155.3	< 0.1	-----	-----
-----	-----	149.6	< 0.1	-----	-----

[a]Number of photons per 100 neutron captures.
[b]These gamma-rays were observed but their intensities could not be determined.

A careful comparison of these three spectra confirms that Har93 is the best data source. Three classes of gamma-rays result from such a comparison. There are gamma-rays observed by only one experimenter, gamma-rays observed by two experimenters, and gamma-rays observed by all three. If each data source is equally reliable, the following conclusions can be drawn. Gamma-rays observed by only one experimenter cast doubt on that experimenter. Gamma-rays observed by two experimenters but not the third cast doubt on the third experimenter. If all three experimenters observe a gamma-ray, and only two of them agree (E_γ and / or I_γ), doubt is cast on the experimenter that disagrees. An analysis of each of these classes of gamma-rays suggests that Har93 is the best data source.

Consider the gamma-rays observed by only one experimenter. Hof75 observed 44 gamma-rays not observed by anyone else, or about 32% of the total number of gamma-rays listed in his spectrum. Given his inflated total yield (about 5% greater than the available energy), and the fact that no one else observed them, these gamma-rays are most likely *not* from ^{58}Ni(n,γ)^{59}Ni. Ish77 observed only six gamma-rays not measured by anyone else.

In contrast, most of the gamma-rays observed by Har93 were not seen by the other experimenters. However, this does not cast doubt on the Har93 data since only Har93 operated his pair spectrometers in compton-suppression mode. Such operation allows for more precise measurements and the ability to correctly identify much weaker gamma-rays. If Har93 had observed *fewe*r gamma-rays than the other authors, serious doubt would have been cast on his measurements.

The second class of gamma-rays consists of those observed by only two experimenters. There are *no* gamma-rays observed by everyone *except* Har93. This suggests Har93 observed *all* gamma-rays from the ^{58}Ni(n,γ)^{59}Ni reaction. In contrast, there are over 55 gamma-rays observed by Har93 and only *one* other experimenter, suggesting the other spectra are incomplete.

If we combine the second and third classes of gamma-rays, we have the set of gamma-rays observed by *two or more* experimenters. An analysis of such gamma-rays revealed good agreement between Har93 and Ish77, with Hof75 agreeing poorly with the other two. The analysis also showed that the intensities from Hof75 were consistently higher than the corresponding intensities from the other experimenters. This helps explain his inflated yield.

To quantify the level of disagreement between the three data sets, the average intensity disagreement (AID) between each possible pair of sets was defined. It was defined as

$$AID \equiv \left(\sum_i \frac{|I1_i - I2_i|}{0.5 \cdot (I1_i + I2_i)} \right) \big/ N$$

where $I1_i$ is a gamma-ray intensity from one data set, $I2_i$ is the matching intensity from the other data set, and the sum is over the N number of matching gamma-rays. Note that *larger* numbers indicate *less agreement*. The average intensity disagreement between each possible pair of data sets is given in Table 4. Note that Hof75 disagrees with the other two sets quite strongly, while Har93 and Ish77 are in considerably better agreement.

Table 4: Average intensity disagreement between the data sets in Table 3.

Data Sets Compared	Average Intensity Disagreement
Har93 / Hof75	0.382
Har93 / Ish77	0.173
Ish77 / Hof75	0.230

The main result of these analyses is that Har93 represents the best available experimental data. The intensities from Hof75 are consistently inflated and many contaminant gamma-rays are probably included, resulting in a yield about 5% higher than energetically possible. The data from Ish77 and Har93 are in good agreement, but the spectrum from Har93 is the most recent and complete. There is no evidence that any gamma-rays were missed by Har93, whereas the other spectra appear incomplete. Since Har93 represents the best available experimental data, it should be used for ^{58}Ni. The next section compares the ^{58}Ni thermal-neutron capture spectrum from ENSDF with the experimental data just discussed.

B. Comparison of Experimental Data with ENSDF

A detailed comparison of the ^{58}Ni thermal-neutron capture spectrum from ENSDF and the ^{58}Ni spectrum from Har93 was performed. Except for occasional rounding (for example 846.819 keV from Har93 vs. 846.82 keV from ENSDF) the two spectra are equivalent above E_γ = 423.465 keV. Below this energy, ENSDF lists five gamma-rays from Hof75. Two of these gamma-rays (E_γ = 423.465 keV and 339.418 keV) were observed by Har93, but their intensities could not be determined due to a lack of calibration points at low energy. The other three gamma-rays listed by ENSDF were not observed by Har93, and it is not clear why they were included while other gamma-rays observed only by Hof75 were not. The five differences between Har93 and ENSDF are listed in Table 5. Except for these five differences, the two spectra are equivalent except for occasional rounding by ENSDF.

Table 5: Differences between ENSDF and Har93

ENSDF		Har93	
E_γ (keV)	I_γ[a]	E_γ (keV)	I_γ[a]
155.3[b]	< 0.1[b]	---	---
289.6[b]	< 0.1[b]	---	---
311.0[b]	< 0.1[b]	---	---
339.418[d]	7.1[b]	339.418	---[c]
423.465[d]	0.3[b]	423.465	---[c]

[a]Number of photons per 100 neutron captures.
[b]From Hof75.
[c]Observed, but intensity could not be determined.
[d]From Har93.

C. Comparison of Preliminary ACTI Spectrum with ENSDF

Finally, a comparison between ENSDF and the preliminary ACTI data created by T-2 was performed. The two spectra are presented in Table 6. The percent difference between each matching ACTI and ENSDF intensity, defined as

$$PD \equiv \left[\frac{(I_{ENSDF} - I_{ACTI})}{I_{ENSDF}}\right] \cdot 100$$

is also listed.

As mentioned in the introduction, the T-2 data was obtained from the "Nuclear Data for ACTI CRADA" web page. The documentation there states that "very weak gammas" were removed from ENSDF, and the remaining intensities were normalized to give a yield of 9000.0 keV. Table 6 reveals possible inconsistencies in the methodology used to create the preliminary ACTI spectrum. For example, the preliminary ACTI spectrum omits the ENSDF line at 5817.19 keV (I_γ = 3.6) but includes the much weaker line at 5956.75 keV (I_γ = 0.058). Also, the omission of 79 gamma-rays in the preliminary ACTI spectrum, followed by renormalization to a yield of 9000.0 keV, means the remaining intensities are overestimated more than they need to be.

Finally, it is unclear why the preliminary ACTI intensities are not always a consistent fraction *larger* than the ENSDF intensities. Table 6 shows that 15 ACTI intensities are actually *smaller* than their ENSDF counterparts, some are a few percent larger, while others are as much as 25% larger.

D. Recommended ACTI Spectrum for ^{58}Ni

The recommended ACTI spectrum for ^{58}Ni is also listed in Table 6. The recommended ACTI intensities are the ENSDF intensities normalized to Audi's Q-value of 8999.44 keV, with the three gamma-rays with intensities known only as < 0.1 excluded. The recommended ACTI energies are simply the ENSDF energies. As discussed in section B, the ENSDF spectrum is identical to Har93 except for occasional rounding and the five gamma-rays listed in Table 5. The two gamma-rays in Table 5 that were observed by Har93 are included in the recommended ACTI spectrum. Their energies are from Har93, while their intensities are from ENSDF.

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
8998.40	52.3140	8998.41	50.000	4.63	50.889
8533.40	25.1100	8533.36	24.000	4.63	24.427
8120.50	4.4990	8120.51	4.300	4.63	4.376
7697.10	1.3078	7697.12	1.250	4.62	1.272
7264.10	0.2511	7264.05	0.236	6.40	0.240
6597.70	0.1046	6597.67	0.098	6.77	0.100
6583.90	2.7308	6583.85	2.610	4.63	2.656
6391.90	0.0314	6391.93	0.034	-7.68	0.035
6258.70	0.0419	6258.74	0.038	10.13	0.039
6141.20	0.0628	6141.20	0.061	2.91	0.062
6105.30	2.4587	6105.28	2.350	4.63	2.392
6030.30	0.0523	6030.34	0.051	2.58	0.052
5993.80	0.0314	5993.84	0.029	8.23	0.030
5973.00	0.9207	5973.01	0.880	4.63	0.896
5956.80	0.0628	5956.75	0.058	8.23	0.059
-----	-----	5817.19	3.600	-----	3.664
-----	-----	5754.36	0.018	-----	0.018
-----	-----	5701.76	0.039	-----	0.040
-----	-----	5676.80	0.014	-----	0.014
-----	-----	5636.80	0.010	-----	0.010
-----	-----	5631.99	0.016	-----	0.016
5621.40	0.1360	5621.41	0.126	7.95	0.128
5617.00	0.0837	5617.04	0.075	11.60	0.076
-----	-----	5590.00	0.005	-----	0.005
-----	-----	5565.96	0.019	-----	0.019
5546.60	0.0732	5546.62	0.066	10.97	0.067
5458.70	0.0837	5458.74	0.079	5.95	0.080
5435.80	0.6592	5435.77	0.630	4.63	0.641
5384.50	0.0314	5384.52	0.025	25.55	0.025
5362.70	0.0523	5362.67	0.045	16.25	0.046
5312.60	1.8205	5312.64	1.740	4.63	1.771
5292.70	0.0419	5292.69	0.038	10.13	0.039

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
-----	-----	5277.35	0.021	-----	0.021
5268.60	0.3557	5268.56	0.337	5.56	0.343
-----	-----	5237.00	0.003	-----	0.003
5223.40	0.0314	5223.38	0.027	16.25	0.027
-----	-----	5167.60	0.007	-----	0.007
5152.30	0.0523	5152.30	0.047	11.31	0.048
5145.20	0.1360	5145.18	0.131	3.83	0.133
5140.80	0.0314	5140.76	0.026	20.72	0.026
-----	-----	5115.90	0.007	-----	0.007
5109.10	0.1151	5109.06	0.108	6.56	0.110
-----	-----	5078.92	0.024	-----	0.024
5068.60	0.1151	5068.63	0.109	5.59	0.111
5044.90	0.0314	5044.89	0.030	4.63	0.031
4977.00	0.2616	4977.00	0.253	3.39	0.257
4949.70	0.1779	4949.68	0.165	7.80	0.168
4919.50	0.0314	4919.54	0.034	-7.68	0.035
-----	-----	4912.80	0.005	-----	0.005
4858.60	1.5276	4858.61	1.460	4.63	1.486
-----	-----	4841.20	0.012	-----	0.012
-----	-----	4823.91	0.023	-----	0.023
4805.10	0.0628	4805.10	0.059	6.40	0.060
-----	-----	4753.60	0.006	-----	0.006
4746.00	0.1256	4745.96	0.117	7.31	0.119
-----	-----	4729.19	0.017	-----	0.017
4715.00	0.2930	4715.04	0.284	3.15	0.289
4646.40	0.1256	4646.44	0.120	4.63	0.122
-----	-----	4629.20	0.019	-----	0.019
-----	-----	4603.90	0.012	-----	0.012
-----	-----	4565.99	0.009	-----	0.009
4506.50	0.0419	4506.50	0.040	4.63	0.041
4503.60	0.0523	4503.57	0.049	6.76	0.050
-----	-----	4459.20	0.002	-----	0.002
-----	-----	4452.80	0.007	-----	0.007
-----	-----	4442.54	0.008	-----	0.008

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	(%)	Iγ [a]
4428.50	0.0419	4428.49	0.037	13.11	0.038
-----	-----	4426.30	0.007	-----	0.007
-----	-----	4420.80	0.002	-----	0.002
-----	-----	4406.50	0.003	-----	0.003
-----	-----	4401.80	0.003	-----	0.003
4375.80	0.0628	4375.83	0.063	-0.36	0.064
4352.20	0.0628	4352.19	0.060	4.63	0.061
-----	-----	4332.40	0.003	-----	0.003
-----	-----	4314.50	0.011	-----	0.011
-----	-----	4295.55	0.019	-----	0.019
4283.70	0.4499	4283.67	0.426	5.61	0.434
4253.10	0.0732	4253.05	0.072	1.72	0.073
4250.10	0.0419	4250.06	0.042	-0.35	0.043
-----	-----	4244.70	0.009	-----	0.009
-----	-----	4223.20	0.004	-----	0.004
4191.00	0.1151	4190.96	0.110	4.63	0.112
4140.10	0.2302	4140.05	0.218	5.59	0.222
-----	-----	4090.79	0.011	-----	0.011
-----	-----	4083.23	0.016	-----	0.016
4049.90	0.3348	4049.94	0.321	4.30	0.327
4030.20	0.5231	4030.17	0.497	5.26	0.506
4022.00	0.0419	4021.96	0.035	19.57	0.036
4019.90	0.0314	4019.88	0.028	12.10	0.028
3952.20	0.0314	3952.24	0.032	-1.91	0.033
-----	-----	3937.49	0.010	-----	0.010
3930.00	0.4081	3930.01	0.392	4.09	0.399
-----	-----	3913.20	0.006	-----	0.006
-----	-----	3897.11	0.008	-----	0.008
3889.50	0.0628	3889.53	0.058	8.23	0.059
-----	-----	3880.10	0.005	-----	0.005
3858.00	0.0314	3858.04	0.025	25.55	0.025
3853.70	0.0419	3853.72	0.043	-2.67	0.044
-----	-----	3818.50	0.005	-----	0.005
3800.80	0.0732	3800.79	0.072	1.72	0.073

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
3787.90	0.0419	3787.85	0.040	4.63	0.041
3779.90	0.2616	3779.94	0.252	3.80	0.256
3767.40	0.0314	3767.43	0.032	-1.91	0.033
3730.20	0.1046	3730.19	0.098	6.77	0.100
-----	-----	3705.20	0.005	-----	0.005
3686.00	0.3871	3685.97	0.368	5.20	0.375
3675.20	1.0044	3675.23	0.960	4.63	0.977
3667.40	0.0523	3667.42	0.054	-3.12	0.055
-----	-----	3648.30	0.002	-----	0.002
3614.40	0.1883	3614.37	0.177	6.40	0.180
-----	-----	3585.20	0.004	-----	0.004
-----	-----	3578.60	0.003	-----	0.003
3562.90	0.2511	3562.91	0.241	4.19	0.245
-----	-----	3526.66	0.014	-----	0.014
3514.10	0.0628	3514.06	0.058	8.23	0.059
3452.40	0.0523	3452.30	0.046	13.73	0.047
-----	-----	3412.03	0.011	-----	0.011
3391.20	0.0419	3391.23	0.038	10.13	0.039
3388.80	0.0419	3388.79	0.036	16.25	0.037
3381.90	0.2406	3381.89	0.228	5.54	0.232
3377.10	0.0628	3377.14	0.064	-1.91	0.065
3367.10	0.2720	3367.05	0.260	4.63	0.265
3346.70	0.2406	3346.65	0.227	6.01	0.231
-----	-----	3334.59	0.007	-----	0.007
3296.60	0.1779	3296.62	0.173	2.82	0.176
3265.30	0.1988	3265.31	0.190	4.63	0.193
3262.30	0.0419	3262.32	0.043	-2.67	0.044
3244.60	0.0732	3244.58	0.074	-1.03	0.075
-----	-----	3234.08	0.011	-----	0.011
3221.10	0.5545	3221.11	0.530	4.63	0.539
3200.50	0.1256	3200.46	0.123	2.07	0.125
3181.60	0.4394	3181.59	0.422	4.13	0.430
-----	-----	3163.55	0.017	-----	0.017
3143.80	0.0732	3143.84	0.070	4.63	0.071

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
3136.80	0.0314	3136.75	0.025	25.55	0.025
-----	-----	3112.80	0.011	-----	0.011
3063.60	0.0732	3063.63	0.068	7.70	0.069
-----	-----	3051.14	0.015	-----	0.015
3041.80	0.1674	3041.77	0.155	8.00	0.158
3037.90	0.1674	3037.94	0.158	5.95	0.161
3025.70	0.4708	3025.73	0.454	3.70	0.462
-----	-----	3012.10	0.006	-----	0.006
3004.80	0.1151	3004.84	0.112	2.76	0.114
-----	-----	2987.12	0.013	-----	0.013
-----	-----	2980.59	0.011	-----	0.011
-----	-----	2975.50	0.006	-----	0.006
2968.50	0.3348	2968.52	0.320	4.63	0.326
2951.60	0.0628	2951.58	0.061	2.91	0.062
-----	-----	2912.28	0.018	-----	0.018
2897.70	0.1256	2897.70	0.119	5.50	0.121
2893.10	0.4499	2893.12	0.430	4.63	0.438
2857.60	0.1360	2857.56	0.127	7.10	0.129
2842.10	1.8519	2842.10	1.770	4.63	1.801
2808.20	0.3348	2808.19	0.320	4.63	0.326
-----	-----	2763.92	0.018	-----	0.018
-----	-----	2738.70	0.017	-----	0.017
-----	-----	2723.93	0.011	-----	0.011
2719.40	0.1256	2719.35	0.123	2.07	0.125
2716.60	0.0942	2716.62	0.092	2.35	0.094
2685.10	0.4394	2685.13	0.420	4.63	0.427
-----	-----	2661.38	0.009	-----	0.009
-----	-----	2616.66	0.022	-----	0.022
2574.60	0.0314	2574.62	0.032	-1.91	0.033
-----	-----	2560.55	0.022	-----	0.022
2554.10	1.6845	2554.14	1.610	4.63	1.639
-----	-----	2541.49	0.021	-----	0.021
-----	-----	2517.80	0.004	-----	0.004
-----	-----	2504.83	0.013	-----	0.013

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	(%)	Iγ [a]
2497.50	0.2302	2497.47	0.216	6.56	0.220
-----	-----	2460.76	0.014	-----	0.014
-----	-----	2450.52	0.012	-----	0.012
2437.20	0.1151	2437.16	0.108	6.56	0.110
2428.60	0.2930	2428.57	0.280	4.63	0.285
2422.10	0.1465	2422.14	0.140	4.63	0.142
2415.00	0.5127	2414.97	0.490	4.63	0.499
2401.00	0.2302	2400.95	0.221	4.15	0.225
2384.80	0.2720	2384.80	0.260	4.63	0.265
2303.70	0.1569	2303.69	0.151	3.93	0.154
-----	-----	2300.80	0.024	-----	0.024
-----	-----	2287.80	0.011	-----	0.011
-----	-----	2254.80	0.015	-----	0.015
-----	-----	2248.10	0.011	-----	0.011
2178.60	0.0837	2178.63	0.080	4.63	0.081
2147.90	0.4499	2147.91	0.430	4.63	0.438
2075.50	0.0942	2075.45	0.087	8.23	0.089
2050.80	0.0419	2050.78	0.043	-2.67	0.044
2015.70	0.5127	2015.70	0.490	4.63	0.499
1992.80	0.5022	1992.83	0.480	4.63	0.489
1950.10	1.7787	1950.05	1.700	4.63	1.730
-----	-----	1901.75	0.022	-----	0.022
1880.30	0.1360	1880.26	0.130	4.63	0.132
-----	-----	1865.30	0.012	-----	0.012
-----	-----	1837.40	0.017	-----	0.017
1816.80	0.0523	1816.76	0.049	6.76	0.050
1734.80	0.5545	1734.78	0.530	4.63	0.539
1728.80	0.0523	1728.81	0.048	8.99	0.049
1724.60	0.2302	1724.63	0.220	4.63	0.224
-----	-----	1717.30	0.009	-----	0.009
1704.90	0.1151	1704.86	0.109	5.59	0.111
1679.60	0.1256	1679.59	0.119	5.50	0.121
1663.10	0.1360	1663.10	0.130	4.63	0.132
-----	-----	1615.20	0.007	-----	0.007

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
-----	-----	1605.00	0.012	-----	0.012
-----	-----	1595.20	0.005	-----	0.005
1592.20	0.0419	1592.22	0.040	4.63	0.041
-----	-----	1568.48	0.014	-----	0.014
1537.00	0.6592	1536.95	0.630	4.63	0.641
1501.90	0.5127	1501.88	0.490	4.63	0.499
1446.90	0.3557	1446.90	0.340	4.63	0.346
1395.30	0.1674	1395.28	0.160	4.62	0.163
1392.90	0.1151	1392.92	0.105	9.61	0.107
1379.00	0.0628	1378.96	0.056	12.10	0.057
1362.80	0.0523	1362.80	0.053	-1.29	0.054
1340.30	0.6696	1340.30	0.640	4.63	0.651
1301.50	1.8833	1301.47	1.800	4.63	1.832
1269.70	0.1151	1269.70	0.112	2.76	0.114
1226.10	0.4290	1226.11	0.410	4.63	0.417
1213.90	0.0732	1213.92	0.073	0.33	0.074
-----	-----	1210.20	0.005	-----	0.005
1188.80	1.8833	1188.80	1.800	4.63	1.832
-----	-----	1158.80	0.006	-----	0.006
-----	-----	1148.31	0.012	-----	0.012
-----	-----	1132.21	0.015	-----	0.015
1114.00	0.0314	1114.00	0.031	1.25	0.032
1113.00	0.0314	1113.00	0.028	12.10	0.028
934.60	0.1988	934.60	0.190	4.63	0.193
877.97	7.9517	877.97	7.600	4.63	7.735
-----	-----	857.75	0.011	-----	0.011
849.37	0.0837	849.37	0.081	3.34	0.082
846.82	0.1465	846.82	0.140	4.63	0.142
-----	-----	843.57	0.017	-----	0.017
-----	-----	841.00	0.010	-----	0.010
836.46	0.3139	836.46	0.300	4.63	0.305
-----	-----	828.30	0.010	-----	0.010
-----	-----	801.81	0.013	-----	0.013
-----	-----	766.61	0.086	-----	0.088

Table 6: Comparison of preliminary ACTI and ENSDF spectra for ^{58}Ni

Preliminary ACTI Spectrum (ENSDF-based)		ENSDF		Difference Between Preliminary ACTI and ENSDF Iγ	Recommended ACTI Intensity[c]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	(%)	Iγ[a]
-----	-----	723.85	0.018	-----	0.018
712.75	0.0419	712.75	0.043	-2.67	0.044
545.90	0.0942	545.90	0.088	7.00	0.090
538.55	0.0942	538.55	0.086	9.49	0.088
465.00	24.0640	465.00	23.000	4.63	23.409
423.46	0.3139	423.47	0.300	4.63	0.305
339.42	7.4285	339.42	7.100	4.63	7.226
311.00	0.1046	311.00	< 0.1	4.63	-----
289.60	0.1046	289.60	< 0.1	4.63	-----
155.30	0.1046	155.30	< 0.1	4.63	-----
Total Yield (keV)	9000.008		8842.250[b]		8999.440[b]

[a]Number of photons per 100 neutron captures.
[b]Excluding gamma-rays with uncertain intensities.
[c]Intensity from ENSDF normalized to Q-value of Audi[8].

III. ^{60}Ni

A. Comparison of Experimental Data with ENSDF

The search for thermal-neutron capture data for ^{60}Ni resulted in eight experimental papers. Brief information for each paper as well as the ENSDF thermal-neutron capture spectrum for ^{60}Ni are given in Table 7.

Table 7: Comparison of sources of thermal-neutron capture data for ^{60}Ni

Author(s)	Designation	Year	Number of Gamma-Rays Listed	Yield of Listed Spectrum (keV)
ENSDF[6]	ENSDF	1977[c]	69	5445.51
A. Harder et al.[9]	Har93	1993	142	7676.06
S. Ulbig et al.[10]	Ulb91	1991	2	97.39
A. Ishaq et al.[11]	Ish77	1977	49	7693.15
W. Wilson et al.[13]	Wil75	1975	2	---[a]
R. Knerr and H. Vonach[14]	Kne71	1971	2	5244.02
F. Stecher-Rasmussen et al.[15]	Ste72	1972	4	5484.00
J. Kopecky et al.[17]	Kop72	1972	6[b]	5503.70
J. Gardien[18]	Gar70[d]	1970	???	???

[a]Only relative intensities were listed.
[b]Including one tentative gamma-ray not observed by any other experimenter.
[c]The latest data referenced by this evaluation is from 1977.
[d]This source, a 1970 French thesis, could not be located.

The ENSDF documentation for ^{60}Ni reveals that ENSDF is *not* equivalent to the latest experimental data. The latest experimental paper with the most complete gamma-ray spectrum is Har93. However, the ENSDF documentation references two older papers for its evaluation; Ish77 and Gar70[18]. Gar70 is a 1970 thesis by a student at the University of Paris, and was not present at the Los Alamos National Laboratory Library. It is unclear why ENSDF references Har93 for its ^{58}Ni evaluation, but not for ^{60}Ni. The ENSDF documentation states that most of its intensities come from Ish77, but they were normalized to match the capture-to-ground-state intensity of Gar70. This explains why the ENSDF yield is so far below the Q-value of the reaction (7820.04 keV), while the yield from Ish77 is fairly close to the Q-value, despite ENSDF having more lines.

The spectra of Har93, Ish77, and ENSDF are compared in Table 9. Also included are the Har93 intensities normalized to the Q-value of Audi. Other spectra were not included since they contain too few gamma-rays, or in the case of Gar70, could not be located. A line-by-line comparison of the spectra suggests that Har93 and Ish77 are in good agreement with each other, but in poor agreement with ENSDF. As a quantitative comparison, the average intensity disagreement between each pair of data sets was calculated as before, and the results are listed in Table 8. As with ^{58}Ni, the average intensity disagreement between Har93 and Ish77 is roughly 0.18, while the AID between ENSDF and either data set is much larger. Recall that *larger* AID values indicate *poorer* agreement.

B. Recommended ACTI Spectrum for ^{60}Ni

Since the spectrum from Har93 represents the latest and most complete spectral measurements, is in good agreement with the next-most recent and complete measurements (Ish77), and was obtained using compton-suppression techniques, it is the spectrum that should be used for ^{60}Ni. The intensities from Har93 normalized to the Q-value of Audi[8] are listed in Table 9, along with the Har93 energies.

Table 8: Average intensity disagreement between Har93, Ish77, and ENSDF

Pair of Data Sets	Average Intensity Disagreement
Har93 / ENSDF	0.399
Har93 / Ish77	0.178
Ish77 / ENSDF	1.999

Table 9: Comparison of ^{60}Ni spectra from Har93, Ish77, and ENSDF

Harder 1993		Ishaq 1977		ENSDF		Recommended ACTI Intensity[b]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
-----	-----	-----	-----	374	0.4	-----
282.9	-----	-----	-----	-----	-----	-----
529.225	0.27	-----	-----	529.2	0.5	0.275
588.5	0.124	-----	-----	-----	-----	0.126
650.28	0.039	-----	-----	-----	-----	0.040
652.63	0.026	-----	-----	-----	-----	0.026
656.048	0.95	-----	-----	655.3	1.3	0.968
701.11	0.029	-----	-----	-----	-----	0.030
816.72	1.73	-----	-----	815.9	2.2	1.762
820.8	0.046	-----	-----	-----	-----	0.047
841.29	0.094	-----	-----	-----	-----	0.096

Table 9: Comparison of ^{60}Ni spectra from Har93, Ish77, and ENSDF

Harder 1993		Ishaq 1977		ENSDF		Recommended ACTI Intensity[b]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
902.52	0.061	-----	-----	898.2	0.1	0.062
908.611	0.35	-----	-----	907.6	0.5	0.357
912.87	0.022	-----	-----	-----	-----	0.022
938.631	0.73	-----	-----	937.7	1	0.744
1021.1	0.041	-----	-----	1022.1	0.1	0.042
1032.249	0.26	-----	-----	1031.6	3.1	0.265
1064.987	0.15	-----	-----	1065.1	0.2	0.153
1073.65	0.101	-----	-----	1073.2	0.1	0.103
1099.679	1.25	-----	-----	1099.1	1.9	1.273
1132.411	0.28	-----	-----	1133.6	0.2	0.285
1185.302	2.3	-----	-----	1184.7	2.7	2.343
1253.22	0.022	-----	-----	-----	-----	0.022
1332.58	0.034	-----	-----	-----	-----	0.035
1402.25	0.012	-----	-----	-----	-----	0.012
1415.24	0.053	-----	-----	-----	-----	0.054
1446.78	0.089	-----	-----	1446.9	0.1	0.091
1501.81	0.037	-----	-----	-----	-----	0.038
1535.13	0.015	-----	-----	-----	-----	0.015
1542.43	0.105	-----	-----	1542.6	0.2	0.107
1609.88	0.091	-----	-----	-----	-----	0.093
1612.38	0.134	-----	-----	1611.7	0.2	0.137
1613.95	0.1	-----	-----	-----	-----	0.102
1621.82	0.112	-----	-----	-----	-----	0.114
1632.6	0.017	-----	-----	-----	-----	0.017
1662.28	0.093	-----	-----	1662.7	0.1	0.095
1665.31	0.031	-----	-----	-----	-----	0.032
1679.17	0.02	-----	-----	-----	-----	0.020
1729.76	0.077	-----	-----	1730.6	0.2	0.078
1857.31	0.013	-----	-----	-----	-----	0.013
1876.89	0.019	-----	-----	-----	-----	0.019
1959.68	0.085	-----	-----	-----	-----	0.087
2045.35	0.208	-----	-----	-----	-----	0.212
2099.4	0.125	-----	-----	-----	-----	0.127
2118.89	0.151	-----	-----	-----	-----	0.154
2124.015	6.3	2123.93	5.46	2123.93	3.74	6.418

Table 9: Comparison of ^{60}Ni spectra from Har93, Ish77, and ENSDF

Harder 1993		Ishaq 1977		ENSDF		Recommended ACTI Intensity[b]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
2129.76	0.132	-----	-----	-----	-----	0.134
2230.01	0.112	-----	-----	-----	-----	0.114
2249.4	0.007	-----	-----	-----	-----	0.007
2315.59	0.037	-----	-----	-----	-----	0.038
2356.75	0.018	-----	-----	-----	-----	0.018
2406.238	0.143	2406.24	0.14	2406.2	0.1	0.146
2482.6	0.065	-----	-----	-----	-----	0.066
2488.93	0.054	-----	-----	-----	-----	0.055
2536.49	0.012	-----	-----	-----	-----	0.012
2568.97	0.022	-----	-----	-----	-----	0.022
2572.56	0.015	-----	-----	-----	-----	0.015
2575.88	0.055	-----	-----	-----	-----	0.056
2580.75	0.036	-----	-----	-----	-----	0.037
2639.631	0.171	2639.84	0.2	2639.8	0.14	0.174
2644.2	0.023	-----	-----	-----	-----	0.023
2677.3	0.012	-----	-----	-----	-----	0.012
2684.57	0.017	-----	-----	-----	-----	0.017
2707.77	0.125	2706.6	0.11	2706.6	0.08	0.127
2764.67	0.068	2763.5	0.06	2763.5	0.04	0.069
2770.43	0.009	-----	-----	-----	-----	0.009
2779.11	0.014	-----	-----	-----	-----	0.014
2783.85	0.104	2782.9	0.08	2782.9	0.06	0.106
2795.55	0.015	-----	-----	-----	-----	0.015
2803.07	0.014	-----	-----	-----	-----	0.014
2856.7	0.071	-----	-----	-----	-----	0.072
2862.114	0.293	2861.73	0.33	2861.7	0.23	0.298
2868.23	0.014	-----	-----	-----	-----	0.014
2933.887	0.139	2934.1	0.14	2934.1	0.1	0.142
3012.83	0.136	3012.66	0.1	3012.7	0.07	0.139
3062.19	0.075	3062.7	0.07	3062.7	0.05	0.076
3077.55	0.029	3076.7	0.06	3076.7	0.04	0.030
3082.37	0.032	3089.7	0.07	3089.7	0.05	0.033
3106.95	0.052	3106.5	0.06	3106.5	0.04	0.053
3132.19	0.216	3131.9	0.21	3131.9	0.14	0.220
3139.49	0.017	-----	-----	-----	-----	0.017

Table 9: Comparison of ^{60}Ni spectra from Har93, Ish77, and ENSDF

Harder 1993		Ishaq 1977		ENSDF		Recommended ACTI Intensity[b]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
3144.93	0.177	3144.55	0.18	3144.6	0.12	0.180
3164.33	0.021	-----	-----	-----	-----	0.021
3213.76	0.029	-----	-----	-----	-----	0.030
3231.72	0.096	3232.2	0.09	3232.2	0.06	0.098
3242.67	0.068	3243.3	0.08	3243.3	0.06	0.069
3305.94	0.053	3305.54	0.07	3305.5	0.05	0.054
3347.56	0.031	-----	-----	-----	-----	0.032
3352.45	0.007	-----	-----	-----	-----	0.007
3380.45	0.113	-----	-----	-----	-----	0.115
3386.07	0.391	3385.6	0.37	3385.6	0.25	0.398
3415.08	0.204	3415.2	0.18	3415	0.12	0.208
3493.63	0.016	-----	-----	-----	-----	0.016
3525.38	0.016	3530.3	0.05	3530.3	0.03	0.016
3580.26	0.457	3580.72	0.5	3580.7	0.34	0.466
3584.02	0.123	-----	-----	-----	-----	0.125
3601.33	0.019	-----	-----	-----	-----	0.019
3641.3	0.094	3642	0.12	3642	0.08	0.096
3644.03	0.037	-----	-----	-----	-----	0.038
3670.29	0.008	-----	-----	-----	-----	0.008
3709.23	0.039	-----	-----	-----	-----	0.040
3711.36	0.285	3711.45	0.32	3711.4	0.22	0.290
3738.44	0.01	-----	-----	-----	-----	0.010
3777.46	0.024	-----	-----	-----	-----	0.024
3786.06	0.014	-----	-----	-----	-----	0.014
3831.31	0.009	-----	-----	-----	-----	0.009
-----	-----	3851.2	0.05	3851.2	0.03	-----
3864.12	0.009	-----	-----	-----	-----	0.009
3869.83	0.154	3869.78	0.14	3869.8	0.1	0.157
3895.93	0.018	3898.5	0.05	3898.5	0.03	0.018
3904.2	0.007	-----	-----	-----	-----	0.007
3950.06	0.233	3950.14	0.24	3950.1	0.16	0.237
3956.57	0.006	-----	-----	-----	-----	0.006
4043.41	0.12	4043.51	0.12	4043.5	0.08	0.122
4056.9	0.013	-----	-----	-----	-----	0.013
4081.5	0.061	4081.44	0.07	4081.4	0.05	0.062

Table 9: Comparison of ^{60}Ni spectra from Har93, Ish77, and ENSDF

Harder 1993		Ishaq 1977		ENSDF		Recommended ACTI Intensity[b]
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Iγ[a]
4108.61	0.457	4108.63	0.44	4108.63	0.3	0.466
4150.91	0.482	4150.92	0.46	4150.9	0.32	0.491
4177.5	0.004	-----	-----	-----	-----	0.004
4230.32	0.019	4228.8	0.05	4228.8	0.03	0.019
4239.62	0.234	4239.81	0.22	4239.8	0.15	0.238
4294.43	0.082	4294.6	0.08	4294.6	0.06	0.084
4404.72	0.649	-----	-----	4404.1	0.7	0.661
4456.6	0.012	-----	-----	-----	-----	0.012
4588.08	0.479	4588.23	0.47	4588.23	0.32	0.488
4603.03	0.008	-----	-----	-----	-----	0.008
4674.9	0.86	4675.4	0.83	4675.04	0.57	0.876
4713.02	0.026	-----	-----	-----	-----	0.026
4753.07	0.029	-----	-----	-----	-----	0.030
4757.6	0.209	4757.29	0.2	4757.3	0.14	0.213
4818.41	0.037	-----	-----	-----	-----	0.038
4885.69	0.019	-----	-----	-----	-----	0.019
4956.24	0.131	-----	-----	-----	-----	0.133
4962.73	0.033	-----	-----	-----	-----	0.034
4968.4	0.039	-----	-----	-----	-----	0.040
5045	0.017	-----	-----	-----	-----	0.017
5054.74	0.164	5054.9	0.14	5054.9	0.1	0.167
5112.1	0.047	-----	-----	-----	-----	0.048
5180.04	0.162	5180.1	0.15	5180.1	0.1	0.165
5695.67	6.43	5696.3	6.31	5696.03	4.32	6.551
6090.16	0.032	6091.2	0.03	6091.2	0.02	0.033
-----	-----	6249.5	0.02	6429.5	0.014	-----
6634.27	1.24	6634.79	1.15	6634.79	0.79	1.263
6719.89	2.4	6720.36	2.3	6720.4	1.57	2.445
-----	-----	6752.0	0.05	6752	0.03	-----
-----	-----	7164.3	0.07	7164.3	0.05	-----
7536.49	30.3	7537.29	32	7537.29	21.9	30.868
7819.42	53.3	7820.25	54.8	7820.25	37.5	54.300
Yield (keV)	7676.060	7693.149		5445.506		7820.040

[a]Number of photons per 100 neutron captures.

[b]From Har93, normalized to Q-value of Audi[8].

A comparison of the preliminary ACTI and ENSDF spectra for ^{60}Ni again revealed differences. The preliminary ACTI spectrum omits the 4404.1 keV line from ENSDF, and the documentation on the Nuclear Data for ACTI CRADA web page does not indicate why this was done. Except for this omission, the two spectra have the same number of lines, and the gamma-ray energies are the same. The preliminary ACTI intensities were normalized to the Q-value determined by Ish77 (7820.14 keV), and are therefore much higher than the ENSDF intensities since the ENSDF yield is so low. A full comparison of the spectra will not be presented since the data from Har93 is superior to both data sets.

IV. ^{61}Ni

A. Comparison of Experimental Data with ENSDF

The search for experimental papers resulted in only three sources of data for ^{61}Ni. All three sources predate 1976, and only one contains an appreciable amount of spectral information. Fortunately for the ACTI CRADA, only 0.61% of the thermal-neutrons captured in natural nickel are captured in ^{61}Ni, meaning ^{61}Ni contributes very little to the total gamma-ray spectrum of natural nickel. Brief information for each experimental source as well as the corresponding ENSDF evaluation are listed in Table 10. No preliminary ACTI spectrum for ^{61}Ni was created by T-2.

Table 10: Sources of thermal-neutron capture data for ^{61}Ni

Author(s)	Designation	Year	Number of Gamma-Rays Listed	Total Yield Listed (keV)
W. Wilson et al.[13]	Wil75	1975	7	---[b]
U. Fanger et al.[19]	Fan70	1970	76	5598.20
G. Bartholomew et al.[20]	Bar67	1967	6[c]	463.32[d]
ENSDF[6]	ENSDF	1970[a]	77	5911.66

[a]Based almost exclusively on Fan70.
[b]Only relative intensities are listed.
[c]Five of the six gamma-rays are listed as possibly being from other isotopes.
[d]This yield is based on the one gamma-ray known to be from ^{61}Ni.

The spectrum from each source is listed in Table 11. There are several important facts to note about these four spectra. First, the spectrum from Wil75 only contains relative intensities. The relative intensities were obtained by normalizing to the 8999.3 keV ^{59}Ni transition, which was arbitrarily set equal to 100. The isotopically-enriched target used in the experiments was obtained by irradiating a natural nickel sample in a neutron beam for two months. From known cross-sections and neutron fluxes, the authors then estimated the amount of ^{61}Ni in the irradiated sample. It is not clear how or if the uncertainty in ^{61}Ni enrichment was included in the quoted ^{61}Ni intensities. The absolute intensities listed in Table 11 were obtained by normalizing the 9422.3 keV line to the absolute intensity of Fan70. The two intense gamma-rays with energies of 10364.5 keV and 10490.9 keV were not observed by any other experimenter, and Wil75 states these may *not* be from ^{61}Ni.

Table 11: Comparison of thermal-neutron capture spectra for ^{61}Ni

ENSDF		Fanger 1970		Wilson 1975			Bartholomew 1967	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a] Rel. Int.	Iγ[a] Abs. Int.[b]	Iγ[a]	Eγ (keV)
264.94	0.1	264.94	0.1	-----	-----	-----	-----	-----
310.4	0.09	310.36	0.09	-----	-----	-----	-----	-----
450.4	0.04	450.4	0.04	-----	-----	-----	-----	-----
459.74	0.35	459.74	0.35	-----	-----	-----	-----	-----
464.63	1.5	464.63	1.5	-----	-----	-----	-----	-----
479.6	0.4	479.6	0.4	-----	-----	-----	-----	-----
579.42	0.55	579.42	0.55	-----	-----	-----	-----	-----
678.5	0.55	678.5	0.55	-----	-----	-----	-----	-----
703.1	0.2	703.1	0.2	-----	-----	-----	-----	-----
722	0.65	722	0.65	-----	-----	-----	-----	-----
756.8	1.55	756.76	1.55	-----	-----	-----	-----	-----
855.6	0.55	855.6	0.55	-----	-----	-----	-----	-----
875.64	14.3	875.64	14.3	-----	-----	-----	-----	-----
968.2	0.52	968.16	0.52	-----	-----	-----	-----	-----
1045.9	0.5	1045.90	0.50	-----	-----	-----	-----	-----
1067.6	0.35	1067.6	0.35	-----	-----	-----	-----	-----
1092.5	0.9	1092.50	0.9	-----	-----	-----	-----	-----
1128.73	6.8	1128.73	6.8	-----	-----	-----	-----	-----
1163.3	5.8	1163.3	5.8	-----	-----	-----	-----	-----
1172.8	76	1172.8	75.7	-----	-----	-----	-----	-----
1185.9	2.5	1185.85	2.5	-----	-----	-----	-----	-----
1220.8	5.2	1220.76	5.2	-----	-----	-----	-----	-----

Table 11: Comparison of thermal-neutron capture spectra for ^{61}Ni

ENSDF		Fanger 1970		Wilson 1975			Bartholomew 1967	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a] Rel. Int.	Iγ [a] Abs. Int.[b]	Iγ [a]	Eγ (keV)
1322.1	0.3	1322.1	0.30	-----	-----	-----	-----	-----
1455.2	0.4	1455.2	0.40	-----	-----	-----	-----	-----
1470.4	0.45	1470.4	0.45	-----	-----	-----	-----	-----
1548	0.5	1548.02	0.5	-----	-----	-----	-----	-----
1661.3	0.4	1661.3	0.4	-----	-----	-----	-----	-----
1718.26	1.2	1718.26	1.2	-----	-----	-----	-----	-----
1761	1	1760.97	1.0	-----	-----	-----	-----	-----
1815.8	0.4	1815.8	0.4	-----	-----	-----	-----	-----
1850	0.6	1850.0	0.6	-----	-----	-----	-----	-----
1886.2	1.7	1886.23	1.7	-----	-----	-----	-----	-----
1985.1	4.1	1985.13	4.1	-----	-----	-----	-----	-----
2084.2	4	2084.2	4.0	-----	-----	-----	-----	-----
2097.3	7.2	2097.32	7.2	-----	-----	-----	-----	-----
2289.7	0.28	2289.7	0.28	-----	-----	-----	-----	-----
2301.41	10.4	2301.41	10.4	-----	-----	-----	-----	-----
2345.64	4.5	2345.64	4.5	-----	-----	-----	-----	-----
2583.6	0.5	2583.6	0.5	-----	-----	-----	-----	-----
2799.4	1.8	2799.4	1.8	-----	-----	-----	-----	-----
3060	0.5	3060	0.5	-----	-----	-----	-----	-----
3158	1.7	3158	1.7	-----	-----	-----	-----	-----
3270	1.6	3270	1.6	-----	-----	-----	-----	-----
3370	1.6	3370	1.55	-----	-----	-----	-----	-----
3456	0.35	3456	0.35	-----	-----	-----	-----	-----
3518	0.3	3518	0.3	-----	-----	-----	-----	-----
3546	0.35	3546	0.35	-----	-----	-----	-----	-----
3828	0.55	3828	0.55	-----	-----	-----	-----	-----
3860	1.6	3860	1.6	-----	-----	-----	-----	-----
3972	1.2	3972	1.2	-----	-----	-----	-----	-----
4061	0.9	4061	0.9	-----	-----	-----	-----	-----
4318	0.25	4318	0.25	-----	-----	-----	-----	-----
4416	0.4	4416	0.4	-----	-----	-----	-----	-----
4998	0.45	4998	0.45	-----	-----	-----	-----	-----
5596	0.15	5596	0.15	-----	-----	-----	-----	-----
5877	0.3	5877	0.3	-----	-----	-----	-----	-----

Table 11: Comparison of thermal-neutron capture spectra for ^{61}Ni

ENSDF		Fanger 1970		Wilson 1975			Bartholomew 1967	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a] Rel. Int.	Iγ[a] Abs. Int.[b]	Iγ[a]	Eγ (keV)
5968	0.7	5968	0.7	-----	-----	-----	-----	-----
6179	1	6179	1.0	-----	-----	-----	-----	-----
6277	0.4	6277	0.4	-----	-----	-----	-----	-----
6364	0.5	6364	0.5	-----	-----	-----	-----	-----
6387	0.4	6387	0.4	-----	-----	-----	-----	-----
6395	0.5	6395	0.5	-----	-----	-----	-----	-----
6445	1.2	6445	1.2	-----	-----	-----	-----	-----
6532	1.8	6532	1.8	-----	-----	-----	-----	-----
6623	1.7	6623	1.7	-----	-----	-----	6629[c]	0.21
-----	-----	-----	-----	-----	-----	-----	6676[c]	0.16
-----	-----	-----	-----	-----	-----	-----	6716[c]	0.44
6738	1.2	6738	1.2	-----	-----	-----	-----	-----
6748	1.3	6748	1.3	-----	-----	-----	-----	-----
7073	1.5	7073	1.5	-----	-----	-----	-----	-----
7078	3.6	7078	3.6	-----	-----	-----	-----	-----
7326	4.8	7326	4.8	-----	-----	-----	-----	-----
7338	1.4	7338	1.4	-----	-----	-----	-----	-----
7436	2	7436	2.0	-----	-----	-----	-----	-----
7703.4	4	-----	-----	7703.4	0.16	4.21	7693[c]	0.79
8302.5	0.8	8296	0.8	8302.5	0.13	3.42	-----	-----
-----	-----	-----	-----	-----	-----	-----	8525[c]	13
8551.3	4.6	8545	4.6	8551.3	0.58	15.26	-----	-----
9422.3	5	9425	5.0	9422.3	0.19	5.00	9417	0.03
-----	-----	-----	-----	10364.5	0.11	2.89	-----	-----
-----	-----	-----	-----	10490.9	2.0	52.63	-----	-----
10594.6	3.7	10597	3.7	10594.6	0.16	4.21	-----	-----

[a]Number of photons per 100 neutron captures.
[b]Absolute intensity obtained by normalizing the 9422.3 keV line to the intensity of Fan70.
[c]Possibly from another isotope.

The ^{61}Ni spectrum from Bar67 contains five gamma-rays listed as possibly coming from other nickel isotopes. Since the intensities measured by Bar67 were obtained using a natural target, the full gamma-ray intensity arising from capture in pure ^{61}Ni is obtained by dividing the natural-nickel intensity by the ^{61}Ni contribution to the natural spectrum (0.0061). The resulting gamma-ray intensities from Bar67 are listed in Table 12. Note that if the natural-target intensities are accurate, only one gamma-ray (the 9417 keV line) is likely from ^{61}Ni. The other five gamma-rays have either physically impossible ^{61}Ni intensities (> 100 photons per 100 captures), or are large enough that they would certainly have been observed by other experimenters.

Table 12: Gamma-rays from Bar67

Energy (keV)	Intensity[a] in Natural Target	Intensity[a] in Pure ^{61}Ni Target (if actually from ^{61}Ni)
9417	0.03	4.92
8525	13	2131.15
7693	0.79	129.51
6716	0.44	72.13
6676	0.16	26.23
6629	0.21	34.43

[a]Number of photons per 100 neutron captures.

Finally, Fan70 is clearly the best source of data. It contains by far the most complete listing of gamma-rays, and its yield is closest to the Q-value of Audi (though still far below it). Whereas Bar67 observed only *one* likely ^{61}Ni(n,γ)^{62}Ni gamma-ray, Wil75 only lists relative intensities, and the methodology of Wil75 is not clear, Fan70 clearly details all experimental procedures and results.

Having made these observations about the ^{61}Ni spectra, we now turn to the ENSDF spectrum. Except for occasional rounding, the ENSDF spectrum is identical to the spectrum of Fan70 up to the 7436 keV line. The five remaining gamma-rays in the ENSDF spectrum, all above 7436 keV, differ somewhat from Fan70. Four of the five (the 8302.5 keV, 8551.3 keV, 9422.3 keV and 10594.6 keV lines) have the same intensities, but their energies are taken from the more precise measurements of Wil75. The energy and intensity of the fifth line (7703.4 keV, 4 photons per 100 captures) were apparently estimated from comparing the intensities given by Wil75 and Bar67. It is not clear why this line was included, while other lines listed only by Bar67 or Wil75 were not. Except for this one line ENSDF and Fan70 are basically identical.

B. Recommended ACTI Spectrum for ^{61}Ni

Since Fan70 represents the best source of data, the ENSDF spectrum for ^{61}Ni is essentially equivalent to the best available data. The ENSDF spectrum normalized to Audi's Q-value for the ^{61}Ni(n,γ)^{62}Ni reaction is listed in Table 13. This is the recommended ACTI spectrum. Note that the unnormalized yield (5911.66 keV) is well below the available energy (10597.23 keV). This leads to the most intense gamma-ray (1172.8 keV) having an unphysical *normalized* intensity of over 100 photons per 100 neutron captures. Since the sources of 72 gamma-rays observed by Fan70 could not be identified, it is likely that many transitions have been missed and better measurements are needed. In fact, even if the 72 unidentifiable gamma-rays from Fan70 are included, the yield is only 6380.77 keV, still far below the Q-value of 10597.23 keV.

Finally, a word of caution to potential users of this recommended spectrum. While it is based on the best available experimental data, the best available data is seriously inconsistent with the expected photon yield for this nuclide. To conserve energy in the codes that will use this spectrum, the recommended intensities have been significantly inflated. This should be fine when modeling problems with natural nickel since ^{61}Ni contributes so little (0.61%) to the overall photon production spectrum at thermal neutron energies. However, if pure ^{61}Ni is a significant portion of one's problem, these recommended intensities may be problematic. In such cases the unnormalized ENSDF intensities listed in Table 11 may be preferable.

Table 13: Recommended ACTI Spectrum for ^{61}Ni[b]

Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
264.94	0.179	1067.6	0.627
310.4	0.161	1092.5	1.613
450.4	0.072	1128.73	12.190
459.74	0.627	1163.3	10.397
464.63	2.689	1172.8	136.237
479.6	0.717	1185.9	4.481
579.42	0.986	1220.8	9.322
678.5	0.986	1322.1	0.538
703.1	0.359	1455.2	0.717
722	1.165	1470.4	0.807
756.8	2.779	1548	0.896
855.6	0.986	1661.3	0.717
875.64	25.634	1718.26	2.151
968.2	0.932	1761	1.793
1045.9	0.896	1815.8	0.717

Table 13: Recommended ACTI Spectrum for $^{61}Ni^b$

Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
1850	1.076	5596	0.269
1886.2	3.047	5877	0.538
1985.1	7.350	5968	1.255
2084.2	7.170	6179	1.793
2097.3	12.907	6277	0.717
2289.7	0.502	6364	0.896
2301.41	18.643	6387	0.717
2345.64	8.067	6395	0.896
2583.6	0.896	6445	2.151
2799.4	3.227	6532	3.227
3060	0.896	6623	3.047
3158	3.047	6738	2.151
3270	2.868	6748	2.330
3370	2.868	7073	2.689
3456	0.627	7078	6.453
3518	0.538	7326	8.604
3546	0.627	7338	2.510
3828	0.986	7436	3.585
3860	2.868	7703.4	7.170
3972	2.151	8302.5	1.434
4061	1.613	8551.3	8.246
4318	0.448	9422.3	8.963
4416	0.717	10594.6	6.633
4998	0.807		

[a]Number of photons per 100 neutron captures.
[b]Data are from ENSDF with the intensities normalized to match the yield of Audi[8].

V. ^{62}Ni

A. Comparison of Experimental Data with ENSDF

The search for experimental data resulted in six papers with thermal-neutron capture data for ^{62}Ni, only two of which contain an appreciable amount of spectral information. Brief information for each paper as well as the ENSDF data for ^{62}Ni are given in Table 14. As will be seen, the ENSDF thermal-neutron capture spectrum for ^{62}Ni is *not* equivalent to the latest experimental data.

Table 14: Sources of thermal-neutron capture data for ^{62}Ni

Author(s)	Designation	Year	Number of Gamma-Rays Listed	Yield of Listed Spectrum (keV)
S. Ulbig et al.[10]	Ulb91	1991	1	14.03
A. Ishaq et al.[11]	Ish77	1977	36	6826.88
R. Knerr and H. Vonach[14]	Kne71	1971	1	2871.54
F. Stecher-Rasmussen et al.[15]	Ste72	1972	2	3048.00
J. Kopecky et al.[17]	Kop72	1972	5	5923.04
A. Harder et al.[21]	Har92	1992	93	6839.51
ENSDF[6]	ENSDF	1977[a]	46	6889.30

[a]Latest paper referenced is Ish77.

The only two sources of experimental data that contain appreciable amounts of information for ^{62}Ni are Ish77 and Har92. Of these two, Har92 was able to identify more than twice the number of gamma-rays. Har92 also observed a yield only 1.7 keV different than the Q-value listed by Audi, compared with a difference of 11.0 keV for Ish77. Since Har92 also comprises the latest experimental measurements, it represents the best source of data.

When ENSDF is compared to Har92 and Ish77, significant differences are found. The ENSDF documentation explains the differences. While Ish77 is referenced in the ENSDF evaluation, Har92 is not. Instead, the 1970 French thesis referenced by ENSDF for ^{60}Ni (designated earlier as Gar70[18]) is used. The spectra from ENSDF, Har92, and Ish77 are compared in Table 15. As discussed earlier, Gar70 could not be found for comparison.

Table 15: Comparison of ^{62}Ni spectra from ENSDF, Har92, and Ish77

Harder 1992		ENSDF		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
-----	-----	86.8	-----	-----	-----
155.505	----- [b]	155.5	7	-----	-----
322.36	----- [b]	-----	-----	-----	-----
362.423	----- [b]	362.1	2.9	-----	-----
430.707	----- [b]	430.7	0.07	-----	-----
483.380	3.8	483.2	1.49	-----	-----
517.910	0.86	517.3	0.36	-----	-----
805.84	0.055	-----	-----	-----	-----
845.739	4.2	845.5	1.66	-----	-----
913.961	0.097	-----	-----	-----	-----
981.813	0.075	-----	-----	-----	-----
1001.259	0.25	1001.1	0.11	-----	-----
1069.15	0.053	-----	-----	-----	-----
1168.152	1.17	1168.2	0.53	-----	-----
1236.502	0.40	1237	0.14	-----	-----
1323.651	0.51	1324.1	0.22	-----	-----
1474.09	0.056	-----	-----	-----	-----
1506.32	0.046	-----	-----	-----	-----
1512.71	0.041	-----	-----	-----	-----
1581.38	0.020	-----	-----	-----	-----
1621.76	0.039	-----	-----	-----	-----
1623.26	0.027	-----	-----	-----	-----
1659.38	0.061	-----	-----	-----	-----
1691.39	0.029	-----	-----	-----	-----
1694.60	0.023	-----	-----	-----	-----
1719.47	0.045	-----	-----	-----	-----
1762.04	0.019	-----	-----	-----	-----
1844.22	0.041	-----	-----	-----	-----
1889.29	0.022	-----	-----	-----	-----
1900.83	0.034	-----	-----	-----	-----
2042.76	0.044	-----	-----	-----	-----
2070.75	0.046	-----	-----	-----	-----
2177.94	0.046	-----	-----	-----	-----
2265.66	0.079	2265.9	0.07	2265.88	0.07

Table 15: Comparison of ^{62}Ni spectra from ENSDF, Har92, and Ish77

Harder 1992		ENSDF		Ishaq 1977	
Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]	Eγ (keV)	Iγ [a]
2352.92	0.354	2353.1	0.3	2353.10	0.30
2378.88	0.123	2379.2	0.12	2379.23	0.12
2452.71	0.066	-----	-----	-----	-----
2525.61	0.046	2525.8	0.05	2525.8	0.05
2540.443	0.285	2540.9	0.23	2540.93	0.23
2577.63	0.023	-----	-----	-----	-----
2632.30	0.044	-----	-----	-----	-----
2695.920	0.167	2696.8	0.11	2696.77	0.11
2783.43	0.126	2784	0.12	2783.96	0.12
2821.90	0.025	-----	-----	-----	-----
2858.75	0.019	-----	-----	-----	-----
2941.49	0.029	-----	-----	-----	-----
2986.60	0.030	-----	-----	-----	-----
3041.28	0.028	-----	-----	-----	-----
3047.23	0.027	-----	-----	-----	-----
3098.97	0.498	3099.4	0.48	3099.41	0.48
3115.82	0.050	3115.1	0.04	3115.1	0.04
3127.91	0.090	3128.5	0.04	3128.5	0.04
3151.88	0.091	-----	-----	-----	-----
3204.52	0.187	-----	-----	-----	-----
3206.69	0.090	3205.6	0.26	3205.60	0.26
3221.05	0.027	3221.6	0.02	3221.6	0.02
3236.57	0.024	3237.4	0.01	3237.4	0.01
3256.52	0.053	3256.6	0.05	3256.55	0.05
3362.22	0.043	3363.1	0.03	3363.1	0.03
3419.79	0.086	3419.6	0.07	3419.59	0.07
3475.93	0.114	3476.9	0.13	3476.91	0.13
3530.37	0.016	-----	-----	-----	-----
3554.39	0.119	3555	0.08	3555.00	0.08
3583.48	0.132	3584	0.13	3583.97	0.13
3601.39	0.040	3601.5	0.04	3601.45	0.04
3634.29	0.022	3635.8	0.03	3635.8	0.03
3651.69	0.110	3652.1	0.1	3652.05	0.10
3738.94	0.106	3740.3	0.11	3740.32	0.11
3794.19	0.013	-----	-----	-----	-----
3823.57	0.028	3824.7	0.02	3824.7	0.02

Table 15: Comparison of ^{62}Ni spectra from ENSDF, Har92, and Ish77

Harder 1992		ENSDF		Ishaq 1977	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
3899.05	0.030	3900	0.03	3900.0	0.03
4054.45	0.060	4055.7	0.04	4055.7	0.04
4134.43	0.006	-----	-----	-----	-----
4141.94	0.516	4142.5	0.46	4142.52	0.46
4171.86	0.015	4176	0.01	4176.1	0.01
4225.08	0.011	-----	-----	-----	-----
4293.37	0.009	-----	-----	-----	-----
4295.69	0.007	-----	-----	-----	-----
4330.31	0.016	-----	-----	-----	-----
4331.69	0.015	4331.9	0.03	4331.86	0.03
4362.41	0.016	-----	-----	-----	-----
4458.97	0.043	4460.8	0.04	4460.8	0.04
4484.78	0.363	4485.7	0.36	4485.71	0.36
4660.17	0.011	-----	-----	-----	-----
5022.72	0.015	-----	-----	-----	-----
5209.00	0.010	-----	-----	-----	-----
5248.10	0.011	-----	-----	-----	-----
5254.67	0.022	-----	-----	-----	-----
5513.89	1.63	5514.6	1.7	5514.64	1.70
5820.50	0.011	-----	-----	-----	-----
5836.22	6.30	5837	6.5	5837.03	6.52
6319.48	4.05	6320.3	4.1	6320.34	4.10
6681.88	1.42	6682.6	1.47	6682.63	1.47
6837.4	84.5	6838.2	86	6838.16	85.9
Yield (keV)	6839.505	6889.300		6826.878	

[a]Number of photons per 100 neutron captures.
[b]Intensity could not be determined.

An inspection of the ENSDF spectrum reveals that, except for a few instances of rounding, it is equivalent to Ish77 from the 2265.9 keV line and up. Ish77 only lists gamma-rays above this energy. The 11 ENSDF gamma-rays below the 2265.9 keV line are apparently from Gar70.

A comparison of ENSDF and Har92 reveals good agreement in the region above the 2265.9 keV line (where ENSDF = Ish77), but poor agreement below this energy (where ENSDF = Gar70). If we calculate the average intensity disagreement between ENSDF and Har92 in these two energy regions (see Section II for a definition of the AID) this observation is substantiated. The AID between ENSDF and Har92 for each region is listed in Table 16.

Table 16: AID between ENSDF and Har92 in different energy regions

Energy Region (E_γ in keV)	AID
0.0 - 2177.9	0.835
2265.9 - 6838.2[a]	0.220
all energies	0.320

[a]The highest energy gamma-ray in any paper.

Har92 agrees well with ENSDF from 2265.9 keV and up, and also agrees well with Ish77. Since Har92 could not determine intensities for the 155.5 keV, 362.4 keV, and 430.7 keV lines (they were below his first calibration point), the intensities from ENSDF (Gar70) must be used.

A quick comparison of the T-2 and ENSDF spectra revealed that except for three small differences they are equivalent. Since ENSDF does not represent the best possible data for ^{62}Ni, and the preliminary ACTI spectrum created by T-2 is based on ENSDF, no detailed analysis of the preliminary ACTI spectrum will be presented.

B. Recommended ACTI Spectrum for ^{62}Ni

The recommended spectrum of gamma-rays from thermal-neutron capture in ^{62}Ni is listed in Table 17. Except for the three low-energy gamma-rays taken from ENSDF (Gar70), the data is from Har92 and the intensities have been normalized to Audi's Q-value. Note that the final spectrum has an *unnormalized* yield only 0.34% different than the Q-value of Audi.

Table 17: Recommended ACTI spectrum for ^{62}Ni

Eγ (keV)	Iγ [a]	Source	Eγ (keV)	Iγ [a]	Source
155.505	6.976	ENSDF[b]	2525.61	0.046	Har92
362.423	2.890	ENSDF[b]	2540.443	0.284	Har92
430.707	0.070	ENSDF[b]	2577.63	0.023	Har92
483.380	3.787	Har92	2632.30	0.044	Har92
517.910	0.857	Har92	2695.920	0.166	Har92
805.84	0.055	Har92	2783.43	0.126	Har92
845.739	4.186	Har92	2821.90	0.025	Har92
913.961	0.097	Har92	2858.75	0.019	Har92
981.813	0.075	Har92	2941.49	0.029	Har92
1001.259	0.249	Har92	2986.60	0.030	Har92
1069.15	0.053	Har92	3041.28	0.028	Har92
1168.152	1.166	Har92	3047.23	0.027	Har92
1236.502	0.399	Har92	3098.97	0.496	Har92
1323.651	0.508	Har92	3115.82	0.050	Har92
1474.09	0.056	Har92	3127.91	0.090	Har92
1506.32	0.046	Har92	3151.88	0.091	Har92
1512.71	0.041	Har92	3204.52	0.186	Har92
1581.38	0.020	Har92	3206.69	0.090	Har92
1621.76	0.039	Har92	3221.05	0.027	Har92
1623.26	0.027	Har92	3236.57	0.024	Har92
1659.38	0.061	Har92	3256.52	0.053	Har92
1691.39	0.029	Har92	3362.22	0.043	Har92
1694.60	0.023	Har92	3419.79	0.086	Har92
1719.47	0.045	Har92	3475.93	0.114	Har92
1762.04	0.019	Har92	3530.37	0.016	Har92
1844.22	0.041	Har92	3554.39	0.119	Har92
1889.29	0.022	Har92	3583.48	0.132	Har92
1900.83	0.034	Har92	3601.39	0.040	Har92
2042.76	0.044	Har92	3634.29	0.022	Har92
2070.75	0.046	Har92	3651.69	0.110	Har92
2177.94	0.046	Har92	3738.94	0.106	Har92
2265.66	0.079	Har92	3794.19	0.013	Har92
2352.92	0.353	Har92	3823.57	0.028	Har92
2378.88	0.123	Har92	3899.05	0.030	Har92
2452.71	0.066	Har92	4054.45	0.060	Har92

Table 17: Recommended ACTI spectrum for ^{62}Ni

Eγ (keV)	Iγ[a]	Source	Eγ (keV)	Iγ[a]	Source
4134.43	0.006	Har92	4660.17	0.011	Har92
4141.94	0.514	Har92	5022.72	0.015	Har92
4171.86	0.015	Har92	5209.00	0.010	Har92
4225.08	0.011	Har92	5248.10	0.011	Har92
4293.37	0.009	Har92	5254.67	0.022	Har92
4295.69	0.007	Har92	5513.89	1.624	Har92
4330.31	0.016	Har92	5820.50	0.011	Har92
4331.69	0.015	Har92	5836.22	6.279	Har92
4362.41	0.016	Har92	6319.48	4.036	Har92
4458.97	0.043	Har92	6681.88	1.415	Har92
4484.78	0.362	Har92	6837.4	84.212	Har92

[a]Number of photons per 100 neutron captures, normalized to a yield of 6837.85 keV.
[b]Intensity is from ENSDF, energy is from Har92.

VI. ^{64}Ni

A. Comparison of Experimental Data with ENSDF

Of all the stable nickel isotopes, ^{64}Ni contributes the least to the thermal-neutron capture spectrum of natural nickel (only 0.32%). Nevertheless, the search for experimental data yielded three papers with appropriate spectral information for ^{64}Ni. Brief information on each paper as well as the ENSDF evaluation for ^{64}Ni are given in Table 18. The spectra from each source are compared in Table 19.

Table 18: Sources of thermal-neutron capture data for ^{64}Ni

Author(s)	Designation	Year	Number of Gamma-Rays Listed	Yield of Listed Spectrum (keV)
A. Ishaq et al.[11]	Ish77	1977	22	5866.16
S. Arnell et al.[22]	Arn71	1971	17	6138.26
S. Cochavi and W. Kane[23]	Coc72	1972	16	6189.22
ENSDF[6]	ENSDF	1977[a]	46	6117.86

[a]Latest data source referenced is Ish77.

Table 19: Comparison of thermal-neutron capture data for ^{64}Ni

ENSDF		Ish77		Coc72		Arn71	
Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
63.6	12	-----	-----	63.6	13	-----	-----
247.1	0.5	-----	-----	247.1	0.5	-----	-----
310.2	22	-----	-----	310.5	23.0	310.2	29.1
382	0.7	-----	-----	382.0	0.7	367.1	???
629	7	-----	-----	628.8	7.3	629.0	8.7
692.6	1.4	-----	-----	692.2	1.5	692.6	1.6
726	0.2	-----	-----	726	0.2	-----	-----
1107.4	3.6	-----	-----	1107.4	3.8	1108.1	5.3
-----	-----	-----	-----	-----	-----	1115.5	???
1346	2.4	-----	-----	-----	-----	1346.0	2.5
1418	0.2	-----	-----	1418	0.2	-----	-----
-----	-----	-----	-----	-----	-----	1482.2	???
2083.8	0.6	-----	-----	2083.8	0.6	2082.7	0.9
2146.7	0.62	2146.68	0.62	2147.2	0.3	-----	-----
2401.5	0.58	2401.46	0.58	3950.2	1.1	2400.5	0.6
2647.9	0.22	2647.94	0.22	-----	-----	-----	-----
2810.4	0.07	2810.4	0.07	-----	-----	-----	-----
2819.7	0.19	2819.74	0.19	-----	-----	-----	-----
3088.6	0.26	3088.64	0.26	-----	-----	-----	-----
3099.8	0.07	3099.8	0.07	-----	-----	-----	-----
3219.3	0.11	3219.3	0.11	-----	-----	-----	-----
3386.7	0.83	3386.73	0.83	-----	-----	3387.6	0.8
3651	0.08	3651.0	0.08	-----	-----	-----	-----
3773.7	0.3	3773.74	0.32	-----	-----	3773.6	0.4
3852.8	0.1	3852.80	0.10	-----	-----	-----	-----
3951.4	1.13	3951.41	1.13	-----	-----	3951.9	1.2
3963.1	0.08	3963.1	0.08	-----	-----	-----	-----
4178.1	0.12	4178.10	0.12	-----	-----	-----	-----
4680.3	3.81	4680.31	3.81	4679.5	3.8	4681.0	3.8
4730.2	0.06	4730.2	0.06	-----	-----	-----	-----
5405.8	8.9	5405.82	8.86	5405.2	9.2	5405.7	8.9
5419.9	0.14	5419.9	0.14	-----	-----	-----	-----
5752.7	0.08	5752.7	0.08	-----	-----	-----	-----
5787.8	17.7	5787.83	17.74	5787.1	18	5788.2	18.6
6034.8	67	6034.85	66.5	6034.0	70	6035.1	66.8
Yield (keV)	6117.863	5866.164		6189.221		6138.255	

[a]Number of photons per 100 neutron captures.

An analysis of Table 19 shows that ENSDF represents the best possible combination of the available experimental data. To see this, one must compare the spectra in two energy regions since Ish77 does not list gamma-rays with energies below about 2 MeV. In the region above 2 MeV, there is excellent agreement between Ish77 and Arn71 for all gamma-rays. Except for the 2147 keV line, there is also excellent agreement with Coc72. Since the spectra agree so well in this energy region, ENSDF simply adopts the values from Ish77, the most recent paper. Again, there is slight rounding (for example 66.5 becomes 67 in ENSDF) but ENSDF is basically equivalent to Ish77.

The ENSDF spectrum below 2 MeV consists of a combination of Arn71 and Coc72. The 1346 keV line seen only by Arn71 was included in the ENSDF spectrum. The remaining lines were taken from Coc72. Coc72 was probably chosen because both Coc72 and Arn71 have yields in excess of the available energy (6098.01 keV from Audi) and Coc72 has lower intensities. The intensities taken from Coc72 were re-normalized by the same factor required to normalize the 6034 keV line to the corresponding intensity given in Ish77. The result is an ENSDF spectrum that includes *all* measured gamma-rays and comes closer to the correct yield. Again there is slight rounding, but the ENSDF spectrum essentially represents the best possible thermal-neutron capture data for ^{64}Ni.

B. Comparison of Preliminary ACTI Spectrum with ENSDF

When the preliminary ACTI spectrum created by T-2 is compared to ENSDF there are once again slight differences. The preliminary ACTI spectrum omits the 1346 keV line, perhaps because it was only observed by Arn71, although the T-2 ACTI CRADA web site does not indicate why. The preliminary ACTI spectrum also adopts the intensities from Ish77 without rounding. This results in slight intensity differences with ENSDF for three gamma-rays.

C. Recommended ACTI Spectrum for ^{64}Ni

The preliminary ACTI and ENSDF spectra are compared in Table 20. Also included are the ENSDF intensities normalized to the Q-value of Audi. The ENSDF energies and normalized ENSDF intensities form the recommended ACTI spectrum for ^{64}Ni.

Table 20: Comparison of preliminary ACTI and ENSDF spectra for ^{64}Ni

Preliminary ACTI Spectrum		ENSDF		Recommended ACTI Intensity[a]
Eγ (keV)	Iγ[b]	Eγ (keV)	Iγ[b]	Iγ[b]
63.6	12	63.6	12	11.961
247.1	0.5	247.1	0.5	0.498
310.2	22	310.2	22	21.929
382	0.7	382.0	0.7	0.698
629	7	629.0	7	6.977
692.6	1.4	692.6	1.4	1.395
726	0.2	726.0	0.2	0.199
1107.4	3.6	1107.4	3.6	3.588
-----	-----	1346.0	2.4	2.392
1418	0.2	1418.0	0.2	0.199
2083.8	0.6	2083.8	0.6	0.598
2146.7	0.62	2146.7	0.62	0.618
2401.5	0.58	2401.5	0.58	0.578
2647.9	0.22	2647.9	0.22	0.219
2810.4	0.07	2810.4	0.07	0.070
2819.7	0.19	2819.7	0.19	0.189
3088.6	0.26	3088.6	0.26	0.259
3099.8	0.07	3099.8	0.07	0.070
3219.3	0.11	3219.3	0.11	0.110
3386.7	0.83	3386.7	0.83	0.827
3651	0.08	3651.0	0.08	0.080
3773.7	0.32	3773.7	0.3	0.299
3852.8	0.1	3852.8	0.1	0.100
3951.4	1.13	3951.4	1.13	1.126
3963.1	0.08	3963.1	0.08	0.080
4178.1	0.12	4178.1	0.12	0.120
4680.3	3.81	4680.3	3.81	3.798
4730.2	0.06	4730.2	0.06	0.060
5405.8	8.9	5405.8	8.9	8.871
5419.9	0.14	5419.9	0.14	0.140
5752.7	0.08	5752.7	0.08	0.080
5787.8	17.74	5787.8	17.7	17.643
6034.8	66.5	6034.8	67	66.783
Yield (keV)	6058.454	6117.863		6098.010

[a]Intensity from ENSDF normalized to Q-value of Audi[8].
[b]Number of photons per 100 neutron captures.

VII. Summary

Several sources of thermal-neutron capture data for the stable nickel isotopes have been compared. Based on the comparisons, spectra for use by ACTI applications have been recommended for each isotope.

First, thermal-neutron capture spectra from ENSDF were obtained through Dr. Tuli of the National Nuclear Data Center (NNDC) and compared to experimental data. Except for occasional instances of rounding, the ENSDF spectra for ^{58}Ni, ^{61}Ni, and ^{64}Ni are equivalent to the best available experimental data. The ENSDF spectra for ^{60}Ni and ^{62}Ni are *not* equivalent to the best available experimental data. Using the best available data, spectra for these two isotopes were derived and presented.

The thermal-neutron capture spectra derived from ENSDF by T-2 (the preliminary ACTI spectra) were then compared to ENSDF. For ^{58}Ni, significant differences were found which are not fully explained in the documentation on the ACTI CRADA web site (the source of the preliminary ACTI data). For ^{60}Ni, ^{62}Ni, and ^{64}Ni, slight differences between ENSDF and the preliminary ACTI spectra were found. No preliminary ACTI spectrum for ^{61}Ni was produced by T-2.

Photon production data for iron will be evaluated next. As with nickel, data from ENSDF, experimental papers, and the preliminary ACTI library will be compared to determine which source is best. This research note and the previous research note on the chromium isotopes (XTM-RN(U)97-010) have shown that ENSDF *usually* represents the best available data. However, this is not always so, and care should be taken in using the ENSDF (or any other) evaluation. Perhaps more importantly, ENSDF is extremely useful as a source of references. In all of my research done to date, a useful reference *not listed* by ENSDF has never been found, provided one looks in the time period prior to the latest ENSDF reference. In other words, if ENSDF's latest reference is from 1977, you can bet it's impossible to find a useful reference *prior* to 1977 that is not listed by ENSDF. As we have seen with nickel, it may however be possible to find a more recent and better reference. Of course these observations only apply to thermal-neutron capture data.

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Addendum to Report

As discussed in Section IV part B of this report, the experimental thermal-neutron capture data for ^{61}Ni are probably incomplete since the total yield of the capture spectrum is only about 56% of the Q-value for neutron capture. (All other experimental spectra considered for the ACTI work are within 5% of the Q-value.) Normalization of the spectrum to the Q-value conserved energy, but led to physically unrealistic gamma-ray intensities.

After further discussion, it was decided that conserving energy in the ^{61}Ni spectrum (and therefore allowing accurate heating calculations) is less important than providing accurate gamma-ray intensities. Therefore, the recommended ACTI spectrum for ^{61}Ni should *not be normalized*. The new recommended ACTI spectrum (unnormalized) for ^{61}Ni is listed below. It is simply the ENSDF spectrum listed in Table 11 with the experimental uncertainties in E_γ and I_γ suppressed.

Table 21: New Recommended ACTI spectrum for ^{61}Ni[a]

Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
264.94	0.10	1455.20	0.40
310.40	0.09	1470.40	0.45
450.40	0.04	1548.00	0.50
459.74	0.35	1661.30	0.40
464.63	1.50	1718.26	1.20
479.60	0.40	1761.00	1.00
579.42	0.55	1815.80	0.40
678.50	0.55	1850.00	0.60
703.10	0.20	1886.20	1.70
722.00	0.65	1985.10	4.10
756.80	1.55	2084.20	4.00
855.60	0.55	2097.30	7.20
875.64	14.30	2289.70	0.28
968.20	0.52	2301.41	10.40
1045.90	0.50	2345.64	4.50
1067.60	0.35	2583.60	0.50
1092.50	0.90	2799.40	1.80
1128.73	6.80	3060.00	0.50
1163.30	5.80	3158.00	1.70
1172.80	76.00	3270.00	1.60
1185.90	2.50	3370.00	1.60
1220.80	5.20	3456.00	0.35
1322.10	0.30	3518.00	0.30

Table 21: New Recommended ACTI spectrum for ^{61}Ni[a]

Eγ (keV)	Iγ[a]	Eγ (keV)	Iγ[a]
3546.00	0.35	6445.00	1.20
3828.00	0.55	6532.00	1.80
3860.00	1.60	6623.00	1.70
3972.00	1.20	6738.00	1.20
4061.00	0.90	6748.00	1.30
4318.00	0.25	7073.00	1.50
4416.00	0.40	7078.00	3.60
4998.00	0.45	7326.00	4.80
5596.00	0.15	7338.00	1.40
5877.00	0.30	7436.00	2.00
5968.00	0.70	7703.40	4.00
6179.00	1.00	8302.50	0.80
6277.00	0.40	8551.30	4.60
6364.00	0.50	9422.30	5.00
6387.00	0.40	10594.60	3.70
6395.00	0.50		

[a]Number of photons per 100 neutron captures.