NUCLEAR ASTROPHYSICS & NEUTRON CROSS SECTION MEASUREMENTS

Final Report

1 January 2006 31 July 2008

Robert F. Carlton
Director
Principal Investigator
Dept. of Physics & Astronomy

Dr. Myra Norman,
Sponsored Programs

Middle Tennessee State University
Murfreesboro, Tennessee 37132
February 2005

Prepared for
THE U.S. DEPARTMENT OF ENERGY
Under Contract No. DE-FG05-86ER40293

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, produce or process disclosed or represents that its use would not infringe privately owned rights

Summary Survey of Research

(Contract # DE 86ER-40293)

This enduring research program of 28 years has taken advantage of the excellent research facility of ORELA at Oak Ridge National Laboratory. The fruitful collaborations include a number of scientists from ORNL and some from LASL. This program which has ranged from nuclear structure determinations to astrophysical applications has resulted in the identification and/or the refinement of the nuclear properties of more than 5,000 nuclear energy levels or compound energy states. The nuclei range from ^{30}Si to ^{250}Cf , the probes range from thermal to 50 MeV neutrons, and the studies range from capture gamma ray spectra to total and differential scattering and absorption cross sections. Specific target nuclei studied include the following:

^{120}Sn	^{124}Sn	^{125}Sn	^{113}Sn
^{115}Sn	^{117}Sn	^{119}Sn	^{249}Cf
^{33}S	^{34}S	^{249}Bk	^{186}Os
^{187}Os	^{188}Os	^{30}Si	^{32}S
^{40}Ca	^{48}Ca	^{60}Ni	^{54}Fe
^{86}Kr	^{88}Sr	^{40}Ar	^{122}Sn
^{90}Zr	$^{122}\text{Sn}(n,\gamma)$	^{208}Pb	^{204}Pb
^{52}Cr	^{54}Cr	^{50}Cr	^{53}Cr

As can be seen, we have studied, on average, more than one isotope per year of grant funding and have focused on exploiting those elements having multiple isotopes in order to investigate systematic trends in nuclear properties, for the purpose of providing more stringent tests of the nuclear spherical optical model with a surface imaginary potential. We have investigated an l -dependence of the real-well depth of the spherical optical model; we have used these measurements to deduce the existence of doorway states in the compound nucleus; and in the total cross section measurements we have, in addition to resonance energies and widths, obtained values for the level density and neutron strength function. Due to the high neutron energy resolution of the ORELA and in some cases the addition of differential scattering cross section data, we have been able to disaggregate the spin states and provide level spacing and strength function for each partial wave in the neutron-nucleus interaction, in some cases up to $d_{5/2}$. In the following we will summarize the most recent analyses of neutron total cross section measurements, some of which have not been previously reported.

$^{204}\text{Pb} + n$

A sudden onset of large s -wave strength in the neutron energy region of 40 to 500 keV has been reported for $^{206,207,208}\text{Pb}+n$, interpreted in the framework of doorway states (see Fig 4 in Ref. [1]). Horen, *et al.*[2], found evidence for p - and d -wave doorway structures in $^{206}\text{Pb} + n$ through an analysis of differential scattering and total cross sections up to a neutron energy of 600 keV, reporting significant changes in the neutron strength function for p -wave neutrons at energies of 40 and 145 keV, which they attributed to doorway states arising from a $(d_{3/2}, 3^-)$ particle-core excitation. The d -wave strength function showed similar patterns near 425 keV for $^{206}\text{Pb} + n$. Similar doorway structures

have been reported [3] for $^{207}\text{Pb} + n$ in the same energy interval and were similarly interpreted.

A high-resolution study [4] of $^{204}\text{Pb} + n$, over the neutron energy range 0 – 100 keV revealed numerous, small s -wave resonances in this energy region, well below the onset of large s -wave strength in $^{206, 207, 208}\text{Pb} + n$, with the s -wave strength more than a factor of ten greater than that of these other isotopes in this limited energy interval. We have measured and analyzed higher resolution differential scattering and total cross section data from the Oak Ridge Electron Linear Accelerator (ORELA) and have extended the neutron energy range of the analysis to 1 MeV, identifying spins and parities for more than 1340 resonances in this energy interval. We have examined the s -wave strength over the larger energy interval for comparison with results of other lead isotopes.

This study and analysis cover the neutron energy range from 50 keV to 1 MeV. Resonances with lower energies have been included in our resonance parameter file with their widths held fixed at values taken from Ref [5]. Unambiguous parity assignments to many of the resonances were made from the scattering results for 90° and 160° . R-matrix parameters deduced from the analysis were used to deduce average properties of the levels (level density and strength function). In the following discussion of the results, two values of deduced average quantities are given. The first is based upon an upper energy of 550 keV and the second, presented in parentheses, is based upon an upper energy value of 1000 keV.

s -waves

We observe a total of 204 (303) resonances over the energy region up to 550 keV. The s -wave strength function for $^{204}\text{Pb} + n$ is represented by the slope of a plot of the cumulative reduced neutron width as a function of energy. The result is $1.2 \pm 0.1 \times 10^{-4}$ ($0.80 \pm 0.07 \times 10^{-4}$). The level density, deduced from the plot of the cumulative number of levels versus energy was found to be uniform up to an energy of 550 keV, with the suggestion of either missing resonances or disappearing strength above that energy. We did not correct for missing resonances but chose, rather, to calculate the strength functions and level densities based upon upper energies of both 550 keV and 1000 keV. The level density is determined, from the cumulative number of resonances, to be $0.39 \pm 0.01 \text{ keV}^{-1}$ ($0.31 \pm 0.01 \text{ keV}^{-1}$). We found 19 s -wave resonances between 50 and 100 keV, in agreement with Ref [4]. In the energy range 0 – 100 keV that study reported 38 s -wave resonances, due to their increased sensitivity to low-energy resonances. The number of s -wave resonances for $^{206, 207, 208}\text{Pb}$ is 3, 1, and 0, respectively. There is no evidence in the present results for doorway-type structure in either the s -wave strength or level density plots, in contrast to other neighboring isotopes of Pb.

p - and d -waves

We identified a total of 223 (424) and 332 (616) p -wave and d -wave resonances, respectively. The plot of cumulative reduced neutron width as a function of neutron energy for p - and d -waves also reveals an absence of any structure suggestive of doorway states, the same being true of the plots for level density for these parity groups. The strength function, based upon the entire energy interval, is $0.23 \pm 0.02 \times 10^{-4}$ ($0.38 \pm 0.03 \times 10^{-4}$) and $1.5 \pm 0.1 \times 10^{-4}$ ($1.37 \pm 0.08 \times 10^{-4}$) for p - and d -waves, respectively. The level densities due to p - and d -wave interaction are $0.44 \pm 0.02 \text{ keV}^{-1}$ ($0.44 \pm 0.01 \text{ keV}^{-1}$) and $0.71 \pm 0.02 \text{ keV}^{-1}$ ($0.67 \pm 0.01 \text{ keV}^{-1}$), respectively. The trends of the plots for p - and d -waves similarly suggest that resonances are being missed, and we have followed the same

approach as for the *s*-wave group. The integrity of the parity assignments is quite good below 550 keV and thus the average parameters based upon that upper energy are with greater confidence for the strength. The differences between the level densities for the different energy ranges are minimal.

Conclusion

The uniformity of the cumulative strength and number of levels as a function of neutron energy are not supportive of the conjecture of doorways playing a significant role in this isotope. Though the parity groupings may not be completely unambiguous, the difference seen, if changes were made in some assignments where subjective judgments were employed in the analysis, would not be such as to produce the type of large step increases in either the strength functions or level spacings. It has been conjectured[4] that this could be due to the fact that the doorway state is completely mixed with the background states and thus that ^{204}Pb is sufficiently removed from the doubly-magic core that the particle and phonon excitations that would give rise to any doorways are highly fragmented. The strength functions deduced from this study are consistent with general trends in this mass region and differences with respect to other lead isotopes are a result of nuclear structure details present in lead. Further discussion of these results as well as the experimental conditions may be seen in Phys. Rev. **C 67**, 024601 (2003).

Experimental Conditions – Cr isotopes

We have measured the total neutron cross sections for all the stable or long-lived isotopes of chromium. The results for $^{52}\text{Cr} + n$ have been previously reported but results from that measurement will be combined with new results in our later discussions. As was the case for ^{52}Cr , differential elastic scattering data were also measured and analyzed for ^{54}Cr to provide for spin and parity assignments for many of the 300 or so resonances observed in that isotope up to an energy of 2.0 MeV. The experimental process was similar for the different transmission measurements but the details of the experimental conditions were varied. Conditions for the different isotopes are included in the following table.

Experimental Conditions for six (4 transmission and 2 scattering) neutron cross section measurements

	^{50}Cr	^{52}Cr	^{53}Cr	^{54}Cr
1/N (b/ atom)	16.483 (of Cr)	17.39 (of Cr)	16.48 (of Cr)	18.48 (of Cr)
O-compensation	Y	N	Y	N
Scattering Data	N	Y	N	Y
Flight Path (m)	201.568	201.575	201.568	201.568
Burst Width (ns)	5	6	5.5	4
% abundance	100	99.87	99.42	95.40
Weight (g) of Cr oxide	42.963 ($^{50}\text{Cr}_2\text{O}_3$)	42.135	44.603	19.962 ($^{54}\text{Cr}_2\text{O}_3$)
Power (kW)	6	4	6	6
Pulse Rate (Hz)	710	575	730	800
Resolution ($\frac{dE}{E}$) ²	49E(MeV) $\times 10^{-8}$	0.64E(MeV) $\times 10^{-6}$		(4+30E(MeV) $\times 10^{-8}$)
Run Time (d)	8d in 25d	11d in 21d	5d in 11d	6d in 7d
Energy (keV)	45 - 1200	50 - 1000	40 - 600	23 - 2000

All of the measurements were performed at the Oak Ridge Electron Linear Accelerator (ORELA) facility using the 200-m flight path. The table indicates that we have performed differential elastic scattering measurements, in addition to transmission measurements, for two of the samples.

Both transmission and elastic scattering measurements have employed the time-of-flight technique, using neutron pulses from the ORELA. The 140-MeV pulsed electron beam provided corresponding neutron bursts with a continuous energy spectrum produced by the photoneutron process in tantalum and subsequent moderation in the 15-cm-diameter, beryllium-clad, water-filled target housing. The neutron energy resolution function is expressible by a combination in quadrature of the fluctuations in flight-path length and the burst width and has been determined to have a Gaussian shape with a full width at half maximum dE given in the table above, with E expressed in MeV.

Transmission

For the transmission measurements collimators were used both before and after the sample to select neutrons from only the Ta target. Overlap neutrons were eliminated by a 0.3-g/cm^2 ^{10}B filter. Gamma rays were reduced by a 1.095 cm-thick filter 16.5 cm in diameter and a 0.712 cm-thick Pb filter, placed 5 m from the neutron source, covered the entire Ta target.

Each of the samples was in the form of $^{xx}\text{Cr}_2\text{O}_3$ with individual enrichments as shown and minor impurity components from other isotopes of chromium. To avoid the problematic correction for ^{16}O contributions to the measured transmissions we employed O-compensation for ^{52}Cr and ^{54}Cr by alternate cycling in and out of the neutron beam of the sample of $^{xx}\text{Cr}_2\text{O}_3\text{Be}$ and a sample of BeO whose thickness was identical to that of the oxide portion of the particular Cr sample. These samples were located 9 m from the neutron target where the neutron beam was collimated to a diameter of 2.38 cm. The samples were cycled into and out of the neutron beam under computer control with a cycle time of approximately 20 min. and 14 min., respectively, per sample. We used a neutron monitor to compensate for fluctuations in the neutron production rate during the data collection period. The individual runs for a given isotope were added to form the final data set which was then corrected for dead time. Neutrons were detected by a proton recoil detector as they traversed a 2.54 cm thickness of a 5.2 cm by 8.9 cm piece of NE110. The plastic scintillator was optically coupled to an RCA 8854 photomultiplier tube which was operated in a “selective gating” mode.[6] Additional information concerning the data acquisition has been reported in detail elsewhere.[7] Sources of background considered in processing and correcting these pulse height spectra included 2.2 MeV gamma rays from neutron capture in the water moderator, 478-keV gamma rays from the $^{10}\text{B}(n,\alpha\gamma)$ reaction, delayed pulses within the photo tube and scintillator, and a constant beam-independent background. A discussion of these and other experimental details may be found elsewhere.[8]

The transmissions were then computed from the background-corrected sample-in and sample-out ratio, normalized to the corresponding neutron monitor counts. Before beginning the resonance analysis, the transmission data were averaged in order to reduce the number of data points in regions absent of structure and thus speed calculations.

Scattering

The scattering measurements used the time-of-flight technique with neutron pulses from the water moderator of the ORELA. Beam filtering to reduce the intensity of the gamma flash and eliminate overlap neutrons was the same as in the transmission measurements. The neutron beam was collimated such that both moderated and unmoderated neutrons reached the scattering sample. The scattering samples, like the samples used for transmission measurements, consisted of $^{xx}\text{Cr}_2\text{O}_3$ with enrichments as shown in the table. The scattering samples were pressed into a cylindrical shape, which was suspended within a thin-walled (0.0127 cm) cylinder of natural chromium in the center of the 1.83-m diameter evacuated scattering chamber at a distance of 200.191 m from the neutron moderator. The scattering chamber was isolated from the neutron beam tube via a Mylar window.

The six neutron detectors in the scattering chamber each consisted of a 4.32-cm diameter, 7.62-cm length cylinder of NE-110 optically connected at each end to RCA 8850 photomultiplier tubes. These two-phototube detectors were located 19.1 cm from the center of the scattering chamber at angles of 39° , 55° , 90° , 120° , 140° , and 160° . Each of the detectors was operated with a threshold below the single photoelectron level in a fast coincidence (between the paired phototubes) mode, with two separate pulse height spectra formed of the anode signals based on the proton recoil energy.

The summed output signals from the photomultiplier pair of a given detector were processed to provide 45000-channel time-of-flight (TOF) spectra for each detector. The signal processing was configured so that only one event could be recorded in a detector, for each neutron pulse from the accelerator. The count rate of scattering events in any detector could thus never exceed the pulse rate of the accelerator.

Because individual detector efficiencies were not established, only relative scattering cross sections were obtained. A detector was placed in the beam at zero degrees to record the energy dependence of the detector efficiency and the incident flux. This spectrum was used to correct each of the scattering spectra for these combined effects. Corrections were also made for a constant room background and for the deadtime in each detector system resulting from scattering of the gamma flash, by the sample, into the detector. Neither geometrical nor multiple scattering corrections were made, since the use being made of these data required only relative cross sections. A neutron monitor detector was used to normalize each of the spectra. Since these data were used only to assess the likelihood of a given resonance having an assumed spin and parity, and that in a manner which did not call for fitting of individual scattering resonances, no data averaging was employed.

R-matrix Analysis of Cr + n Transmission Data

The resonances have been analyzed using the multilevel Reich-Moore R-matrix formalism. The transmissions are resolution broadened. These are converted to cross sections before Doppler broadening. In the latter a nuclear effective temperature of 300 K was used. In all of the analysis a channel radius of $1.45A^{(1/3)}$ fm was used. The choice of radius is arbitrary but is nonetheless significant in that it influences the resonance-potential scattering interference asymmetry. Different approaches may be taken with regard to the choice of this parameter. Since this asymmetry is different for different interaction parity, one could choose radii that reproduce the observed resonance asymmetries, a different radius for each partial wave of the interaction. We have used an approach that assumes the same radius for all partial waves but interprets the need for

differing asymmetries as indicative of corresponding differing neutron strength outside the region of analysis. In this approach the external strength is modeled as a logarithmic function of neutron energy, as

$$R^{ext} = \alpha + \beta E - \tilde{s} \ln \left(\frac{E^{up} - E}{E - E_{lo}} \right).$$

This approach permits the strength outside the region of analysis to be either uniform or a linear function of energy. In the present case we find that a uniform strength is sufficient and we have taken that strength to be equal to the strength observed within the region, for each partial wave. The resulting external R-function then simply becomes an additive term in the total R-function of the R-matrix formalism. This approach has been discussed elsewhere. Its motivation is related to the ease with which we can compare the partial wave analysis with predictions of an optical model. Any presentation of the resonance parameters deduced from R-matrix analyses must therefore include the parameters of the R-function: α , β , s .

$^{54}\text{Cr} + \text{n}$

The general structure of the total cross section is seen in Fig. 1 below, where the data are plotted as dots and the solid line represents the R-matrix representation of the data based upon a Bayesian least squares fit. The presence of the ^{16}O in the spectrum is seen in the broad structure at 430, 1000 and 1300 keV. These contributions were included in the R-matrix representation by using resonance parameters from a careful analysis of the oxygen total cross section by Sayers, *et al.*[9] It can be seen in Fig. 1 of Ref. [10] that these data are less well represented than below 1 MeV, the resonances being more numerous and in some cases overlapping. Thus resonance identification is less certain in this energy region.

Figure 1. Total cross section for $^{54}\text{Cr} + \text{n}$, showing prominent s-waves

Figure 2. $^{54}\text{Cr} + n$ Total Cross Section for the energy range 1000 – 2000 keV.

Results

s-waves:

We have plotted the cumulative reduced neutron widths and the cumulative number of levels as a function of energy, from which we deduce the strength and level density, respectively, and by which we can easily see trends or anomalies. The identification of the *s*-wave resonances is least ambiguous because of their unique asymmetry and that group of resonances shows the greatest anomalies when looking at the cumulative width plot. One can see in Fig. 3 that the strength in the region 500 keV to 1200 keV is more than 50% greater than that below 500 keV. This was posited as evidence of intermediate or doorway structure in this nuclide. However, when looking at the fit over the entire region this anomalous feature seems not as compelling. We assign *s*-wave character to 57 of the resonances. The corresponding *s*-wave strength function (in units of 10^{-4}), calculated over the entire region of analysis, is 2.7 ± 0.5 and the level density in keV^{-1} is 0.028 ± 0.002 . This value for the strength is in accord with trends of this average parameter over the range of atomic masses. Nor do these values differ significantly with the results of Agrawal, *et al.*[11], despite the different number of resonances in the two studies. Whether the slopes of the plots include resonances up to 1200 keV or 2000 keV matters little.

Figure 3. ^{54}Cr s -wave cumulative reduced neutron width and number of levels vs. neutron energy

p -waves:

Agreement with earlier results ends with s -waves because of Agrawal's mistaken attribution of negative parity to all other resonances. In the present analysis there is sufficient difference at these energies in the resonance-potential scattering interference between p - and d -waves that distinctive asymmetry differences result. As a result we have identified 71 resonances up to a neutron energy of 2 MeV that correspond to p -wave interaction. The p -wave strength function deduced from these resonances accords with expectations. ^{54}Cr is in the mass region where the s -wave strengths are near a maximum of $3 - 4 \times 10^{-4}$ and the p -wave strengths are a factor of ten smaller. Our value of $0.70 \pm 0.13 \times 10^{-4}$ differs from the s -wave value by a factor of four. Over the energy range 0 – 1000 keV the 25 observed resonances result in a strength of $0.4 \pm 0.2 \times 10^{-4}$. Fig. 4 shows evidence of an increase of strength above 1 MeV that is approximately double that over the entire energy range. This seems stronger evidence of intermediate structure than in the case of s -waves where there are several step increases but for the two energy ranges the average results are almost the same. The level density for p -waves is $0.039 \pm 0.002 \text{ keV}^{-1}$ and from Fig. 4 it can be seen that the trends are similar over both energy ranges.

Figure 4. ^{54}Cr p -wave cumulative reduced neutron width and number of levels vs. neutron energy

d -waves

The d -wave interaction is the strongest of the three partial waves in addition to revealing more resonances than the other two interactions, having combined totals of 99 [198] over the energy ranges 0 – 1000 and [0 – 2000], respectively. The trends for the cumulative number of resonances in the two energy ranges are indistinguishable in Fig. 5, giving rise to near identical level densities of 0.107 ± 0.006 [0.102 ± 0.004] keV^{-1} . The d -wave strengths, 4.4 ± 0.7 [3.4 ± 0.4] $\times 10^{-4}$, are almost double that of s -waves and there are hints of a diminution of strength in the region between 1 and 2 MeV. This mirrors the dramatic increase in strength of p -waves over the same energy range. The parameters for the energy region where the parity assignments are most unambiguous (0 – 1000 keV) are shown in an appendix at the end of this document. Resonances are also included whose energies are between 1000 keV and 1200 keV because of their influence upon the resonance asymmetries in the energy below 1000 keV.

Figure 5. ^{54}Cr d -wave cumulative reduced neutron width and number of levels vs. neutron energy

$^{50}\text{Cr} + n$

Figure 6 shows the total cross section for $^{50}\text{Cr} + n$ over the energy range 0 – 900 keV. We have analyzed the transmission data carefully up to 1000 keV and have identified the more prominent resonances up to 2000 keV. We list in the table in an appendix only those below the 1000 keV neutron energy. The addition of only four neutrons to ^{50}Cr has a marked effect upon the s -wave level density. Where 14 prominent resonances were seen in ^{50}Cr in the first 300 keV, only 4 are manifest in ^{54}Cr . For comparison the number for ^{52}Cr , in the same energy interval, was three. The prominence of s -wave resonances in the case of ^{50}Cr is likely related to the proximity to the $N = 28$ neutron shell. The same is true for p - and d -waves. We have identified a total of 413 resonances in the energy interval 0 – 1000. Of that number, 73, 145, and 195 are s -, p -, and d -wave, respectively. In addition, we have investigated the trends, with isotope, of the s -wave level spacing in the context of the conditions relating to chaotic behavior in the compound nucleus formed by neutron interaction with the target nucleus.

Figure 6. Selected energy ranges of the total cross section for $^{50}\text{Cr} + n$ *s*-waves

Results

s-waves:

We identified and included in our analysis a total of 73 *s*-wave resonances up to a neutron energy of 1000 keV. We have plotted the *s*-wave cumulative reduced neutron widths and the cumulative number of *s*-wave levels as a function of energy in Fig. 7, from which we deduce the strength and level density, respectively, and by which we can easily see trends or anomalies. The situation is different from $^{54}\text{Cr} + n$ (see Fig. 3) in that there is no evidence of structure in either of these plots, for ^{50}Cr . At the same time, the number of resonances observed is greatly expanded over that for ^{54}Cr .

Figure 7. *s*-wave strength and level density plots for $^{50}\text{Cr} + n$

We assign *s*-wave character to 73 of the resonances below 1000 keV in neutron energy. The corresponding *s*-wave strength function (in units of 10^{-4}), calculated over the entire region of analysis, is 2.7 ± 0.2 and the level density in keV^{-1} is 0.076 ± 0.01 . This value for the strength is in accord with trends of this average parameter over this range of atomic masses.

***p*-waves:**

We have identified 145 resonances up to a neutron energy of 1 MeV that correspond to *p*-wave interaction. The *p*-wave strength function deduced from these resonances accords with expectations. ^{50}Cr is in the mass region where the *s*-wave strengths are roughly 10 times the *p*-wave strengths. Over the energy range 0 – 1000 keV the 145 observed resonances result in a neutron strength of $0.5 \pm 0.1 \times 10^{-4}$. This value differs from the *s*-wave value by a factor of five. The level density for *p*-waves is $0.15 \pm 0.006 \text{ keV}^{-1}$ up to a neutron energy of 1000 keV. Parameters for these resonances are presented in the appendix.

***d*-waves**

The *d*-wave interaction is comparable in strength to that of *s*-waves, but almost 10 times greater than for *p*-waves. One hundred ninety-five (195) resonances were observed over the energy range 0 – 1000. The corresponding level density is $0.22 \pm 0.016 \text{ keV}^{-1}$. The *d*-wave strength, $4.4 \pm 0.7 \times 10^{-4}$, is 60% greater than that for *s*-waves. The parameters for the energy region where the parity assignments are most unambiguous (0 – 1000 keV) are shown in an appendix at the end of this document. Resonances are also included whose energies are between 1000 keV and 1200 keV because of their influence upon the resonance asymmetries in the energy below 1000 keV.

Quantum Chaoticity in the Cr Compound Nucleus

Whether nuclear energy level spectra display uniformity or not may suggest whether the associated nuclear dynamics is regular or chaotic, respectively. In general, the spectra of nuclear levels with the same quantum numbers have been found to display fluctuations from uniformity, with the spacing of adjacent levels being tightly grouped about the mean and manifesting repulsion effects. Distributions for the nearest neighbor spacings (NNS) for a broad collection of nuclei, with excitation in the region of 8 MeV, have, for common J^π , been generally well described[12] by the Wigner distribution,

$$P(s) = A \cdot s \cdot e^{-\pi \frac{s^2}{4}},$$

which can be derived from the Gaussian orthogonal ensemble (GOE) of random-matrix theory. Such is expected to be the case for quantum systems for which the underlying dynamics is chaotic. Conversely, if the underlying dynamics is non-chaotic, the NNS distribution should more nearly reflect the character of independent random variables of a Poisson sample. One expects therefore that the statistics of energy level spacings will be typically described either by random matrix theory, when the classical limit is chaotic, or by a Poisson process when the classical dynamics is regular, i.e., completely integrable.

Since we have data to support a systematic investigation of trends in this feature of nuclear structure, we are currently looking at the NNS distribution for each of the chromium nuclides. The Wigner and Poisson representations of the NNS distribution for ^{54}Cr is seen in Fig. 8 where the NNS distribution for the 18 levels up to 1000 keV populated by *s*-wave neutron interaction is plotted as a function of the spacing *s*, normalized by the average spacing. That corresponding to Wigner and Poisson distributions is shown as solid lines. The distribution, absent a peak, manifests the uniformity of the distribution and the lack of repulsion between levels.

Figure 8. Poisson and Wigner representations of s -wave adjacent level spacings for $^{54}\text{Cr} + n$.

As in the case of $^{54}\text{Cr} + n$ mentioned above, non-uniform features in the structures of the level spacing and cumulative neutron width plotted as a function of energy has been interpreted as due to the formation of doorway states. Such states correspond to the neutron-nucleus interaction being a simple two-body collision process in which two-particle one-hole ($2p - 1h$) states are formed. Such simple interactions should be more pronounced for closed-neutron-shell nuclei and for energy ranges near the neutron separation energy[13]. Another indicator of doorway state formation has been suggested that involves the distribution of adjacent level spacings, a Gaussian distribution suggesting the presence of doorway states. As we move away from the closed shell region, the contribution of other more complicated interactions ($3p - 2h$; $4p - 3h$; etc.) should render the observable “doorway” features indiscernible and the level-spacing distribution non-Gaussian. Having numerous data sets of this nature, some already analyzed and some to be analyzed, one could investigate the systematic trends of this approach: with energy above neutron separation energy, with atomic mass number, and with proximity to closed neutron shells, thus providing a base for a number of undergraduate student research projects.

Efforts were focused on the analysis of extant $^{50}\text{Cr} + n$ data and a comparison of the adjacent level spacing distributions with both Gaussian and Wigner distributions. Fig. 9 shows the distributions for both ^{50}Cr and ^{52}Cr . It is seen that the neutron-closed-shell distribution is well described by the Gaussian distribution function but fails in the case of ^{50}Cr . As expected, the Wigner level spacing distribution describes both.

Figure 9. Gaussian and Wigner representations of s -wave adjacent level spacings for $^{50,52}\text{Cr} + n$

A number of questions could be addressed in future studies: How effective will a statistical distribution study be in indicating that a compound nucleus type process proceeds via a simple or doorway interaction? What type of statistical distribution would best serve the proposed purposes? Will the extent of agreement with a suitable statistical distribution vary with proximity to neutron shell closure? Will the agreement vary with neutron energy, with the region of the periodic table? This work has focused currently on these two isotopes of chromium, but will pave the way for more extensive application of the approach if proven so suited in this work.

The strength and level density plots for $^{54,50}\text{Cr}$ are shown in Figs. 3 & 7, respectively for comparison. One can surmise that the contrasts between these results for isotopes that differ by only four neutrons would not be expected, except for the fact that these two isotopes straddle the shell model's neutron magic number of 28. The linearity of the level density over the neutron energy interval is consistent for both isotopes, but that of the strength, in the case of ^{50}Cr , is not present in ^{54}Cr .

$^{53}\text{Cr} + n$

This is the only stable (or long-lived) isotope of Cr whose spin is non-zero. Its spin and parity ($I^\pi = 3/2^-$) thus affords many more spin group possibilities than do spin-zero target nuclei. The density for compound states formed by neutron resonances in $^{53}\text{Cr} + n$ is greater than for the other isotopes studied with the result that the energy resolution would not permit definitive analysis beyond ~ 550 keV in neutron energy. The total neutron cross section from our latest analysis is seen in Fig. 10. The pronounced s -wave interaction asymmetry is seen throughout the analyzed energy range. The large resonances above 550 keV have not been included in the analysis but have been included in the parameter file because of the resonance-resonance interference between those outside the energy limit of the analysis (550 keV). The resonance parameters are included in the Resonance Parameter Appendix. In the parameter table for $^{53}\text{Cr} + n$, the differing spin groups are distinguished first by the conventional notation for orbital angular momentum (s -, p -, d -, for $\ell = 0, 1, 2$, respectively) with the channel spin and total angular

momentum quantum numbers given in parentheses. For example, the designation $\ell(s, j)$ represents a resonance with orbital angular momentum ℓ , channel spin s , and total angular momentum j .

Figure 10. Total neutron cross section for $^{53}\text{Cr} + n$ over the energy range 0 – 600 keV. The solid red line is the R-matrix representation of the data.

The analysis performed for this reaction includes only s - and p -wave strength functions. These are shown together in Figure 11 where it can be seen that there are no departures from linearity in either group.

Figure 11. ^{53}Cr cumulative reduced neutron width versus neutron energy, for s -waves and p -waves.

These graphs plot the cumulative reduced neutron width versus neutron energy. The slope of the graph for s -waves gives the s -wave strength, and the slope for p -waves, divided by $2\ell + 1 = 3$, gives the p -wave strength. The larger than normal increase in p -

wave strength around neutron energy 300 – 350 keV, does not significantly alter the overall strength.

The neutron strength functions for all the isotopes of Cr that have been studied during the tenure of this grant are presented in the table below. The value of neutron strength and the number of resonances (in parentheses) observed in a given spin-group sample are presented for each isotope. All strength function values are in units of 10^{-4} .

	s	p	d
^{50}Cr	2.7 (73)	0.5 (145)	4.4 (195)
^{52}Cr	3.5 (28)	0.4 (67)	2.9 (99)
^{53}Cr	4.4 (98)	0.9 (143)	
^{54}Cr	2.7 (21)	0.4 (25)	4.4 (99)

Table of Cr-isotope strength functions for the different ℓ -waves.

All except the ^{53}Cr data cover the energy range 0 – 1000 keV. The number of resonances for that group corresponds to the neutron energy range 0 – 550 keV. In the Resonance Parameter Appendix, energy and neutron width are given for each observed resonance and at the end the R-function parameters, α , β , $\mathcal{S}$ are presented for each possible spin group. This R-function provides for the resonance-potential scattering interferences for each spin group resulting from strength outside the region of analysis.

Appendices of Resonance Parameters

-
- [1] R. Köhler, J. A. Wartena, H. Weigmann, L. Mewissen, F. Poortmans, J. P. Theobald, and S. Raman, *Phys. Rev. C* **35**, 1646(1987).
- [2] D. J. Horen, J. A. Harvey, and N. W. Hill, *Phys. Rev.*, **C20** 478 (1979).
- [3] D. J. Horen, J. A. Harvey, and N. W. Hill, *Phys. Rev.*, **C18** 722 (1978).
- [4] D. J. Horen, R. L. Macklin, J. A. Harvey, and N. W. Hill, *Phys. Rev.*, **C29** 2126(1984).
- [5] Mughabghab, and Holden
- [6] R. F. Carlton, J. A. Harvey, and N. W. Hill, *Phys. Rev. C* **59**, 1400 (1995).
- [7] D.C. Larson, N.M. Larson, and J.A. Harvey, N. W. Hill, and C. H. Johnson, Oak Ridge National Laboratory Report No. ORNL/TM-8203, Oak Ridge, Tennessee, 1984 (unpublished).
- [8] D.C. Larson, N.M. Larson, and J.A. Harvey, Oak Ridge National Laboratory Report No. ORNL/TM-8880, Oak Ridge, Tennessee, 1984 (unpublished).
- [9] R.O. Sayer, L. C. Leal, N. M. Larson, R. R. Spenser, and R. Q. Wright, Oak Ridge National Laboratory Report No. ORNL/TM-2000/212, Oak Ridge, Tennessee, 2000 (unpublished).
- [10] R.F. Carlton, C. Baker, and J.A. Harvey, *Phys. Rev. C* **74**, 044614 (2006).
- [11] H. M. Agrawal, J. B. Garg, and J. A. Harvey, *Phys. Rev. C* **30**, 1880 (1984).
- [12] Shriner J. F, Mitchell G. E., von Egidy, T., *Zeitschrift Fur Physik A-Hadrons And Nuclei* **338** (3): 309-318 1991.
- [13] G. Rohr, in *Proceedings of the International Conference on Statistical Properties of Nuclei*, Albany, 1971, edited by J. B. Garg, (Plenum Press, New York, 1972), p. 572

⁵⁰Cr Resonance Parameters

$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	J^π	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	J^π	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	J^π
36.97	3.07E+00	s-1/2	218.0568	1.13E-02	d-3/2	347.6419	1.04E-01	d-3/2
51.08933	6.35E-03	p-1/2	219.6878	2.24E-01	s-1/2	352.4955	5.79E+00	s-1/2
55.14282	3.71E-01	s-1/2	220.1998	5.92E-03	d-3/2	352.5089	2.64E-02	d-5/2
59.20851	3.15E-02	p-1/2	222.6728	2.82E-02	d-5/2	353.3921	7.57E-02	p-1/2
64.83684	5.31E-02	s-1/2	232.5108	6.68E-01	s-1/2	355.9812	4.24E-02	d-5/2
73.34235	5.91E-03	p-1/2	232.8009	6.61E-03	p-3/2	358.9538	1.70E+00	s-1/2
77.88056	1.70E-02	p-1/2	233.0374	2.81E-02	d-3/2	360.0924	3.95E-02	d-5/2
88.69087	2.22E-02	p-1/2	233.3549	3.17E-01	p-1/2	366.7771	2.78E-02	d-5/2
94.96632	1.79E+00	s-1/2	239.6117	2.59E-02	s-1/2	369.2311	1.06E+01	s-1/2
106.1725	3.70E-02	p-1/2	242.8749	3.76E-02	d-5/2	370.1047	7.67E-02	d-5/2
110.5251	1.28E-02	p-1/2	246.0706	1.16E-02	d-3/2	374.0417	5.84E-02	d-3/2
112.2979	6.94E-02	p-1/2	247.6351	2.00E-01	p-1/2	376.1527	2.91E-02	d-3/2
112.4872	6.80E-02	p-1/2	251.4885	3.85E-02	d-3/2	381.3159	8.20E-02	p-3/2
115.0461	1.69E-01	s-1/2	251.5852	2.06E-02	d-5/2	387.179	3.60E+00	s-1/2
118.7029	2.26E-02	p-1/2	258.3439	1.06E-01	p-1/2	390.3055	2.51E-02	d-3/2
129.4465	1.21E-02	d-3/2	262.5054	2.07E-02	d-3/2	391.0075	2.96E-02	d-5/2
129.4813	5.78E-01	s-1/2	263.3911	1.76E-02	d-5/2	391.5625	1.16E-02	d-3/2
129.8781	1.21E-03	d-3/2	267.2248	7.64E-03	d-3/2	391.9157	8.75E-03	d-5/2
136.8009	4.48E-02	p-1/2	273.8294	5.37E-02	d-3/2	395.3465	1.31E-01	d-3/2
141.2339	4.92E-02	d-3/2	276.5875	2.55E-02	d-3/2	395.8799	5.88E-02	p-3/2
142.4257	1.37E-02	d-3/2	276.7754	3.22E-02	d-3/2	403.0823	4.87E-02	d-3/2
146.8868	1.07E-01	p-1/2	277.6686	2.75E+00	s-1/2	403.684	2.65E-01	p-1/2
150.5829	2.44E-02	d-3/2	283.5481	2.88E-01	p-3/2	404.1713	4.21E-01	s-1/2
156.8475	4.00E-03	d-5/2	286.0835	2.14E-02	p-1/2	411.539	2.29E-01	d-3/2
156.9925	1.47E+00	s-1/2	286.9141	5.20E-02	p-1/2	414.8747	1.76E-02	d-3/2
162.4184	4.43E-02	p-1/2	289.1942	2.93E-02	d-3/2	415.7272	1.19E+01	s-1/2
162.8825	8.54E-01	s-1/2	291.3066	5.80E+00	s-1/2	416.6012	8.24E-02	p-1/2
169.12	5.32E-02	p-1/2	296.1572	1.27E-02	d-5/2	418.761	1.80E-02	d-5/2
174.6593	1.40E-02	p-1/2	302.6436	1.90E-02	p-3/2	422.5761	1.82E-02	d-5/2
175.8908	9.73E-03	p-1/2	303.8547	2.41E-02	d-3/2	427.5239	2.11E-02	d-3/2
176.5162	3.71E-03	p-1/2	306.7524	1.57E+00	s-1/2	431.8639	6.56E-02	d-5/2
176.6947	1.02E-02	d-3/2	309.3726	3.71E-02	d-5/2	432.3522	7.45E+00	s-1/2
177.437	2.34E-02	p-3/2	313.1892	5.06E-01	d-3/2	433.646	4.92E-02	d-5/2
185.6742	3.09E+00	s-1/2	318.1288	1.48E-01	d-3/2	435.6257	2.14E+00	s-1/2
186.7294	4.71E-02	p-3/2	319.7764	1.38E-02	d-5/2	438.5567	1.53E-01	s-1/2
188.4726	1.07E-02	d-3/2	321.5618	5.62E+00	s-1/2	442.1691	1.90E-01	d-3/2
191.2955	2.30E-01	p-1/2	327.7064	2.26E-01	s-1/2	443.3147	2.03E-01	d-3/2
197.2566	2.11E-02	p-3/2	330.7356	1.19E-01	p-1/2	444.8542	1.65E-01	p-1/2
200.7304	8.87E-02	p-1/2	330.8814	1.59E-02	d-5/2	452.9069	7.51E-02	s-1/2
201.8983	3.05E-02	p-3/2	331.2175	2.70E-02	d-5/2	454.3645	1.73E-02	d-3/2
205.2202	5.70E-03	d-3/2	334.9374	2.16E-02	d-5/2	458.3899	1.85E-01	d-3/2
205.7665	4.14E-02	d-3/2	336.7388	5.04E-02	p-1/2	459.11	2.16E-01	d-5/2
207.4791	2.51E-02	d-3/2	340.4006	6.52E-02	d-3/2	465.9759	2.90E+00	s-1/2
213.9172	8.10E-02	p-1/2	340.9365	5.70E-02	p-3/2	468.6328	8.17E-02	d-5/2
215.1349	6.77E-03	d-3/2	343.1213	1.27E-02	d-3/2	470.1562	6.17E-02	d-5/2

⁵⁰Cr Resonance Parameters

E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π
471.78136	6.91E-01	d-5/2	582.3217	3.00E-01	p-3/2	666.985	5.60E-02	p-1/2
478.27312	6.20E-01	d-3/2	586.6331	7.25E-02	d-5/2	667.8586	8.11E-02	p-1/2
478.2663	3.00E+00	s-1/2	588.2211	1.37E-01	p-3/2	668.4719	2.07E-01	p-1/2
479.93845	4.26E-02	d-5/2	589.0311	5.57E-02	p-3/2	670.0819	3.84E-02	d-5/2
481.13779	1.98E-01	p-1/2	590.207	1.60E+00	s-1/2	670.4575	1.38E-01	p-1/2
483.54137	4.76E-01	p-1/2	590.5331	5.19E-02	p-3/2	674.16	1.85E-02	d-5/2
485.84275	5.35E-02	d-5/2	597.7194	4.24E-01	p-1/2	679.1829	7.93E-01	d-5/2
488.3376	3.61E-01	d-3/2	599.3061	1.06E-01	p-1/2	680.2659	1.43E-01	p-3/2
488.3796	1.70E+00	s-1/2	601.4032	2.06E+00	s-1/2	681.2305	1.53E+00	s-1/2
490.43101	3.41E-02	d-5/2	605.9471	3.47E-01	s-1/2	685.6719	2.27E-01	p-1/2
494.37404	6.04E-02	d-3/2	607.9596	9.83E-01	s-1/2	687.9285	7.95E-02	d-5/2
494.6359	4.65E-02	p-3/2	608.3931	1.42E-01	d-3/2	692.2383	2.06E+00	s-1/2
495.08869	1.14E-01	d-3/2	609.2066	8.61E-02	p-3/2	693.4798	5.26E-01	d-3/2
498.64795	5.87E-02	d-5/2	612.0833	5.83E-02	p-1/2	695.3343	1.39E-01	p-1/2
501.6712	2.89E+00	s-1/2	613.645	2.35E-02	d-3/2	696.9473	1.15E-01	s-1/2
508.36866	1.18E-01	d-5/2	614.5471	1.39E-02	p-3/2	698.1958	5.77E-02	p-1/2
514.3653	1.15E+00	s-1/2	616.4451	3.20E-02	d-5/2	702.1971	2.45E-02	d-5/2
517.89445	2.29E-02	p-3/2	617.4491	1.35E-01	d-5/2	703.0233	2.15E-01	p-3/2
521.25077	4.22E-02	p-1/2	618.3999	2.77E-02	p-3/2	706.6982	3.19E-02	d-3/2
523.51812	5.79E-02	p-3/2	622.1152	7.82E-02	d-3/2	707.222	3.02E-02	d-3/2
523.79627	1.50E-01	d-5/2	622.5673	1.51E-01	d-3/2	708.252	8.63E-01	s-1/2
526.35784	1.43E-01	d-5/2	624.2687	5.80E-02	d-5/2	710.2347	8.74E-02	d-5/2
529.20677	3.89E-02	d-3/2	625.9213	2.43E-02	d-3/2	711.0051	3.27E-02	d-3/2
531.95015	5.94E-02	d-3/2	626.9833	2.91E-02	p-3/2	712.0642	3.49E-01	d-5/2
535.34413	9.73E-02	d-5/2	629.3404	3.38E-02	d-5/2	713.0402	6.88E-02	d-5/2
537.7006	2.01E+00	s-1/2	630.3353	5.09E-02	p-1/2	713.5274	5.49E-01	s-1/2
540.61176	6.55E-02	d-5/2	630.7226	3.46E+00	s-1/2	714.1845	3.08E-01	p-1/2
542.83296	4.66E-02	d-5/2	631.6459	3.45E-02	p-1/2	715.1236	7.68E-02	p-1/2
543.47466	8.73E-02	p-1/2	632.4082	2.32E-02	p-1/2	715.9989	5.52E-01	s-1/2
547.26088	5.40E-01	d-3/2	632.52	4.31E-02	p-1/2	721.243	4.27E-01	d-5/2
548.58595	2.39E-01	d-5/2	637.292	8.14E-02	p-1/2	722.212	4.33E-02	d-5/2
553.4478	6.95E+00	s-1/2	640.7584	1.53E-01	d-5/2	722.9222	2.54E-01	p-1/2
556.97358	3.26E-02	d-3/2	642.2357	2.59E+00	s-1/2	726.1253	3.16E-01	d-3/2
557.4269	5.37E-02	p-1/2	643.118	5.11E-02	d-3/2	726.2808	1.55E-01	d-5/2
558.86725	1.58E-01	d-3/2	643.8288	2.78E-01	p-1/2	729.0451	1.29E-01	d-3/2
560.1601	3.65E+00	s-1/2	645.5103	1.11E-01	p-3/2	731.9713	9.54E-02	p-3/2
562.07024	7.52E-02	d-5/2	647.6317	1.00E-01	p-3/2	733.0854	6.61E-01	p-3/2
566.93301	2.96E-02	p-1/2	649.3985	6.03E-02	d-3/2	735.7851	7.92E+00	s-1/2
568.79019	5.74E-02	d-3/2	653.2943	8.73E-02	d-3/2	736.572	7.22E-02	p-3/2
569.35484	4.62E-02	d-3/2	655.4276	1.83E-01	d-3/2	741.0518	6.71E-01	s-1/2
570.30182	1.06E-01	p-1/2	655.8872	5.00E-01	d-5/2	742.8506	6.46E-01	d-5/2
576.9623	3.52E+00	s-1/2	657.1866	1.10E-01	s-1/2	743.9326	2.23E-02	p-3/2
577.85677	4.06E-02	d-5/2	657.334	1.25E+00	p-1/2	749.1849	1.93E-02	d-5/2
580.33844	7.27E-02	d-5/2	659.2826	1.26E+00	s-1/2	750.085	6.76E-02	p-3/2
580.7778	5.03E+00	s-1/2	665.5352	3.07E-01	d-3/2	751.6747	1.47E-01	p-1/2

⁵⁰Cr Resonance Parameters

E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π
752.4892	1.96E-01	d-3/2	820.4849	5.06E-01	d-5/2	903.365	7.08E-02	d-3/2
758.158	1.77E-01	d-3/2	822.0067	1.07E-01	d-3/2	906.2233	1.77E-01	d-3/2
758.4938	2.44E-01	d-5/2	823.307	1.13E+00	p-3/2	908.267	2.91E-01	s-1/2
759.3229	1.58E-01	p-1/2	824.9141	2.62E-01	p-3/2	908.3998	8.56E-01	p-3/2
760.3662	9.88E-02	p-1/2	825.5549	3.25E-01	p-1/2	909.4356	8.01E-01	p-3/2
762.7776	9.60E-02	d-5/2	826.9903	4.26E-01	d-5/2	913.7773	7.72E-01	d-5/2
762.8919	8.64E+00	s-1/2	828.0865	3.07E+00	s-1/2	914.4613	6.23E-01	d-5/2
765.3061	1.57E-01	d-5/2	828.9764	8.82E-02	d-3/2	916.7293	6.10E-01	p-3/2
769.8666	8.41E-01	p-3/2	831.4958	1.20E-01	d-3/2	918.7032	9.79E-02	d-3/2
771.7519	1.20E-01	p-1/2	832.4529	5.17E-02	d-5/2	919.6655	9.28E-02	d-3/2
772.5162	1.45E-01	p-1/2	834.0868	2.63E+00	p-1/2	920.5002	3.53E-02	d-3/2
773.2495	1.42E-01	p-1/2	834.3189	1.46E-01	p-3/2	921.5116	7.89E+00	s-1/2
774.2763	6.32E-02	d-3/2	840.0765	1.59E-01	s-1/2	921.8955	2.01E-01	d-3/2
775.1358	1.22E-01	d-3/2	844.089	8.43E-02	d-3/2	923.2451	2.57E+00	s-1/2
776.6015	1.69E+00	p-1/2	843.8503	9.24E-01	p-3/2	924.9355	1.62E-01	d-3/2
777.2772	2.39E-01	d-3/2	846.6277	4.44E-01	d-5/2	925.7913	4.11E-01	p-1/2
778.6798	3.06E-01	d-5/2	846.8531	1.13E+00	p-1/2	929.8767	2.39E-01	d-5/2
779.5583	1.27E-01	d-3/2	848.6629	2.97E-06	s-1/2	930.9815	2.25E-01	d-5/2
780.3451	1.34E+00	s-1/2	849.0096	1.43E-01	p-3/2	933.6779	1.82E-01	s-1/2
780.6687	8.64E-02	d-5/2	852.5137	5.62E-02	p-3/2	933.9441	1.95E-01	p-3/2
783.344	2.85E-01	d-3/2	853.2298	7.11E-01	d-5/2	935.6443	2.43E-01	s-1/2
784.1327	2.07E-01	p-1/2	854.6035	6.89E-02	d-3/2	936.512	9.75E-02	p-3/2
785.7774	3.18E+00	s-1/2	855.6238	8.69E-02	d-3/2	937.5836	5.52E-01	p-3/2
786.6274	1.11E-01	p-1/2	856.5241	8.03E-02	d-3/2	938.7153	1.62E+00	s-1/2
789.5799	1.11E-01	d-5/2	857.5232	1.35E-01	d-3/2	939.9861	7.52E-02	d-3/2
794.6155	6.20E-02	p-3/2	858.5708	2.28E-01	d-3/2	944.6457	1.72E-01	p-3/2
797.0794	3.74E-01	s-1/2	860.1499	1.14E+00	d-5/2	946.5298	5.33E-02	d-3/2
797.7659	1.03E-01	p-1/2	860.2826	3.45E-07	p-1/2	947.1941	1.70E+00	s-1/2
799.3659	5.03E-01	d-3/2	862.6262	3.32E-01	d-3/2	950.1993	4.39E-01	d-3/2
800.3214	7.68E-01	p-1/2	863.5437	2.01E-01	d-5/2	952.4187	8.99E-02	d-5/2
800.6242	4.19E-01	d-5/2	868.0039	1.74E+01	s-1/2	954.3777	1.48E-01	d-3/2
801.3664	1.58E-01	p-1/2	869.1655	9.42E-02	d-3/2	955.4052	1.93E-01	p-1/2
803.6557	6.02E-02	d-3/2	868.6256	1.37E-01	d-5/2	958.0709	4.86E-02	d-3/2
804.5444	4.86E-02	d-3/2	872.3304	1.17E+00	p-1/2	961.6316	1.73E-01	d-3/2
805.4569	3.52E-01	d-3/2	877.1026	1.62E-01	p-3/2	963.0789	2.89E-01	p-1/2
807.324	1.27E+00	p-1/2	881.8512	4.07E-01	p-3/2	964.9713	9.95E-02	d-5/2
810.1712	2.59E-02	d-5/2	885.1341	5.20E-02	p-1/2	966.1969	2.55E-01	p-1/2
810.7878	1.00E-01	p-1/2	886.0815	5.08E-02	p-1/2	968.8758	3.30E-01	p-3/2
813.2265	3.89E-02	d-3/2	887.0012	5.61E-02	p-1/2	969.3218	1.22E+00	p-1/2
814.5773	2.09E-02	d-3/2	887.8445	6.47E-02	p-1/2	970.2133	1.95E-01	s-1/2
816.7591	1.23E-01	s-1/2	889.338	1.22E-01	p-1/2	972.6274	8.75E-01	p-3/2
816.9529	1.20E-01	p-3/2	892.1654	2.46E-01	p-3/2	975.1971	4.13E-01	p-3/2
817.9701	5.90E-01	p-3/2	893.7681	2.36E+00	s-1/2	978.0979	5.04E-01	p-1/2
818.7924	1.04E-01	d-3/2	893.9846	5.83E-01	d-3/2	981.4965	3.41E-01	p-1/2
819.3231	4.29E-01	d-3/2	900.717	5.27E-01	p-3/2	983.022	2.80E-01	d-3/2

⁵⁰Cr Resonance Parameters

E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π
984.0951	7.21E-06	s-1/2	1083.897	6.98E-01	p-3/2	1190.599	2.00E-01	p-3/2
985.6396	5.54E-01	d-5/2	1083.519	1.64E-01	p-1/2	1195.69	3.25E-01	p-3/2
989.7165	3.78E-01	d-3/2	1087.719	2.02E-01	s-1/2	1196.352	1.58E-02	d-3/2
992.1556	1.18E-01	d-3/2	1089.181	4.81E+00	p-1/2	1197	1.00E-06	d-3/2
993.3973	1.03E+01	p-1/2	1092.325	6.49E-01	p-3/2			
993.3919	1.77E+00	s-1/2	1094.172	1.28E+00	p-3/2			
999.0356	3.98E-01	d-3/2	1097.387	2.55E-01	d-3/2			
999.1763	4.11E-05	p-1/2	1099.531	5.96E-01	p-3/2			
1000.092	1.64E-01	s-1/2	1110.55	1.66E-01	d-5/2			
1001.272	3.27E-01	d-3/2	1112.538	6.18E-01	p-1/2			
1005.609	1.03E+00	d-3/2	1120.763	7.54E-01	d-5/2			
1006.286	1.30E-01	d-5/2	1126.65	3.86E+00	p-1/2			
1007.874	2.64E+00	s-1/2	1127.746	3.30E+00	p-1/2			
1007.763	3.19E-01	d-3/2	1130.678	2.09E+00	p-1/2			
1008.395	5.62E+00	p-1/2	1130.332	5.76E-01	d-3/2			
1012.197	7.15E-01	d-3/2	1131.74	1.27E-01	d-5/2			
1017.898	5.45E-01	d-3/2	1135.908	8.07E-03	p-1/2			
1021.331	2.37E-03	p-1/2	1133.954	1.73E-02	p-1/2			
1022.678	1.63E+00	d-3/2	1135.042	1.59E-01	d-3/2			
1024.893	1.54E+00	s-1/2	1138.155	5.64E-01	d-3/2			
1027.192	8.72E-02	p-1/2	1141.607	2.16E+00	d-3/2			
1027.77	7.14E-02	d-5/2	1143.949	2.17E-01	d-5/2			
1028.546	1.72E+01	s-1/2	1143.698	1.99E-01	p-3/2			
1032.38	1.09E+00	d-3/2	1147.43	8.51E-01	p-3/2			
1034.885	9.65E-02	p-3/2	1148.437	1.09E+00	s-1/2			
1038.081	4.57E-01	p-3/2	1152.336	1.02E+00	p-3/2			
1039.442	1.47E+00	p-1/2	1153.734	4.47E-01	p-3/2			
1041.987	1.08E-01	s-1/2	1155.201	5.37E+00	p-1/2			
1041.099	2.09E-01	p-1/2	1155.269	1.70E-01	d-3/2			
1042.566	2.69E-01	p-1/2	1158.529	2.26E+00	s-1/2			
1045.033	4.15E-01	p-1/2	1160.104	2.37E-01	p-3/2			
1045.065	1.19E+01	s-1/2	1162.285	9.80E-01	p-1/2			
1046.027	1.69E+00	p-3/2	1164.836	3.72E-01	p-3/2			
1047.646	3.30E-01	p-3/2	1168	9.92E-02	d-3/2			
1050.677	2.20E-01	d-3/2	1168.925	4.36E+00	s-1/2			
1054.37	9.10E-01	p-1/2	1172.753	1.08E-01	d-3/2			
1054.633	1.11E-01	p-3/2	1174.024	3.35E-01	p-3/2			
1054.644	5.33E-02	d-3/2	1176.336	4.66E-01	p-1/2			
1061.913	1.26E-01	d-3/2	1177.08	1.82E-01	d-3/2			
1064.238	1.21E+00	p-1/2	1180.685	7.50E-01	s-1/2			
1070.509	1.34E-01	d-3/2	1181.576	4.30E-01	d-3/2			
1072	3.20E+00	s-1/2	1183.649	4.04E-01	p-1/2			
1073.904	4.20E-01	p-1/2	1184.06	1.31E-01	d-3/2			
1075.72	3.05E-02	p-1/2	1187.06	3.54E-01	d-5/2			
1077.204	1.21E-01	d-3/2	1187.785	1.09E-02	d-3/2			

$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$
10	1.00E-04	d(2,4)	177.7245	1.60E-01	p(1,1)	281.0254	2.45E-01	s(1,1)
29.72133	4.10E+00	s(2,2)	179.227	1.31E-01	p(1,1)	282.2298	6.27E-01	p(1,2)
47.21118	2.87E-02	p(1,2)	181.0765	6.48E-02	p(1,2)	282.4069	2.12E-03	p(2,1)
51.05385	7.86E-02	p(1,1)	182.3963	3.92E-02	p(1,1)	285.5909	3.35E-02	p(2,3)
65.99374	4.69E+00	s(2,2)	182.6501	2.34E-02	p(1,1)	287.5633	6.52E-02	p(1,1)
69.48982	2.53E-02	p(1,2)	183.3096	2.37E+00	s(1,1)	288.1518	2.34E-01	p(1,1)
69.70282	2.48E-02	s(1,1)	183.9201	2.70E-02	p(1,1)	290.1497	9.74E-02	p(2,3)
72.97705	1.02E-01	p(1,2)	184.1931	4.55E-02	s(1,1)	291.6543	5.38E-02	p(1,2)
73.68473	1.08E+00	s(1,1)	184.4965	1.78E-01	p(1,1)	291.9765	1.09E-02	s(2,2)
74.35759	9.60E-01	s(2,2)	185.5505	1.15E-01	p(1,2)	294.8997	1.28E-01	p(1,2)
88.16488	6.43E+00	s(1,1)	186.4157	4.48E-01	s(2,2)	295.1243	2.08E+01	s(1,1)
93.63205	9.29E-02	p(2,1)	192.54	1.46E-01	p(2,3)	295.7806	6.49E+00	p(1,1)
94.55848	6.57E-01	s(2,2)	195.2295	1.14E-01	p(1,2)	296.1934	1.09E-01	p(1,2)
98.41455	3.88E-02	p(1,1)	195.8957	6.76E-01	s(2,2)	298.2845	3.81E-02	p(1,2)
100.0405	1.62E-01	p(1,2)	199.6195	6.79E-02	p(1,2)	298.898	5.62E+00	p(1,0)
104.2186	8.24E-02	p(1,1)	201.6969	3.95E-01	s(2,2)	300.3995	1.28E-01	s(2,2)
107.4171	1.28E+00	s(2,2)	201.889	3.00E-01	p(1,0)	301.4229	3.31E-02	p(1,2)
108.3309	5.18E-02	p(1,1)	203.0544	7.33E-02	p(1,1)	302.2264	9.32E-02	p(1,2)
108.8954	5.12E-02	p(1,2)	203.7771	1.96E-01	p(1,1)	304.2324	8.65E-02	p(2,3)
118.6834	4.60E-02	p(1,1)	209.3089	8.12E-02	p(2,3)	305.5102	2.93E+00	s(2,2)
124.2378	3.25E+00	s(1,1)	214.0478	1.11E-01	p(1,1)	305.6119	4.22E-02	p(2,3)
124.6792	2.04E-01	p(1,2)	215.846	1.33E-01	p(1,2)	309.291	1.02E-01	p(1,2)
126.6574	1.50E-01	p(1,1)	220.1449	1.31E-01	p(1,2)	310.2311	3.01E+01	s(1,1)
127.505	4.19E-01	s(2,2)	221.4007	3.29E+00	s(2,2)	315.2396	6.50E-02	s(2,2)
129.8823	1.24E-01	p(1,2)	223.7939	1.51E-01	p(1,1)	316.8184	2.85E-01	s(2,2)
135.042	1.02E-01	p(1,1)	224.8058	3.13E-01	p(1,1)	319.1038	1.04E-01	p(1,2)
135.671	2.31E+01	s(1,1)	227.7001	4.62E-02	s(1,1)	319.6074	6.59E-02	p(2,1)
136.7751	8.94E-02	p(1,2)	227.9671	2.90E-01	s(2,2)	319.6102	7.16E+00	p(1,1)
144.1107	3.83E-02	p(1,1)	228.7028	4.56E-02	p(1,1)	320.0644	1.74E-01	p(1,2)
145.652	1.34E-02	p(1,2)	232.2466	7.33E-02	p(1,1)	320.7871	1.85E-01	p(1,2)
145.8558	6.11E-01	s(2,2)	233.6878	7.82E-02	p(2,3)	321.8197	2.54E-01	s(1,1)
146.4498	2.48E-02	p(1,1)	237.2776	1.43E-01	p(1,1)	322.528	5.63E-02	p(1,2)
146.8	3.58E-02	s(1,1)	238.6885	1.13E+00	s(2,2)	324.5504	4.12E-01	s(1,1)
147.3141	9.25E-02	s(1,1)	239.3708	2.18E-01	p(1,2)	327.3366	7.03E-02	p(2,3)
148.811	3.18E-02	s(2,2)	243.5003	6.10E+00	s(1,1)	328.765	2.31E-01	s(2,2)
157.8736	1.18E+00	s(2,2)	246.206	5.70E-01	s(2,2)	329.0098	2.40E-01	p(2,3)
158.7127	2.85E-02	s(2,2)	249.1462	1.60E-01	s(1,1)	333.8888	1.92E-01	p(2,3)
159.203	1.83E+00	s(2,2)	258.5349	1.62E-01	p(1,2)	336.4008	2.88E-01	s(1,1)
159.464	1.96E-02	p(1,2)	258.835	9.88E-02	p(1,2)	337.3955	9.01E-02	p(1,2)
162.8258	1.65E-02	p(1,2)	264.2246	1.84E-01	p(1,1)	338.429	6.39E+00	s(2,2)
163.658	5.75E-02	p(1,1)	264.5202	1.50E-01	s(2,2)	341.7837	3.94E+00	s(2,2)
172.8046	1.90E-02	p(1,2)	265.3731	6.06E-01	s(1,1)	342.7068	2.27E+00	s(1,1)
172.975	4.90E-01	s(2,2)	270.1471	1.20E-01	s(1,1)	346.7316	1.26E-03	p(1,0)
173.8206	4.17E+00	s(1,1)	271.5144	8.46E-01	p(1,2)	350.4449	1.23E-01	p(2,3)
176.1865	3.70E-02	p(1,2)	275.6048	1.06E-01	p(2,3)	351.209	1.31E-01	p(2,3)

$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$	$E_n(\text{keV})$	$\Gamma_n(\text{keV})$	$\ell(s, j)$
351.9368	4.17E-02	p(2,3)	418.5816	2.11E-01	p(1,2)	503.2767	9.21E-03	s(1,1)
356.864	1.46E+01	s(2,2)	418.9224	1.48E-01	p(1,2)	504.394	8.76E-02	p(1,1)
357.3202	1.40E-01	p(1,2)	421.6352	3.28E-01	s(2,2)	505.927	2.63E-01	p(1,2)
359.5514	1.72E+00	s(1,1)	421.6504	4.79E+00	s(1,1)	507.2082	9.48E-02	p(1,1)
362.7783	2.24E-01	p(1,1)	424.8144	7.40E-01	s(1,1)	509.6859	1.92E+00	s(2,2)
363.7128	3.87E-01	p(1,1)	425.5791	1.64E-01	p(1,1)	510.4531	2.67E-01	p(2,3)
367.92	3.59E-01	p(2,3)	426.6986	7.56E-02	p(2,3)	511.3975	2.25E-01	s(1,1)
368.7204	1.10E-01	s(1,1)	427.1882	2.98E+00	p(1,1)	512.0685	2.09E-01	p(2,3)
374.63	1.21E-01	s(2,2)	429.665	7.39E+00	s(1,1)	514.6492	1.35E+00	s(2,2)
375.4981	1.17E+00	p(1,1)	430.4237	7.23E-01	p(1,1)	517.095	3.58E+00	s(1,1)
377.9419	4.52E-01	s(1,1)	434.7706	3.28E-01	p(1,2)	517.4791	3.48E-01	p(1,1)
378.9894	1.64E-01	p(2,3)	436.4644	5.63E-01	p(1,2)	517.694	2.35E-01	d(2,4)
379.7689	2.22E-01	p(1,2)	443.9512	2.03E+00	s(2,2)	519.9289	1.77E-01	p(1,2)
380.768	5.38E-02	s(2,2)	447.4838	3.08E+00	p(1,2)	521.4833	8.46E-01	p(1,1)
380.8666	1.02E+01	s(1,1)	455.0181	2.24E-01	s(1,1)	524.5505	5.80E+00	s(2,2)
381.9004	2.52E-01	p(2,1)	457.2956	2.42E+00	s(1,1)	526.5691	1.38E+00	p(1,0)
382.6327	4.11E-01	p(1,1)	457.4781	2.34E+01	s(2,2)	530.5272	2.07E+00	s(1,1)
383.2702	8.26E-02	p(2,1)	458.7077	4.97E-01	p(1,1)	533.5794	8.97E-03	s(1,1)
384.0309	4.88E-01	p(1,2)	462.6606	9.17E-02	p(2,3)	533.9456	3.52E-01	p(1,1)
386.8108	1.88E-01	p(1,2)	462.7434	1.38E+00	s(2,2)	535.2768	3.88E-01	s(1,1)
389.8991	2.44E-01	p(2,3)	465.0937	8.90E-02	p(2,3)	535.687	8.45E-02	p(1,2)
390.3249	9.50E-02	p(1,2)	466.445	8.75E+00	s(1,1)	536.6145	1.58E-01	s(2,2)
393.1183	2.34E-01	p(1,1)	467.8575	1.17E+00	p(2,2)	537.6249	2.85E-01	d(2,4)
396.3678	1.99E-01	p(2,3)	474.5433	3.35E-01	p(2,3)	539.5165	6.83E+00	s(1,1)
398.7106	9.61E-01	p(1,1)	478.7382	6.64E+00	s(2,2)	541.4084	2.30E+00	s(2,2)
399.0593	1.78E-01	p(2,3)	480.0983	6.68E+00	s(1,1)	544.9142	6.44E-01	p(1,1)
399.605	1.25E-01	p(1,1)	483.5372	5.71E-01	d(2,4)	548.5048	3.50E+00	s(2,2)
400.5863	9.29E-02	s(1,1)	486.9928	1.99E+00	p(1,1)	550.3711	2.00E+00	s(2,2)
400.7585	7.01E-01	p(1,1)	487.6153	4.76E+00	s(2,2)	567.2393	1.07E+00	s(1,1)
404.0072	2.37E-01	p(1,2)	488.7438	2.25E-01	p(1,2)	568.5248	7.18E-01	s(2,2)
408.0107	3.75E-02	p(1,2)	491.491	1.41E-01	p(2,3)	574.1089	1.73E+00	s(2,2)
408.8896	7.60E+00	s(2,2)	492.1919	6.22E-01	s(2,2)	587.8084	5.93E-03	s(2,2)
410.4316	1.15E-01	p(1,2)	494.6292	3.29E-01	s(1,1)	592.4401	1.43E+00	s(2,2)
411.2633	5.54E-02	p(1,2)	495.2594	1.97E-01	p(2,3)	595.8354	2.62E+00	s(2,2)
411.9746	2.76E-01	s(2,2)	497.0687	8.21E-02	p(1,1)	651.7131	4.19E+01	s(1,1)
412.9104	2.61E-01	p(1,1)	501.0719	1.45E-01	s(2,2)	652.418	1.31E-01	s(2,2)
414.9278	8.82E-02	p(2,3)	501.3959	8.26E-02	p(1,2)			

⁵⁴Cr Resonance Parameters

E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π
23.06436	4.84E-01	s-1/2	431.3788	1.70E-01	d-5/2	690.1103	1.16E-01	d-5/2
54.95827	6.52E-02	p-1/2	431.5968	8.82E-02	s-1/2	706.109	3.09E-01	d-3/2
76.3581	9.24E-03	p-3/2	436.1819	8.96E-02	d-3/2	708.358	3.33E-01	d-5/2
94.68007	9.57E-02	p-1/2	436.5677	1.76E+01	p-1/2	730.9708	2.86E-01	d-5/2
95.85661	1.92E-02	d-3/2	442.1269	3.90E-01	d-5/2	735.2672	3.63E+00	d-3/2
101.3543	1.24E-02	d-5/2	454.0356	6.21E-01	d-5/2	741.2205	4.61E+00	s-1/2
119.4055	5.12E+00	s-1/2	456.8986	1.03E-01	d-3/2	744.5447	2.84E-01	d-3/2
129.1969	1.03E-02	d-5/2	460.5958	9.69E-02	d-5/2	745.4989	6.45E-02	d-5/2
131.4341	3.01E-01	s-1/2	471.3627	3.44E-01	d-3/2	750.56	9.54E-01	d-5/2
136.0084	6.95E-02	d-3/2	477.5816	2.45E-02	d-3/2	754.0779	4.05E+00	s-1/2
156.805	4.08E-02	d-3/2	487.0573	6.19E-02	d-3/2	755.2496	4.52E-01	d-5/2
164.8357	1.23E-02	d-5/2	488.3474	1.74E+01	s-1/2	761.4566	9.89E-02	p-3/2
170.4321	1.08E-01	d-3/2	490.9777	7.26E-01	d-3/2	761.7967	9.78E-02	d-3/2
176.4383	1.93E+00	s-1/2	498.8875	6.22E-02	p-3/2	777.0006	4.02E-01	d-3/2
187.5232	6.02E-03	d-3/2	505.5434	1.76E-01	d-3/2	779.6233	4.77E-02	d-3/2
190.6384	8.79E-02	d-3/2	505.848	1.62E-01	p-1/2	786.3877	6.46E-01	d-3/2
203.8573	3.78E-02	d-3/2	521.9221	1.81E-02	d-3/2	793.1738	1.63E-01	s-1/2
210.0403	4.37E-02	d-3/2	525.7479	6.10E-02	d-5/2	795.3423	8.99E-01	d-3/2
225.8404	1.89E-02	d-3/2	531.2826	1.94E-01	d-3/2	803.3316	2.08E-01	p-1/2
248.7576	1.06E-01	p-3/2	531.4707	1.77E-01	p-3/2	811.7315	4.20E-01	s-1/2
248.958	1.19E-01	d-3/2	538.3915	3.00E-01	d-5/2	813.6736	1.75E-01	p-3/2
249.7808	1.78E-02	d-3/2	538.6492	8.37E-02	d-3/2	816.5982	6.28E-01	d-5/2
250.9979	1.41E-02	d-5/2	552.5569	1.58E-01	d-5/2	817.2182	4.52E-01	p-3/2
265.6114	7.31E-03	d-3/2	553.5367	2.53E-01	d-3/2	824.7367	1.08E-01	d-3/2
267.1585	3.51E-02	d-5/2	553.9915	3.20E-01	p-1/2	838.6759	6.57E-02	d-3/2
274.9114	1.55E-02	d-5/2	561.3427	1.75E-02	d-3/2	842.1047	9.40E-01	d-5/2
276.5115	1.55E-02	d-5/2	567.785	2.16E-01	p-1/2	849.2086	2.60E-01	d-5/2
283.3105	9.86E+00	s-1/2	568.2679	1.92E-01	d-3/2	854.1154	3.75E-01	d-3/2
296.2895	1.78E-02	d-5/2	568.3991	8.97E-02	d-5/2	858.1497	9.88E-02	d-5/2
298.1987	9.22E-03	p-1/2	572.9849	1.01E-01	d-5/2	871.9455	3.11E-01	d-5/2
305.3042	3.38E-02	d-5/2	577.7794	1.02E-01	p-3/2	872.6469	2.05E-01	p-3/2
315.0559	8.18E-02	d-3/2	586.7892	2.07E-01	d-5/2	877.4878	1.46E+00	d-3/2
321.3164	7.14E-02	d-5/2	602.7278	1.08E+02	s-1/2	884.8572	4.10E-01	d-3/2
329.2005	1.19E+01	s-1/2	603.4884	3.04E-02	p-3/2	887.5185	2.96E-01	d-3/2
332.5714	3.53E-02	d-5/2	613.3242	3.99E-02	d-5/2	889.9559	9.34E-01	s-1/2
333.6876	2.17E-01	d-3/2	615.0291	8.17E-02	d-5/2	902.8505	1.13E-01	p-3/2
352.7638	4.09E-01	s-1/2	625.6984	7.75E-01	d-3/2	908.3038	3.05E+00	p-1/2
358.8194	3.28E-01	d-5/2	630.5578	9.99E-01	d-5/2	909.2502	1.38E+00	s-1/2
377.0088	2.15E-02	d-5/2	632.3093	7.73E-01	d-3/2	915.8803	8.32E-02	p-3/2
380.4849	1.86E-01	d-3/2	649.0664	1.69E+00	d-5/2	921.4768	9.55E-02	d-5/2
387.8489	5.60E-01	d-5/2	651.5883	5.83E-02	d-5/2	923.6276	8.06E-01	d-3/2
396.969	2.11E+00	p-1/2	663.6873	6.97E+00	s-1/2	927.3037	5.73E-02	d-3/2
398.0489	4.36E-02	d-5/2	667.1382	1.51E+00	p-1/2	929.3266	1.18E-01	d-3/2
420.6802	3.54E-02	d-5/2	669.7186	1.32E-01	d-3/2	932.4452	2.57E-02	s-1/2
426.92	4.13E-02	d-3/2	686.7014	1.97E-01	d-5/2	941.012	8.26E-02	d-5/2

⁵⁴Cr Resonance Parameters

E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π	E _n (keV)	Γ _n (keV)	J ^π
946.451	9.46E-02	d-3/2	1011.384	4.23E-01	d-5/2	1095.837	5.23E+00	d-3/2
955.6542	1.07E-01	p-3/2	1032.273	1.10E-01	d-5/2	1108	2.45E-01	p-3/2
957.5514	1.50E+00	d-3/2	1036.245	5.52E-01	d-3/2	1109.168	5.22E-01	d-5/2
960.7264	1.02E-01	d-3/2	1050.394	5.11E-01	d-5/2	1119.072	2.45E-01	p-3/2
961.5	3.48E+00	s-1/2	1051.357	2.26E+01	s-1/2	1125.188	1.24E-01	d-3/2
974.0489	1.41E-01	p-3/2	1057.854	4.96E-01	d-3/2	1135.526	2.61E+00	d-3/2
973.0091	1.01E+01	s-1/2	1059.833	2.23E+00	d-5/2	1140.701	2.65E-01	d-5/2
979.3455	4.45E+00	s-1/2	1064.728	1.34E+01	s-1/2	1162.983	1.12E+00	d-3/2
993.4972	1.66E-01	d-3/2	1068.128	2.54E-01	d-5/2	1163.886	3.29E-01	d-5/2
994.2482	7.25E-02	d-3/2	1069.448	9.07E-02	d-3/2	1170.096	1.31E-01	s-1/2
1007.176	4.72E+01	s-1/2	1079.215	9.80E-02	d-5/2	1184.431	1.66E-01	d-3/2
1008.915	7.61E-02	d-3/2	1092.887	2.93E-01	p-3/2			

⁵⁰Cr R-function Parameters

ℓ_J	$E_{lo}(\text{eV})$	$E_{hi}(\text{eV})$	α	$\beta (\text{eV}^{-1})$	$\mathcal{S}$
$s_{1/2}$	1.00E-01	1.30E+06	-6.99E-02	4.40E-07	1.04E-01
$p_{1/2}$	1.00E-01	1.30E+06	-5.37E-01	3.51E-08	6.30E-02
$p_{3/2}$	1.00E-01	1.30E+06	-1.02E+00	1.34E-06	2.37E-02
$d_{3/2}$	1.00E-01	1.30E+06	0.00E+00	0.00E+00	1.78E-01
$d_{5/2}$	1.00E-01	1.30E+06	0.00E+00	0.00E+00	1.21E-01

⁵³Cr R-function Parameters

$\ell(s, j)$	$E_{lo}(\text{eV})$	$E_{hi}(\text{eV})$	α	$\beta (\text{eV}^{-1})$	$\mathcal{S}$
$s(1,1)$	1.00E-01	1.00E+06	-2.40E-01	9.42E-08	1.04E-01
$s(2,2)$	1.00E-01	1.00E+06	4.24E-03	5.63E-07	1.04E-01
$p(1,0)$	1.00E-01	1.00E+06	3.13E-01	3.69E-08	1.04E-01
$p(1,2)$	1.00E-01	1.00E+06	-9.89E-03	3.75E-08	1.04E-01
$p(1,2)$	1.00E-01	1.00E+06	-9.47E-03	4.10E-08	1.04E-01
$p(2,1)$	1.00E-01	1.00E+06	-9.51E-03	3.93E-08	1.04E-01
$p(2,2)$	1.00E-01	1.00E+06	-9.35E-03	3.98E-08	1.04E-01
$p(2,3)$	1.00E-01	1.00E+06	-9.48E-03	3.94E-08	1.04E-01
$d(2,4)$	1.00E-01	1.00E+06	-9.35E-03	3.98E-08	1.04E-01

⁵⁴Cr R-function Parameters

ℓ_J	$E_{lo}(\text{eV})$	$E_{hi}(\text{eV})$	α	$\beta (\text{eV}^{-1})$	$\mathcal{S}$
$s_{1/2}$	1.00E-01	1.78E+06	-2.46E-02	6.10E-07	1.28E-01
$p_{1/2}$	1.00E-01	1.78E+06	-2.44E+00	4.09E-06	2.90E-02
$p_{3/2}$	1.00E-01	1.78E+06	-8.90E-01	4.08E-07	1.56E-02
$d_{3/2}$	1.00E-01	1.78E+06	1.21E-01	0.00E+00	1.60E-01
$d_{5/2}$	1.00E-01	1.78E+06	1.61E-03	0.00E+00	1.60E-01