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**COMPARISON OF THE EVALUATIONS OF THE
CROSS SECTIONS FOR THE NEUTRON
DOSIMETRY REACTIONS**

$^{197}\text{Au}(n,2n)^{196}\text{Au}$, $^{59}\text{Co}(n,2n)^{58}\text{Co}$ and $^{93}\text{Nb}(n,2n)^{92\text{m}}\text{Nb}$

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Abstract: The results of the evaluation of the cross sections for the neutron dosimetry reaction $^{197}\text{Au}(n,2n)^{196}\text{Au}$ performed at the Institute for Radium Research and Nuclear Physics (IRK) of the University of Vienna (Institut für Radiumforschung und Kernphysik der Universität Wien), which are included in the International Reactor Dosimetry File (IRDF-90), were compared with the results of a recent evaluation reported by Yuan Hanrong and Liu Tong. In addition, a comparison with the evaluation reported by Zhao Wenrong et al. and with the existing ENDF/B-VI, JENDL-3 and CENDL-2 evaluations is given.

For completeness, a comparison of the results of the evaluations of the cross sections for the reactions $^{59}\text{Co}(n,2n)^{58}\text{Co}$ and $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$ with the respective evaluations reported by Zhao Wenrong et al. and with the available ENDF/B-VI, JENDL-3 and CENDL-2 evaluations is given. In the case of the reaction $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$, the results of an updated evaluation reported by M. Wagner taking into account recent experimental data, were considered and a comparison with an evaluation reported by V.M. Bychkov et al. and with a model calculation carried out by B. Strohmaier is made.

1. INTRODUCTION

The cross sections for the three important neutron dosimetry reactions $^{197}\text{Au}(n,2n)^{196}\text{Au}$, $^{59}\text{Co}(n,2n)^{58}\text{Co}$ and $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$ were evaluated at the Institut für Radiumforschung und Kernphysik (IRK) der Universität Wien [1,2] in the neutron energy range from threshold to 30, 23 and 20 MeV, respectively, and are included in the International Reactor Dosimetry File (IRDF-90) [3] as recommended values. The details of the evaluation procedure applied to these three reactions, as well as the results of their calculated relative covariance matrices and a comparison of the evaluations with the results of integral cross section measurements in the ^{252}Cf fission spectrum have been published in Ref. 1.

Recently, a new evaluation of the excitation function for the reaction $^{197}\text{Au}(n,2n)^{196}\text{Au}$ was reported [4] and, in the case of the reaction $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$, there was an update [5] of the evaluation reported in Refs. 1 and 2 due to the availability of new, more accurate measurements in the energy region from threshold to 10.6 MeV, where large discrepancies existed between the few existing data sets.

In the present work, a comparison of the results of the evaluation of the cross sections for the reaction $^{197}\text{Au}(n,2n)^{196}\text{Au}$ reported in Refs. 1 and 2 with the results of the recent evaluation reported by Yuan Hanrong and Liu Tong [4] and with the existing ENDF/B-VI, JENDL-3 and

CENDL-2 evaluations was performed. In addition, a comparison of the evaluations of the cross sections for the reactions $^{59}\text{Co}(n,2n)^{58}\text{Co}$ and $^{93}\text{Nb}(n,2n)^{92\text{m}}\text{Nb}$ performed at IRK [1,2] with the evaluation made at the Chinese Institute of Atomic Energy [6] and with the available ENDF/B-VI, JENDL-3 and CENDL-2 evaluations is given. In the case of the reaction $^{93}\text{Nb}(n,2n)^{92\text{m}}\text{Nb}$, the updated evaluation carried out by M. Wagner [5] was used and comparison with an evaluation reported by V.M. Bychkov et al. [7] and with a theoretically calculated excitation function [8] was made. The results of the comparisons suggest that additional experimental data is needed over various parts of the energy ranges. A smoothing procedure was also applied to the discrete evaluated excitation functions of the three reactions.

2. The reaction $^{197}\text{Au}(n,2n)^{196}\text{Au}$

The results of the evaluation carried out at IRK [1,2] are summarized in Table 1. Columns 1 to 6, respectively, list the group energy, the evaluated group cross section, its uncertainty in mb, its uncertainty in % and the consistency factor R, which is the ratio of the external to the internal uncertainty of the evaluated cross section and is applicable for such energy groups only that contain data from different measurements. From the ratio R we can judge the degree of consistency achieved: for $R > 1$, the data is considered inconsistent.

Figure 1 shows the discrete excitation function (Table 1) compared with the smoothed cross sections. As pointed out in Refs. 1 and 2, except in the case of the energy range from 10 to 12 MeV, where a strong inconsistency between the data sets exists (see the respective values of the consistency factor R in Table 1) and where the uncertainties of the evaluated group cross sections are rather large (Table 1), the results of this evaluation appear to be fairly good. Here, it can be seen how well the smoothing procedure was applied to the discrete excitation function.

The results of the evaluation reported by Zhao Wenrong et al. [6] are summarized and compared with the IRK-evaluation in Table 2. Columns 1 to 8, respectively, give the sequential number of the data points, the average neutron energy, the evaluated cross section and its uncertainty as reported by Zhao Wenrong et al., the IRK-evaluated cross section and its uncertainty as reported in Refs. 1 and 2, the difference between the results of the cross sections of the two evaluations and the difference between the results of the cross section uncertainties of the two evaluations. A comparison of the two evaluated excitation functions is shown in Fig. 2. In general, good agreement is observed over the whole energy range.

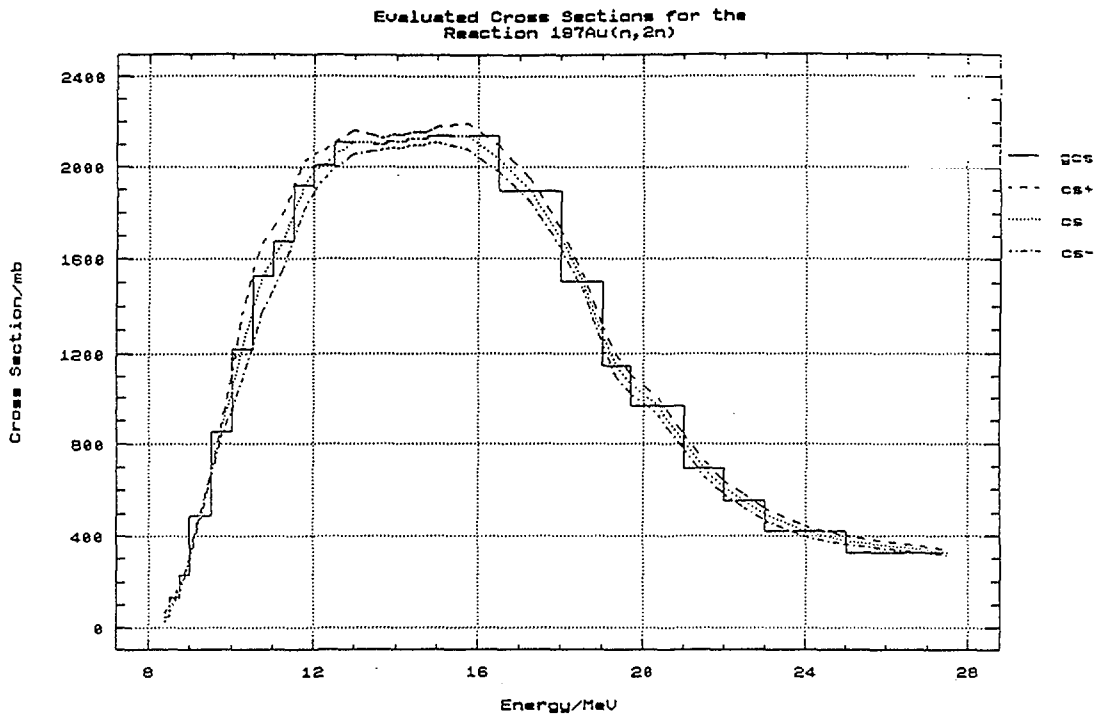
The results of the evaluation reported by Yuan Hanrong and Liu Tong [4] are summarized and compared with the IRK-evaluation in Table 3. Columns 1 to 8, respectively, give the sequential number of the data points, the average neutron energy, the evaluated cross section and its uncertainty as reported by Yuan Hanrong, the IRK-evaluated cross section and its uncertainty as reported in Refs. 1 and 2, the difference between the results of the cross sections of the two evaluations and the difference between the results of the cross section uncertainties of the two evaluations. A comparison of the two evaluated excitation functions is shown in Fig. 3. Not even within the uncertainty limits is there an agreement.

A comparison of the IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluated excitation functions is shown in Fig. 4. Good agreement exists in the energy range from threshold to 11 MeV. However, there are differences between the four evaluations in the other neutron energies, particularly in the energy range from 14 to 18.5 MeV, where the CENDL-2 evaluated cross section values are rather low.

Table 1 Evaluated Group Cross Sections for the Reaction $^{197}\text{Au}(n,2n)$

| Group-Energy [MeV] to [MeV] | Cross Section [mb] | Error [mb] | Error [%] | Ratio |
|--------------------------------|-----------------------|---------------|--------------|-------|
| 8.25 8.50 | 45.809 | 22.330 | 48.75 | —*) |
| 8.50 8.75 | 130.333 | 18.412 | 14.13 | —*) |
| 8.75 9.00 | 229.448 | 12.011 | 5.23 | 0.884 |
| 9.00 9.50 | 488.402 | 19.840 | 4.06 | 0.986 |
| 9.50 10.00 | 850.996 | 24.428 | 2.87 | 0.132 |
| 10.00 10.50 | 1219.070 | 141.914 | 11.64 | 2.275 |
| 10.50 11.00 | 1528.670 | 143.773 | 9.41 | 1.718 |
| 11.00 11.50 | 1674.630 | 120.233 | 7.18 | 1.668 |
| 11.50 12.00 | 1920.080 | 104.402 | 5.44 | 1.152 |
| 12.00 12.50 | 2008.930 | 63.422 | 3.16 | 0.916 |
| 12.50 13.45 | 2107.990 | 51.156 | 2.43 | 0.416 |
| 13.45 13.75 | 2101.270 | 27.786 | 1.32 | 0.362 |
| 13.75 14.00 | 2111.530 | 27.278 | 1.29 | 0.709 |
| 14.00 14.25 | 2112.030 | 27.278 | 1.29 | 0.282 |
| 14.25 14.50 | 2123.940 | 27.585 | 1.30 | 0.290 |
| 14.50 14.75 | 2123.500 | 27.685 | 1.30 | 0.155 |
| 14.75 15.00 | 2135.490 | 28.755 | 1.35 | 0.149 |
| 15.00 16.50 | 2134.710 | 55.664 | 2.61 | 0.382 |
| 16.50 18.00 | 1894.850 | 51.169 | 2.70 | 1.016 |
| 18.00 19.00 | 1504.800 | 34.461 | 2.29 | 0.411 |
| 19.00 19.70 | 1142.730 | 46.560 | 4.07 | 0.732 |
| 19.70 21.00 | 962.319 | 36.660 | 3.81 | 0.971 |
| 21.00 22.00 | 691.524 | 31.883 | 4.61 | 0.248 |
| 22.00 23.00 | 551.059 | 28.414 | 5.16 | 1.086 |
| 23.00 25.00 | 419.871 | 23.215 | 5.53 | 0.027 |
| 25.00 30.00 | 325.153 | 13.472 | 4.14 | 1.136 |

—*) Not applicable (see text)



Group-cs compared with smoothed cs

Figure 1 The evaluated cross sections for the reaction $^{197}\text{Au}(n,2n)^{196}\text{Au}$. The figure shows the discrete excitation function (Table 1) compared with the smoothed cross sections

Table 2 Evaluated Cross Sections for the Reaction $^{197}\text{Au}(n,2n)$.
The IRK-evaluation compared with the data reported by
Zhao Wenrong et al.

| Nr. | Energy [MeV] | X-Section (Zhao) [mb] | Error (Zhao) [mb] | X-Section (IRK) [mb] | Error (IRK) [mb] | X-Section Diff. [mb] | Error Diff. [mb] |
|-----|-----------------|-----------------------------|-------------------------|----------------------------|------------------------|----------------------------|------------------------|
| 1 | 8.40 | 27.800 | 2.000 | 53.640 | 22.054 | -25.840 | 22.145 |
| 2 | 8.80 | 223.000 | 16.000 | 191.701 | 20.538 | 31.299 | 26.035 |
| 3 | 9.20 | 502.000 | 35.000 | 450.294 | 19.895 | 51.706 | 40.259 |
| 4 | 9.60 | 801.000 | 50.000 | 737.508 | 11.888 | 63.492 | 51.394 |
| 5 | 10.00 | 1082.000 | 70.000 | 1038.260 | 83.035 | 43.740 | 108.604 |
| 6 | 10.40 | 1328.000 | 80.000 | 1323.850 | 155.041 | 4.150 | 174.464 |
| 7 | 10.80 | 1531.000 | 77.000 | 1548.960 | 141.567 | -17.960 | 161.153 |
| 8 | 11.20 | 1690.000 | 84.000 | 1656.050 | 122.276 | 33.950 | 148.349 |
| 9 | 11.60 | 1816.000 | 91.000 | 1855.330 | 111.309 | -39.330 | 143.773 |
| 10 | 12.00 | 1908.000 | 95.000 | 1978.111 | 81.153 | -70.111 | 124.943 |
| 11 | 12.40 | 1980.000 | 87.000 | 2031.668 | 58.381 | -51.668 | 104.773 |
| 12 | 12.80 | 2034.000 | 60.000 | 2093.006 | 54.317 | -59.006 | 80.934 |
| 13 | 13.20 | 2074.000 | 43.000 | 2114.325 | 44.089 | -40.325 | 61.586 |
| 14 | 13.60 | 2103.000 | 42.000 | 2101.270 | 27.786 | 1.730 | 50.359 |
| 15 | 14.00 | 2123.000 | 41.000 | 2111.710 | 27.481 | 11.290 | 49.358 |
| 16 | 14.40 | 2135.000 | 40.000 | 2124.400 | 27.604 | 10.600 | 48.600 |
| 17 | 14.80 | 2138.000 | 41.000 | 2131.284 | 26.509 | 6.716 | 48.823 |
| 18 | 15.20 | 2132.000 | 58.000 | 2151.631 | 41.800 | -19.631 | 71.493 |
| 19 | 15.60 | 2116.000 | 77.000 | 2145.677 | 53.610 | -29.677 | 93.824 |
| 20 | 16.00 | 2087.000 | 97.000 | 2108.860 | 57.622 | -21.860 | 112.824 |
| 21 | 16.40 | 2044.000 | 102.000 | 2053.705 | 57.554 | -9.705 | 117.117 |
| 22 | 16.80 | 1986.000 | 99.000 | 1986.404 | 55.214 | -0.404 | 113.356 |
| 23 | 17.20 | 1912.000 | 96.000 | 1904.899 | 51.633 | 7.101 | 109.004 |
| 24 | 17.60 | 1822.000 | 100.000 | 1805.665 | 46.589 | 16.335 | 110.320 |
| 25 | 18.00 | 1716.000 | 111.000 | 1684.030 | 39.654 | 31.970 | 117.870 |
| 26 | 18.40 | 1596.000 | 104.000 | 1545.320 | 34.819 | 50.680 | 109.674 |
| 27 | 18.80 | 1464.000 | 100.000 | 1372.039 | 36.793 | 91.961 | 106.554 |
| 28 | 19.20 | 1323.000 | 93.000 | 1190.757 | 45.460 | 132.243 | 103.516 |
| 29 | 19.60 | 1177.000 | 82.000 | 1081.123 | 45.882 | 95.877 | 93.964 |
| 30 | 20.00 | 1033.000 | 72.000 | 1022.169 | 40.496 | 10.831 | 82.607 |

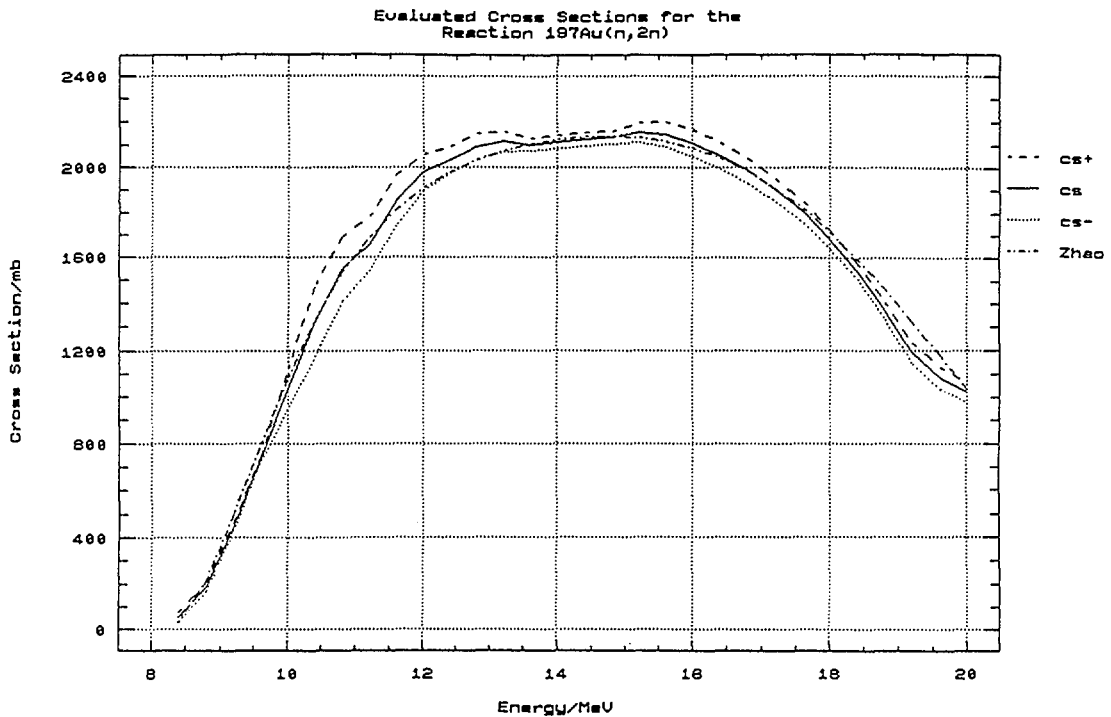


Figure 2 Comparison of the IRK-evaluated cross sections and their uncertainties [1,2] with the evaluation reported by Zhao Wenrong et al. [6] in the energy range from 8 to 20 MeV

Table 3 Evaluated Cross Sections for the Reaction $^{197}\text{Au}(n,2n)$.
The IRK-evaluation compared with the data reported by
Yuan Hanrong and Liu Tong

| Nr. | Energy [MeV] | X-Section (Yuan) [mb] | Error (Yuan) [mb] | X-Section (IRK) [mb] | Error (IRK) [mb] | X-Section Diff. [mb] | Error Diff. [mb] |
|-----|-----------------|-----------------------------|-------------------------|----------------------------|------------------------|----------------------------|------------------------|
| 1 | 8.50 | 75.000 | 5.000 | 87.949 | 20.877 | 12.949 | 21.467 |
| 2 | 9.00 | 329.000 | 20.000 | 308.799 | 14.719 | -20.201 | 24.833 |
| 3 | 9.50 | 718.000 | 43.000 | 673.890 | 12.352 | -44.110 | 44.739 |
| 4 | 10.00 | 1079.000 | 64.000 | 1038.260 | 83.035 | -40.740 | 104.837 |
| 5 | 10.50 | 1349.000 | 54.000 | 1391.590 | 154.728 | 42.590 | 163.880 |
| 6 | 11.00 | 1546.000 | 62.000 | 1603.890 | 131.665 | 57.890 | 145.532 |
| 7 | 11.50 | 1698.000 | 68.000 | 1799.800 | 113.655 | 101.800 | 132.444 |
| 8 | 12.00 | 1824.000 | 64.000 | 1978.111 | 81.153 | 154.111 | 103.353 |
| 9 | 12.50 | 1923.000 | 67.000 | 2049.217 | 56.688 | 126.217 | 87.764 |
| 10 | 13.00 | 1996.000 | 50.000 | 2109.299 | 50.628 | 113.299 | 71.156 |
| 11 | 13.50 | 2043.000 | 51.000 | 2103.650 | 31.113 | 60.650 | 59.741 |
| 12 | 14.00 | 2073.000 | 41.000 | 2111.710 | 27.481 | 38.710 | 49.358 |
| 13 | 14.20 | 2080.000 | 42.000 | 2115.020 | 27.362 | 35.020 | 50.127 |
| 14 | 14.40 | 2087.000 | 42.000 | 2124.400 | 27.604 | 37.400 | 50.259 |
| 15 | 14.50 | 2091.000 | 42.000 | 2123.844 | 27.863 | 32.844 | 50.402 |
| 16 | 14.60 | 2092.000 | 42.000 | 2123.030 | 27.835 | 31.030 | 50.386 |
| 17 | 14.70 | 2094.000 | 40.000 | 2126.274 | 26.014 | 32.274 | 47.715 |
| 18 | 14.80 | 2097.000 | 42.000 | 2131.284 | 26.509 | 34.284 | 49.666 |
| 19 | 15.00 | 2100.000 | 63.000 | 2142.243 | 33.506 | 42.243 | 71.356 |
| 20 | 15.50 | 2101.000 | 73.000 | 2150.914 | 51.556 | 49.914 | 89.370 |
| 21 | 16.00 | 2086.000 | 83.000 | 2108.860 | 57.622 | 22.860 | 101.041 |
| 22 | 16.50 | 2042.000 | 101.000 | 2038.779 | 57.146 | -3.221 | 116.046 |
| 23 | 17.00 | 1960.000 | 98.000 | 1950.030 | 53.656 | -9.970 | 111.727 |
| 24 | 17.50 | 1831.000 | 91.000 | 1835.244 | 48.221 | 4.244 | 102.987 |
| 25 | 18.00 | 1663.000 | 112.000 | 1684.030 | 39.654 | 21.030 | 118.813 |
| 26 | 18.50 | 1471.000 | 102.000 | 1504.800 | 34.461 | 33.800 | 107.664 |
| 27 | 19.00 | 1276.000 | 89.000 | 1275.360 | 41.516 | -0.640 | 98.207 |
| 28 | 19.50 | 1101.000 | 77.000 | 1102.333 | 46.549 | 1.333 | 89.977 |
| 29 | 20.00 | 957.000 | 67.000 | 1022.169 | 40.496 | 65.169 | 78.288 |

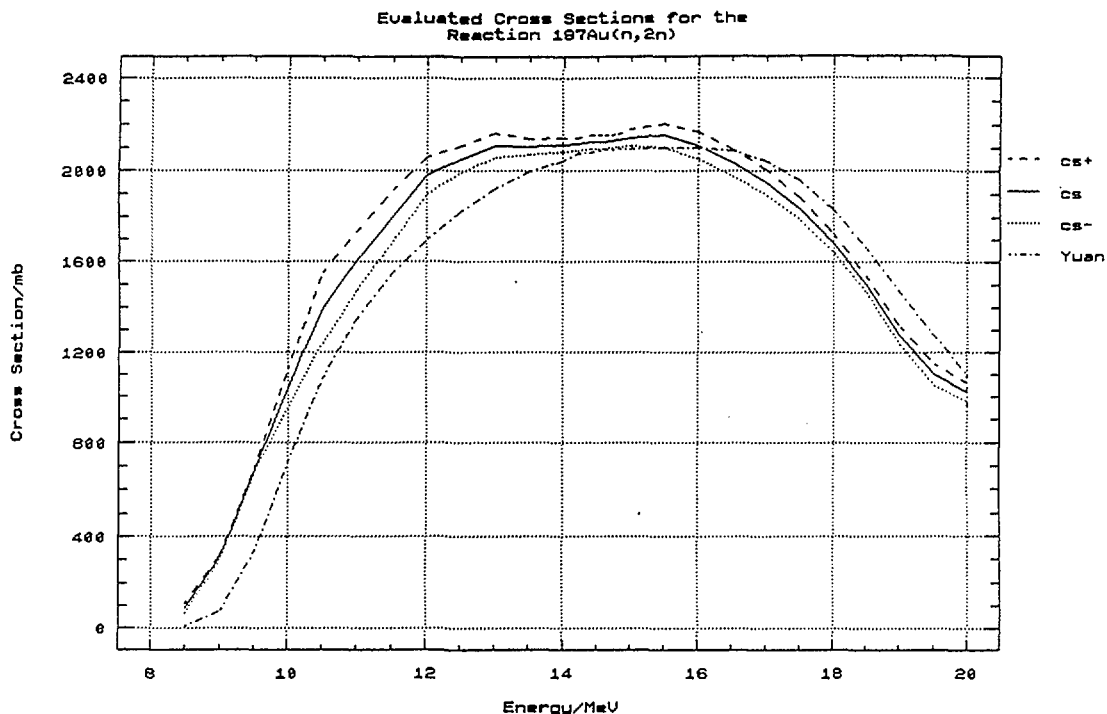


Figure 3 Comparison of the IRK-evaluated cross sections and their uncertainties [1,2] with the evaluation reported by Yuan Hanrong and Liu Tong [4] in the energy range from 8 to 20 MeV

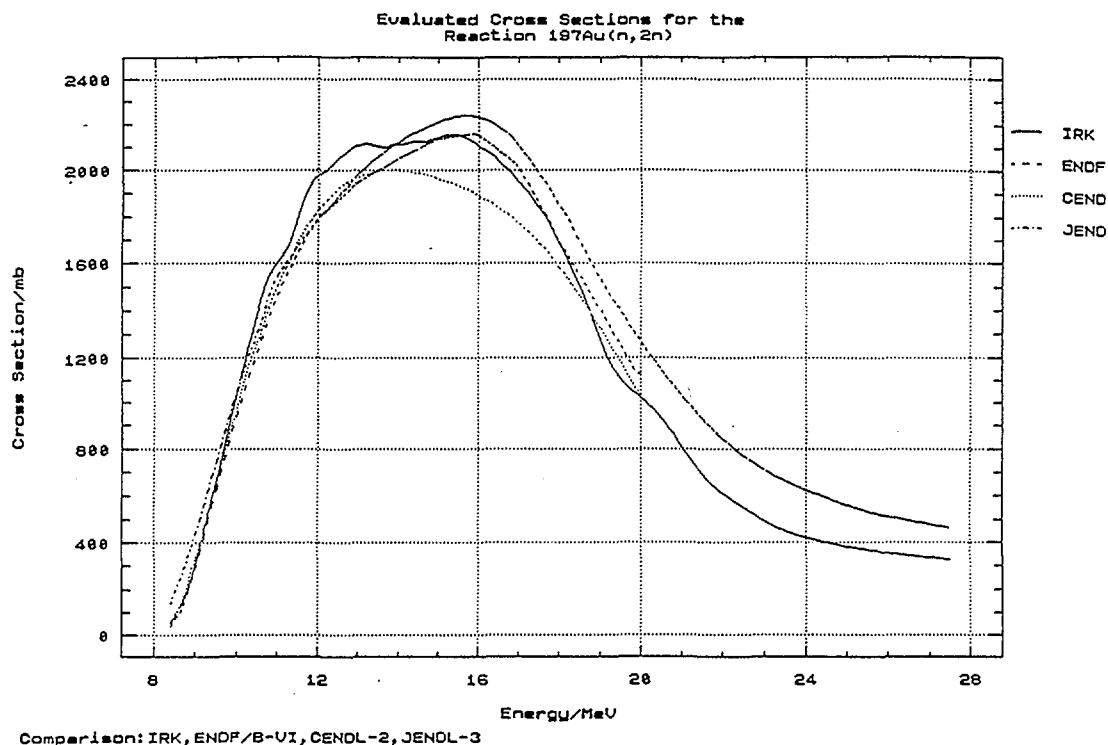


Figure 4 Comparison of the IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluated cross section data

3. The reaction $^{59}\text{Co}(n,2n)^{58}\text{Co}$

The results of the evaluation carried out at IRK [1,2] are summarized in Table 4. All column heading information in Table 4 is the same as in Table 1.

Figure 5 shows the discrete excitation function (Table 4) compared with the smoothed cross sections. Inconsistency between the data sets is observed in the energy ranges from 12 to 12.5 MeV and from 15 to 18 MeV (see the respective values of R in Table 4). In the neutron energy ranges from threshold to 12.5 MeV and above 20 MeV, the uncertainties are rather large.

The results of the evaluation reported by Zhao Wenrong et al. [6] are summarized and compared with the IRK-evaluation in Table 5. All column heading information in Table 5 is the same as in Table 2. A comparison of the two evaluated excitation functions is shown in Fig. 6. The two evaluations agree within their uncertainties. In the energy range from 15 to 18.5 MeV the results of the evaluated cross sections of Ref. 6 are larger than those of the IRK and show smaller uncertainties.

A comparison of the IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluated excitation functions is shown in Fig. 7. In the energy range from threshold to 14.5 MeV only the CENDL-2 evaluated cross section values disagree with those of the other evaluations. There are also some differences in the results of the four evaluations in the neutron energies above 14.5 MeV.

Table 4 Evaluated Group Cross Sections for the Reaction $^{59}\text{Co}(n,2n)$

| Group-Energy [MeV] to [MeV] | Cross Section [mb] | Error [mb] | Error [%] | Ratio |
|-----------------------------|--------------------|------------|-----------|-------|
| 10.80 11.00 | 16.640 | 6.91 | 41.53 | —*) |
| 11.00 11.50 | 87.720 | 8.04 | 9.17 | —*) |
| 11.50 12.00 | 202.280 | 15.54 | 7.68 | —*) |
| 12.00 12.50 | 348.280 | 23.07 | 6.62 | 1.659 |
| 12.50 13.00 | 490.980 | 16.62 | 3.39 | 0.712 |
| 13.00 13.50 | 575.150 | 7.04 | 1.22 | 0.398 |
| 13.50 14.00 | 662.860 | 6.14 | 0.93 | 0.605 |
| 14.00 14.25 | 704.130 | 14.82 | 2.10 | 0.984 |
| 14.25 14.50 | 750.740 | 18.72 | 2.49 | 0.964 |
| 14.50 14.75 | 769.720 | 6.50 | 0.84 | 0.774 |
| 14.75 15.00 | 788.100 | 7.21 | 0.91 | 0.587 |
| 15.00 16.00 | 794.000 | 30.97 | 3.90 | 1.303 |
| 16.00 17.00 | 809.490 | 30.29 | 3.74 | 1.399 |
| 17.00 18.00 | 835.090 | 38.24 | 4.58 | 1.496 |
| 18.00 19.00 | 851.850 | 22.10 | 2.59 | 0.905 |
| 19.00 20.00 | 876.230 | 29.85 | 3.41 | 0.178 |
| 20.00 21.00 | 848.290 | 47.46 | 5.59 | 0.033 |
| 21.00 22.00 | 734.570 | 46.60 | 6.34 | —*) |
| 22.00 23.00 | 629.630 | 63.04 | 10.01 | —*) |

—*) Not applicable (see text)

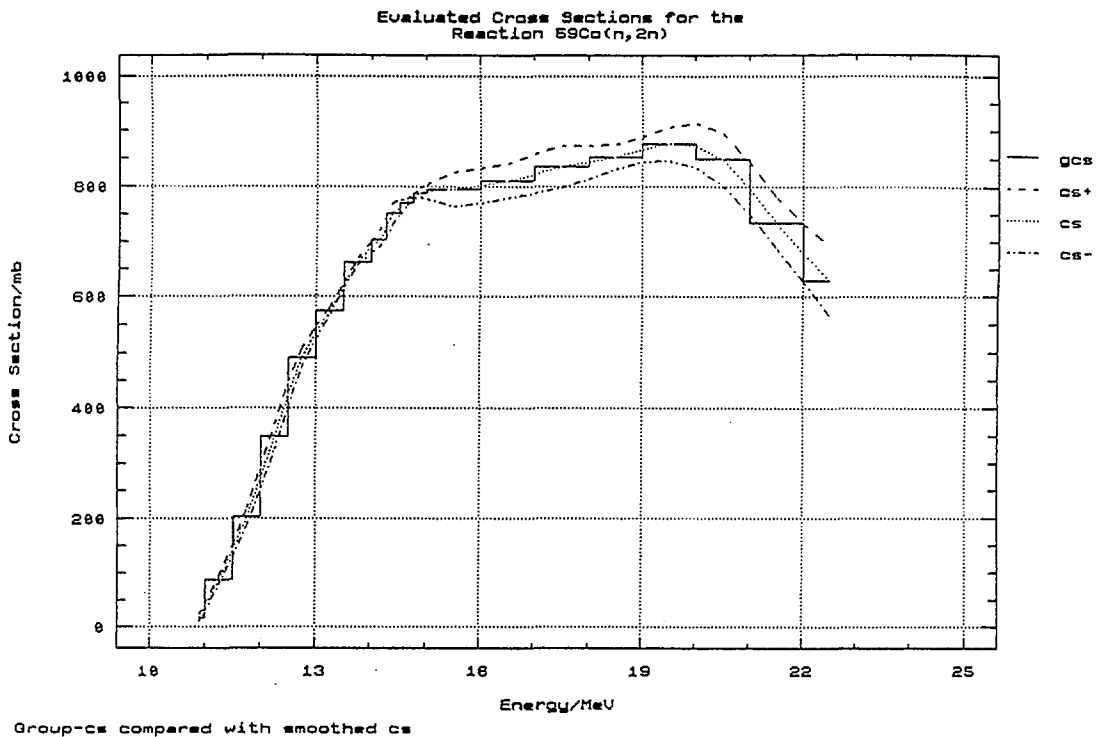


Figure 5 The evaluated cross sections for the reaction $^{59}\text{Co}(n,2n)^{58}\text{Co}$. The figure shows the discrete excitation function (Table 4) compared with the smoothed cross sections

Table 5 Evaluated Cross Sections for the Reaction $^{59}\text{Co}(n,2n)$.
The IRK-evaluation compared with the data reported by
Zhao Wenrong et al.

| Nr. | Energy [MeV] | X-Section (Zhao) [mb] | Error (Zhao) [mb] | X-Section (IRK) [mb] | Error (IRK) [mb] | X-Section Diff. [mb] | Error Diff. [mb] |
|-----|-----------------|-----------------------------|-------------------------|----------------------------|------------------------|----------------------------|------------------------|
| 1 | 10.91 | 20.000 | 6.000 | 18.649 | 6.833 | 1.351 | 9.093 |
| 2 | 11.00 | 46.000 | 14.000 | 35.860 | 6.543 | 10.140 | 15.454 |
| 3 | 11.50 | 184.000 | 15.000 | 142.213 | 11.381 | 41.787 | 18.829 |
| 4 | 12.00 | 314.000 | 20.000 | 273.015 | 20.380 | 40.985 | 28.554 |
| 5 | 12.50 | 435.000 | 6.000 | 424.629 | 21.220 | 10.371 | 22.052 |
| 6 | 13.00 | 549.000 | 8.000 | 536.563 | 11.370 | 12.437 | 13.902 |
| 7 | 13.50 | 631.000 | 9.000 | 620.595 | 5.154 | 10.405 | 10.371 |
| 8 | 14.00 | 699.000 | 11.000 | 689.475 | 11.040 | 9.525 | 15.585 |
| 9 | 14.20 | 722.000 | 11.000 | 715.528 | 16.843 | 6.472 | 20.117 |
| 10 | 14.50 | 753.000 | 12.000 | 761.948 | 13.369 | -8.948 | 17.964 |
| 11 | 14.70 | 772.000 | 9.000 | 776.240 | 4.168 | -4.240 | 9.918 |
| 12 | 14.80 | 780.000 | 12.000 | 785.091 | 4.614 | -5.091 | 12.856 |
| 13 | 15.00 | 796.000 | 12.000 | 790.427 | 12.763 | 5.573 | 17.518 |
| 14 | 15.50 | 829.000 | 15.000 | 794.000 | 30.970 | 35.000 | 34.411 |
| 15 | 16.00 | 852.000 | 15.000 | 800.506 | 31.578 | 51.495 | 34.959 |
| 16 | 16.50 | 867.000 | 16.000 | 809.490 | 30.290 | 57.510 | 34.256 |
| 17 | 17.00 | 875.000 | 16.000 | 822.397 | 35.410 | 52.603 | 38.857 |
| 18 | 17.50 | 877.000 | 16.000 | 835.090 | 38.240 | 41.910 | 41.452 |
| 19 | 18.00 | 874.000 | 16.000 | 843.066 | 30.400 | 30.934 | 34.353 |
| 20 | 18.50 | 865.000 | 16.000 | 851.850 | 22.100 | 13.150 | 27.284 |
| 21 | 19.00 | 852.000 | 60.000 | 866.249 | 22.970 | -14.249 | 64.247 |
| 22 | 19.50 | 834.000 | 59.000 | 876.230 | 29.850 | -42.230 | 66.121 |
| 23 | 20.00 | 814.000 | 58.000 | 872.702 | 39.780 | -58.702 | 70.331 |

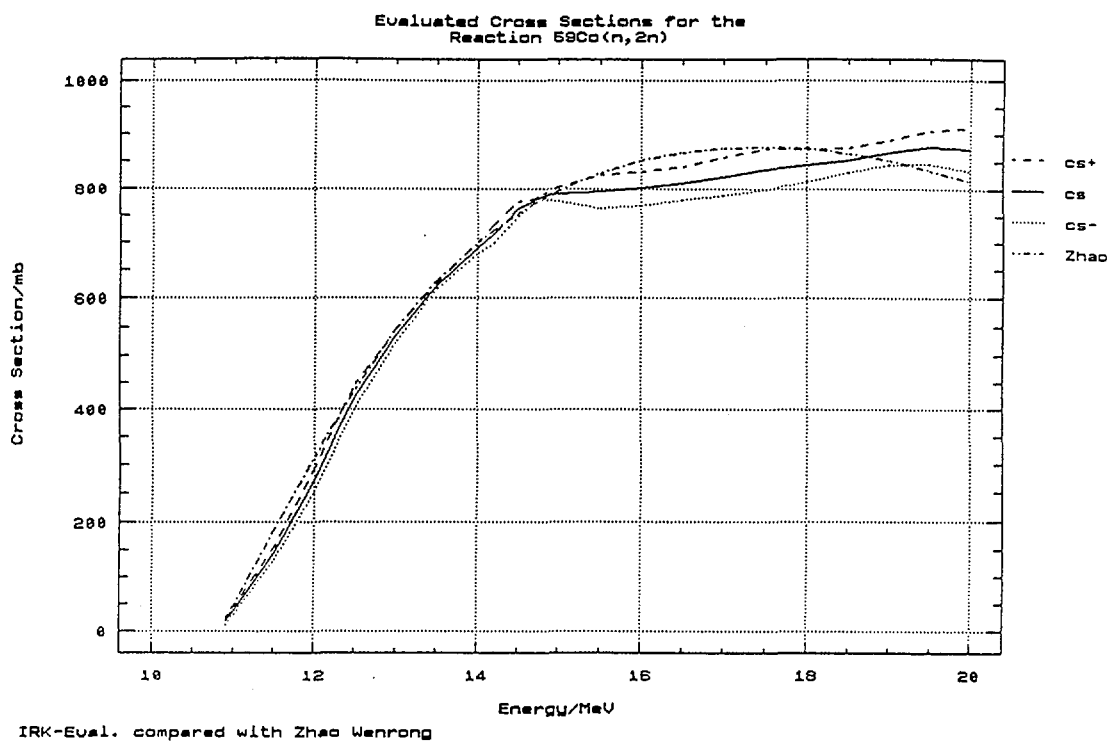


Figure 6 Comparison of the IRK-evaluated cross sections and their uncertainties [1,2] with the evaluation reported by Zhao Wenrong et al. [6] in the energy range from 8 to 20 MeV

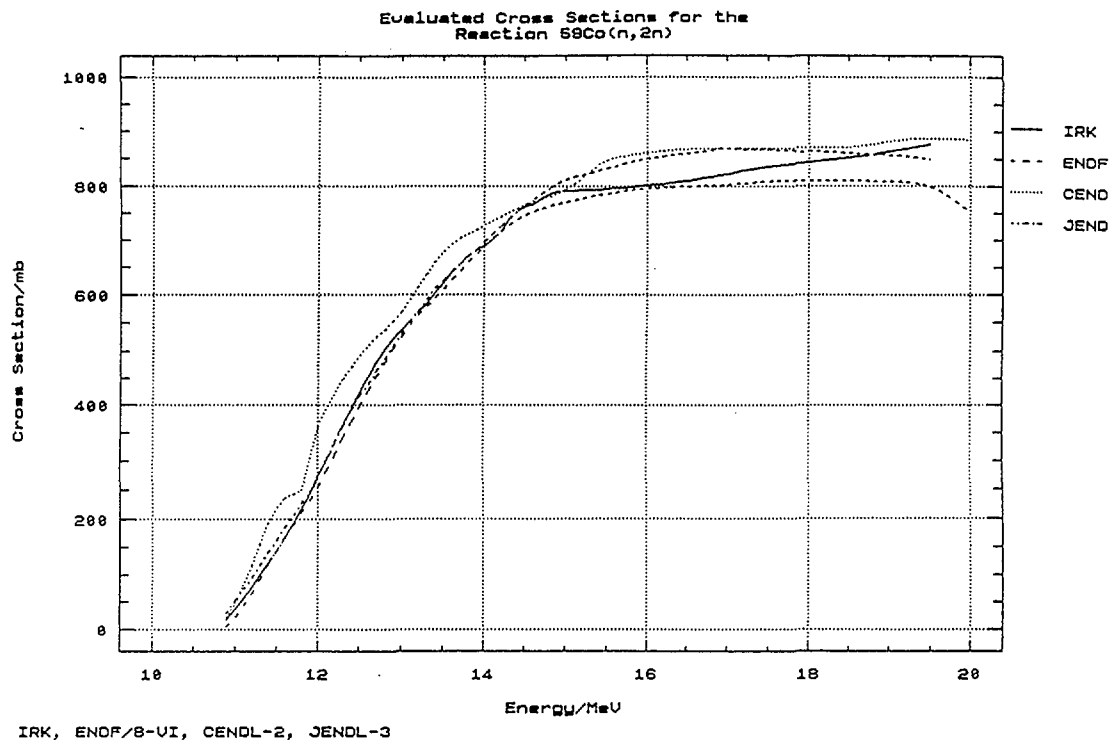


Figure 7 Comparison of the IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluated cross section data

4. The reaction $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$

The results of the evaluation carried out at IRK [1,2] are summarized in Table 6. All column heading information in Table 6 is the same as in Table 1.

Figure 8 shows the discrete excitation function (Table 6) compared with the smoothed cross sections. The results of this updated evaluation are very satisfactory above a neutron energy of 10 MeV, where the uncertainties are less than 5%. Thanks to the availability of new, more accurate measurements in the energy region from threshold to 10.6 MeV, some of the discrepancies pointed out in Ref. 1 have been resolved.

The results of the evaluation reported by Zhao Wenrong et al. [6] are summarized and compared with the IRK-evaluation in Table 7. All column heading information in Table 7 is the same as in Table 2. A comparison of the two evaluated excitation functions is shown in Fig. 9. In general, good agreement is observed over the whole energy range.

The results of the model calculation reported by B. Strohmaier [8] are summarized and compared with the IRK-evaluation in Table 8. Columns 1 to 5, respectively, give the sequential number of the data points, the average neutron energy, the calculated cross section as reported by B. Strohmaier, the IRK-evaluated cross section and the difference between the results of the cross sections. A comparison of the two excitation functions is shown in Fig. 10.

A comparison of the IRK, Bychkov and JENDL-3 evaluated excitation functions with the model calculation of Ref. 8 is shown in Fig. 11. Except for small differences in the energy range from 13 to 16 MeV, there is generally good agreement between the four excitation functions.

Table 6 Evaluated Group Cross Sections for the Reaction $^{93}\text{Nb}(n,2n)$

| Group-Energy [MeV] to [MeV] | | Cross Section [mb] | Error [mb] | Error [%] | Ratio |
|--------------------------------|-------|-----------------------|---------------|--------------|-------|
| 9.00 | 9.25 | 0.990 | 1.02 | 103.03 | 0.148 |
| 9.25 | 9.50 | 15.940 | 2.01 | 12.61 | 1.595 |
| 9.50 | 9.75 | 51.240 | 5.00 | 9.76 | 0.509 |
| 9.75 | 10.00 | 95.320 | 5.79 | 6.07 | 1.623 |
| 10.00 | 10.50 | 164.490 | 5.57 | 3.39 | 0.803 |
| 10.50 | 11.00 | 241.480 | 8.08 | 3.35 | 1.013 |
| 11.00 | 11.50 | 322.790 | 9.90 | 3.07 | 0.898 |
| 11.50 | 12.00 | 370.530 | 14.25 | 3.85 | 1.251 |
| 12.00 | 12.50 | 403.520 | 11.71 | 2.90 | 0.792 |
| 12.50 | 13.40 | 449.240 | 10.59 | 2.36 | 1.327 |
| 13.40 | 14.00 | 458.650 | 6.79 | 1.48 | —*) |
| 14.00 | 14.50 | 459.820 | 6.79 | 1.48 | —*) |
| 14.50 | 15.00 | 459.540 | 5.00 | 1.09 | —*) |
| 15.00 | 16.00 | 447.500 | 9.49 | 2.12 | 0.868 |
| 16.00 | 17.00 | 424.860 | 8.33 | 1.96 | 0.848 |
| 17.00 | 18.00 | 408.270 | 8.16 | 2.00 | 0.915 |
| 18.00 | 19.00 | 387.000 | 12.90 | 3.33 | 1.430 |
| 19.00 | 20.00 | 344.160 | 10.33 | 3.00 | 0.604 |

—*) Not applicable (see text)

Table 7 Evaluated Cross Sections for the Reaction $^{93}\text{Nb}(n,2n)$. The IRK-evaluation compared with the data reported by Zhao Wenrong et al.

| Nr. | Energy [MeV] | X-Section (Zhao) [mb] | Error (Zhao) [mb] | X-Section (IRK) [mb] | Error (IRK) [mb] | X-Section Diff. [mb] | Error Diff. [mb] |
|-----|-----------------|-----------------------------|-------------------------|----------------------------|------------------------|----------------------------|------------------------|
| 1 | 9.40 | 10.300 | 0.100 | 18.100 | 2.205 | 7.800 | 2.208 |
| 2 | 9.80 | 51.900 | 2.700 | 80.756 | 5.779 | 28.856 | 6.379 |
| 3 | 10.20 | 124.000 | 4.000 | 156.288 | 5.470 | 32.288 | 6.776 |
| 4 | 10.60 | 206.000 | 9.000 | 218.095 | 7.342 | 12.095 | 11.615 |
| 5 | 11.00 | 281.000 | 15.000 | 284.225 | 8.804 | 3.225 | 17.393 |
| 6 | 11.40 | 340.000 | 8.000 | 340.669 | 11.255 | 0.669 | 13.809 |
| 7 | 11.80 | 382.000 | 17.000 | 374.430 | 14.299 | -7.570 | 22.214 |
| 8 | 12.20 | 410.000 | 15.000 | 400.300 | 11.896 | -9.700 | 19.145 |
| 9 | 12.60 | 428.000 | 13.000 | 429.443 | 11.202 | 1.443 | 17.161 |
| 10 | 13.00 | 439.000 | 12.000 | 451.179 | 10.393 | 12.179 | 15.875 |
| 11 | 13.60 | 450.700 | 7.400 | 458.306 | 7.127 | 7.606 | 10.274 |
| 12 | 13.80 | 453.500 | 6.000 | 458.964 | 6.558 | 5.464 | 8.889 |
| 13 | 14.00 | 455.800 | 5.000 | 459.401 | 6.694 | 3.601 | 8.355 |
| 14 | 14.20 | 457.600 | 4.500 | 459.745 | 6.879 | 2.145 | 8.220 |
| 15 | 14.40 | 458.700 | 4.500 | 460.181 | 6.131 | 1.481 | 7.605 |
| 16 | 14.60 | 459.100 | 4.900 | 460.441 | 4.939 | 1.341 | 6.957 |
| 17 | 14.80 | 458.600 | 5.600 | 459.003 | 5.189 | 0.403 | 7.635 |
| 18 | 15.00 | 457.000 | 7.000 | 456.464 | 6.512 | -0.536 | 9.560 |
| 19 | 15.20 | 455.000 | 7.000 | 453.281 | 8.108 | -1.719 | 10.712 |
| 20 | 15.40 | 452.000 | 8.000 | 449.495 | 9.203 | -2.505 | 12.194 |
| 21 | 16.00 | 437.000 | 10.000 | 435.829 | 9.343 | -1.171 | 13.685 |
| 22 | 16.40 | 426.000 | 11.000 | 426.711 | 8.477 | 0.711 | 13.888 |
| 23 | 16.80 | 417.000 | 12.000 | 419.298 | 7.886 | 2.298 | 14.359 |
| 24 | 17.20 | 407.000 | 11.000 | 413.039 | 7.620 | 6.039 | 13.381 |
| 25 | 17.60 | 397.000 | 11.000 | 406.589 | 8.496 | 9.589 | 13.899 |
| 26 | 18.00 | 388.000 | 15.000 | 399.401 | 10.634 | 11.401 | 18.387 |
| 27 | 18.40 | 378.000 | 28.000 | 389.946 | 12.642 | 11.946 | 30.722 |
| 28 | 18.80 | 370.000 | 48.000 | 376.666 | 13.080 | 6.666 | 49.750 |
| 29 | 19.20 | 361.000 | 60.000 | 359.350 | 11.921 | -1.650 | 61.173 |

Table 8 Cross Section Data for the Reaction $^{93}\text{Nb}(n,2n)$. The IRK-evaluation compared with the data reported by B. Strohmaier [8]

| Nr. | Energy [MeV] | X-Section (Strohmaier) [mb] | X-Section (IRK) [mb] | X-Section Diff. [mb] |
|-----|--------------|-----------------------------|----------------------|----------------------|
| 1 | 9.37 | 21.410 | 14.913 | 6.497 |
| 2 | 9.62 | 65.400 | 49.672 | 15.728 |
| 3 | 9.88 | 116.100 | 95.320 | 20.780 |
| 4 | 10.13 | 163.700 | 143.671 | 20.029 |
| 5 | 10.38 | 206.700 | 185.486 | 21.214 |
| 6 | 10.63 | 246.900 | 222.820 | 24.080 |
| 7 | 10.89 | 286.500 | 265.141 | 21.359 |
| 8 | 11.14 | 324.200 | 307.154 | 17.046 |
| 9 | 11.39 | 357.400 | 339.603 | 17.797 |
| 10 | 12.40 | 435.600 | 414.301 | 21.299 |
| 11 | 13.41 | 459.600 | 457.757 | 1.843 |
| 12 | 14.42 | 460.500 | 460.243 | 0.257 |
| 13 | 15.44 | 453.200 | 448.607 | 4.593 |
| 14 | 16.45 | 442.700 | 425.671 | 17.029 |
| 15 | 17.46 | 428.900 | 408.931 | 19.969 |
| 16 | 18.47 | 389.800 | 387.908 | 1.892 |
| 17 | 19.48 | 326.700 | 345.227 | -18.527 |

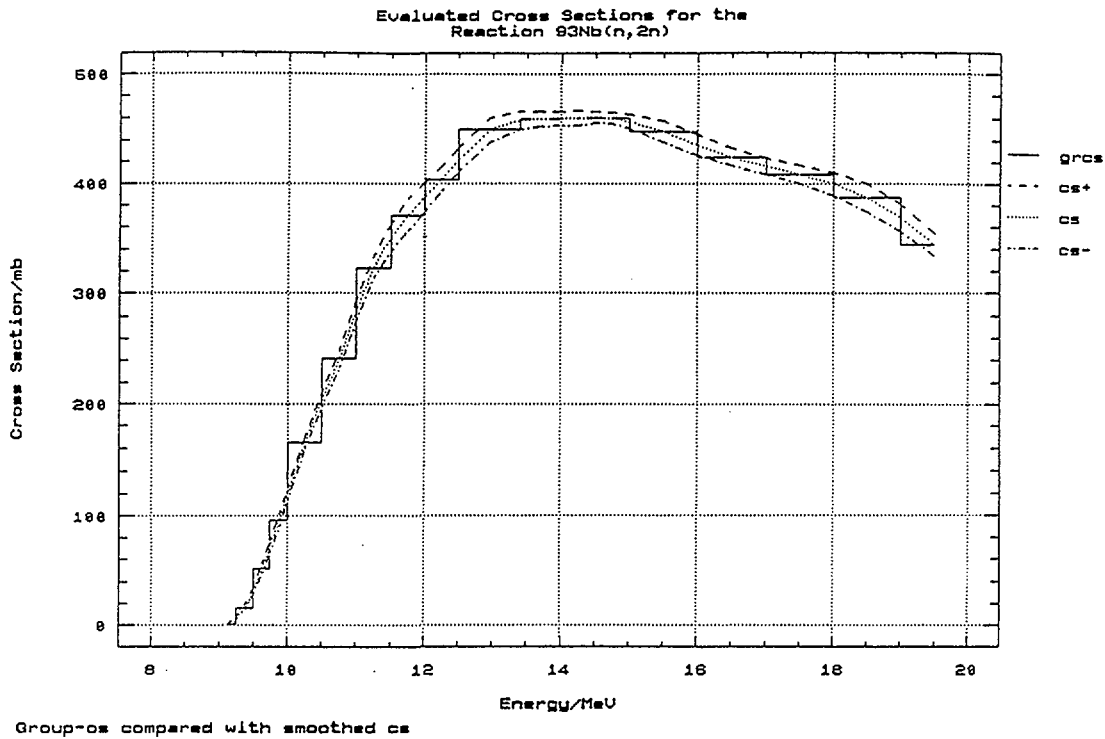


Figure 8 The evaluated cross sections for the reaction $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$. The figure shows the discrete excitation function (Table 6) compared with the smoothed cross sections

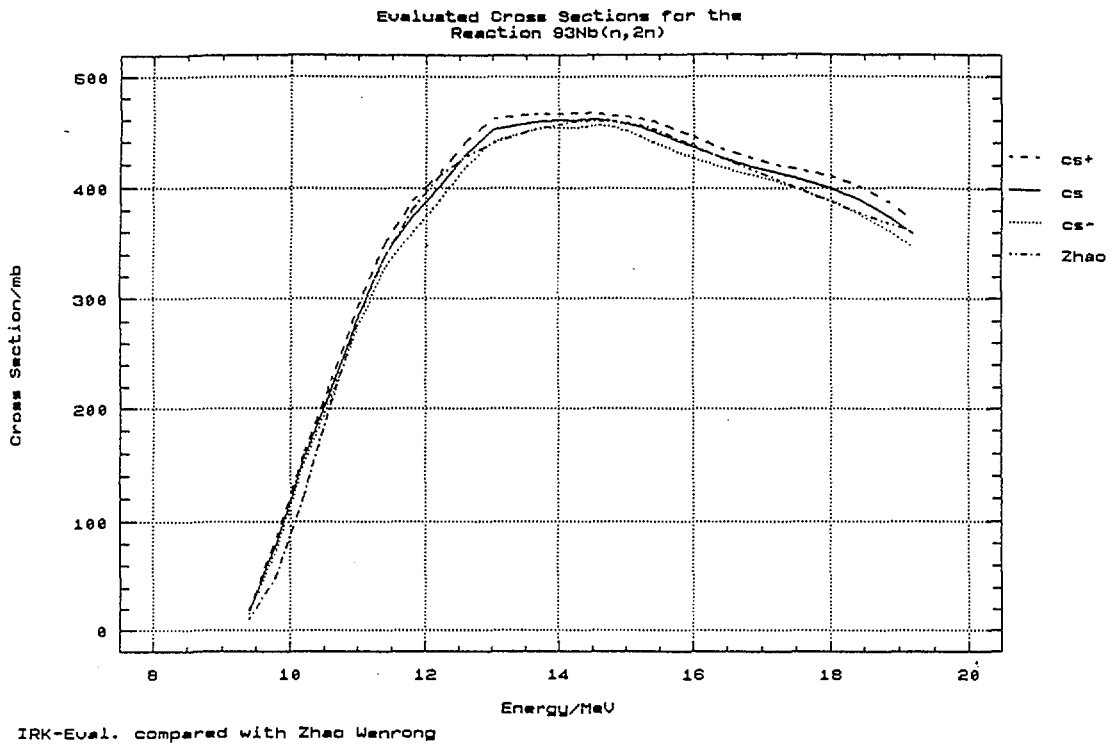


Figure 9 Comparison of the IRK-evaluated cross sections and their uncertainties [1,2] with the evaluation reported by Zhao Wenrong et al. [6] in the energy range from 8 to 20 MeV

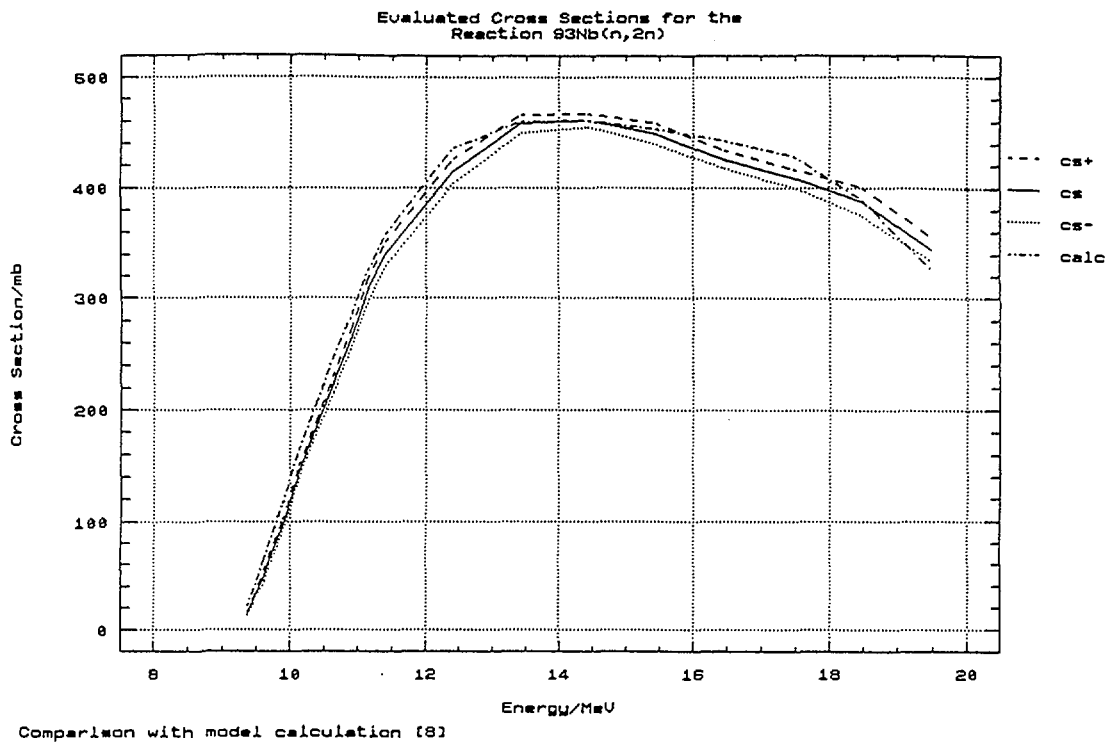


Figure 10 Comparison of the IRK-evaluated cross sections and their uncertainties [1,2] with the model calculation reported by B. Strohmaier [8] in the energy range from 8 to 20 MeV

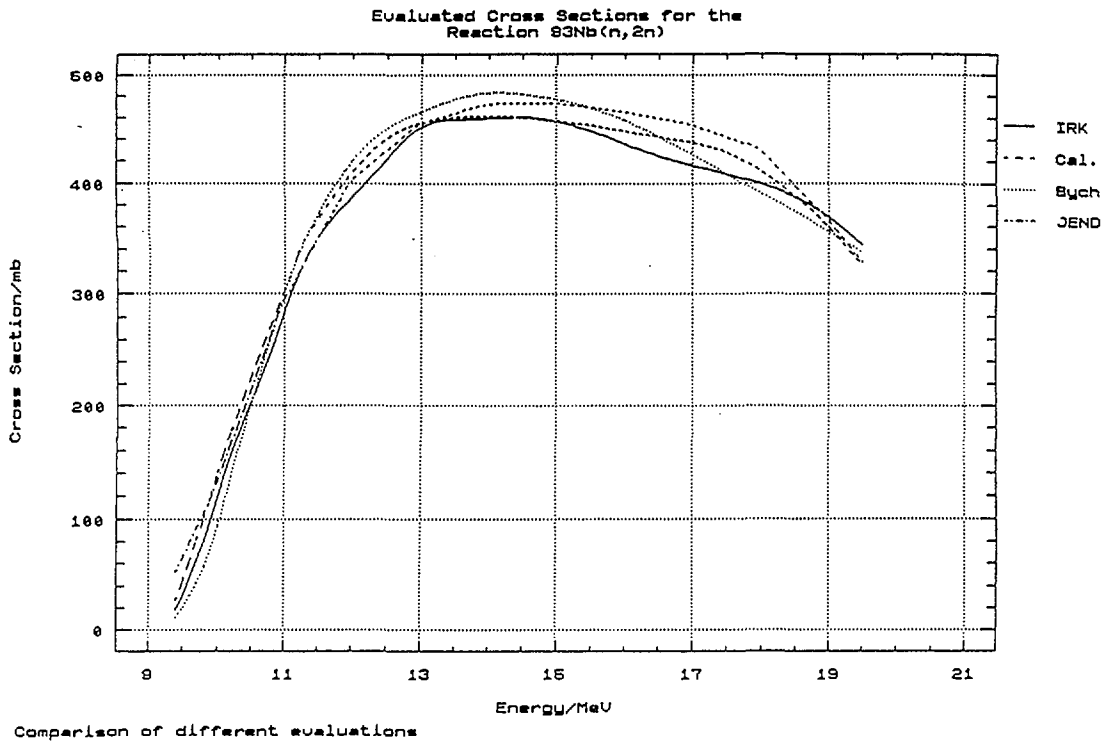


Figure 11 Comparison of the evaluation reported by V.M. Bychkov et al. [7] with the IRK and JENDL-3 evaluations and the model calculation of Ref. 8

5. Conclusions

In the case of the $^{197}\text{Au}(n,2n)^{196}\text{Au}$ reaction, poor consistency in the results of the IRK-evaluation (large values of R) can be identified in the energy regions from 10 to 12 and 22 to 23 MeV (where also large uncertainties exist) as well as from 16.5 to 18 and 25 to 30 MeV. Due to the fact that in the evaluation process the excitation function was divided into three parts [1,2], being the connecting points at 13.5 and 15 MeV, slight deformities in its shape could not be avoided. There is, in general, good agreement between the IRK-evaluation and the evaluation reported in Ref. 6. There is not good agreement when comparing the IRK-evaluation with the evaluation carried out by Yuan Hanrong and Liu Tong [4] and in the neutron energies above 11 MeV there are differences between the IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluations. Further measurements are necessary in order to improve the results of the values of the evaluated cross sections from threshold to 10.3 and from 20 to 30 MeV.

As for the $^{59}\text{Co}(n,2n)^{58}\text{Co}$ reaction, inconsistency in the results of the IRK-evaluation exist in the energy regions from 12 to 12.5 and 15 to 18 MeV, where the results of Ref. 6 are larger than those of the IRK-evaluation due to the different judgement of some data sets which were apparently not used in the Chinese evaluation (for more details see Ref. 1). The IRK, ENDF/B-VI, CENDL-2 and JENDL-3 evaluations do not fully agree with each other in different parts of the whole energy range. Further measurements are recommended in the energy regions from threshold to 12.5 and 20 to 23 MeV, where there are large uncertainties and insufficient data points.

Regarding the $^{93}\text{Nb}(n,2n)^{92m}\text{Nb}$ reaction, although there are inconsistencies in the results of the IRK-evaluation throughout the whole energy range, there is good agreement with the results of

the evaluation of Ref. 6. The model calculation reported by B. Strohmaier [8] also agrees well with the updated evaluation of the experimental data of Ref. 5. In the neutron energies above 13 MeV, the cross section values of the JENDL-3 evaluation as well as those of the evaluation reported in Ref. 7 are somewhat higher than the cross section values of Ref. 8.

Further improvement in the evaluation results of the three reactions in question can be achieved with more accurate measurements in some cases as mentioned above and, generally, with a more rigorous evaluation procedure based on the general least-squares method. A theoretical model calculation would be desired in the case of the $^{197}\text{Au}(n,2n)^{196}\text{Au}$ and $^{59}\text{Co}(n,2n)^{58}\text{Co}$ reactions.

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