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Evaluation of Neutron Monitor Cross Sections for $^{59}Co(n,x)^{56,57,58}Co$, $^{52,54,56}Mn$, ^{59}Fe Reactions

Yu Baosheng   Shen Qingbiao   Cai Dunjiu

(China Nuclear Data Center, CIAE)

Abstract

The neutron monitor cross sections for $^{59}Co(n,x)^{56,57,58}Co$, $^{52,54,56}Mn$, ^{59}Fe reactions were evaluated based on recent experimental data and theoretical calculations from threshold energy to 100 MeV.

Introduction

Cobalt is a constituent of structural materials in fusion reactor and an adequate material of threshold activation detector for monitoring high energy neutron field. So the accurate knowledge of cross sections for $^{59}Co(n,x)^{56,57,58}Co$, $^{52,54,56}Mn$, ^{59}Fe reactions is of importance as the reactions through which radioactive products can be produced in fusion and neutron monitoring reaction in intermediate energy application. The measured cross sections exist below 40 MeV for $^{59}Co(n,x)^{56,57,58}Co$ reactions and below 20 MeV for $^{59}Co(n,x)^{56}Mn$, ^{59}Fe reactions, the experimental data are scarce in higher energy region. In order to recommend the cross sections, the experimental data availably were evaluated so as to guide the theory calculation for higher energy region. The theory model parameters in the calculation were adjusted to fit the measured data. The cross section of $^{59}Co(n,x)^{56,57,58}Co$, $^{52,54,56}Mn$, ^{59}Fe reactions were evaluated and calculated from threshold energy to 100 MeV. All of recommended cross sections were determined based on the evaluated experimental data and improved theoretical calculations.

1 $^{59}Co(n,x)^{56,57,58}Co$ Reactions

The $^{56,57,58}Co$ products come from $^{59}Co(n,4n)$, (n,3n), (n,2n) reactions. Due to ^{59}Co is the sole isotope of the element, no other reactions lead to $^{56,57,58}Co$ productions. For $^{59}Co(n,2n)^{58}Co$ reaction, the measured data are available [1~41] from threshold energy to 40 MeV and shown in Fig. 1. The measured data were mainly carried out by activation method, some data by large liquid scintillation method. The evaluation at 14.7 MeV is carried out firstly based on the data measured by Frehaut[21], Greenwood[27], Garlea[28], Meadows[32], Ikeda[35], Kobayashi[36], Zhao Wenrong[37], Li Tingyan[38] and Mannhart[39] around 14 MeV. The recommended cross section is 770 ± 10 mb. The present result is consistent with recent evaluated values of Zhao Wenrong [37], Cai Dunjiu [42] from CIAE and higher than the cross section from ENDF/B-6. The experimental data of Vesser[17], Frehaut[21], Ikeda[35], Zhao Wenrong[37] and Mannhart[39] are normalized to the recommended value at 14.7 MeV. The comparisons among this evaluated values and the data of ENDF/B-6, JENDL-3, CENDL-2 are shown in Fig. 2.

At present evaluation, the measured data of Frehaut[21], Li Tingyan[38] and Mannhart[39] below 12 MeV and the measured data of Bormann[12], Veeser[17], Ghoran[20] Provoper[22], Huang Jianzhou[33] above 12 MeV were adopted. Recently activation cross section for the $^{59}Co(n,x)^{56,57,58}Co$ reactions have been measured above 28 MeV energy range by Uno[40] with p+Li neutron source using activation technique. Therefore, the recommended data for $^{59}Co(n,2n)^{58}Co$ reaction were obtained between threshold and 40 MeV based on experimental data. The recommended cross sections for $^{59}Co(n,x)^{58}Co$ reaction from threshold to 100 MeV were obtained based on experimental data and calculated theoretical results[43] and shown in Fig. 3.

The measured data for $^{59}Co(n,x)^{56,57}Co$ reactions were carried out based on the activation cross section of Uwamino[41] using p + Be and of Uno[40] using p + Li neutron source with activation technique at higher energy range. The recommended data for $^{59}Co(n,x)^{57}Co$ reaction were obtained based on the experimental data mentioned above and our theoretical results. The calculated data for $^{59}Co(n,x)^{56}Co$ reaction are recommended after normalizing to only measured value at 38.3 MeV. The cross sections mentioned above are also shown in Fig. 3.

2 $^{59}Co(n,x)^{52,54,56}Mn$

For $^{59}Co(n,x)^{52,54,56}Mn$ reactions, the experimental data exist for $^{59}Co(n,\alpha)^{56}Mn$ reaction from threshold to 20 MeV. Our evaluated value at 14.7 MeV is 31.15 ± 0.65 mb which is consistent with ones of Zhao Wenrong[37]. The evaluated data for $^{59}Co(n,x)^{52,54,56}Mn$ reactions were obtained based on the experimental data of Bahal[25], Garlea[28], Berrada[30], Ikeda[35], Li Tingyan[38], Mannhart[39], Liskien[52], Huang Jianzhou[56], Agrawal[57], and Meadows[59] below 20 MeV and calculated theoretically data above 20 MeV. Both of experimental and calculated data are consistent each other within experimental errors between 18 to 20 MeV.

For $^{59}Co(n,x)^{52,54}Mn$ reactions, no experimental data are available. By using the model parameters adjusted based on the evaluated data for $^{59}Co(n,\alpha)^{56}Mn$ reaction below 20 MeV, the cross sections for the $^{59}Co(n,x)^{52,54,56}Mn$ reaction were calculated. The recommended results for $^{59}Co(n,x)^{52,54,56}Mn$ reactions are shown in Figs. 4~6.

3 $^{59}Co(n,x)^{59}Fe$ Reaction

The ^{59}Fe product come from $^{59}Co(n,p)^{59}Fe$ reaction. The measured data available exist from threshold energy to 20 MeV. The cross sections were evaluated by Zhao Wenrong[37] from threshold to 20 MeV. Present evaluation improved greatly the previous evaluation by supplementing the accuracy measured data of Mannhart[39], especially in the energy region 8 to 15 MeV where experimental data had been very scarce. The evaluated data for $^{59}Co(n,x)^{59}Fe$ reaction were obtained based on the experimental data of Li Tingyan[38], Mannhart[39], and Smith[64,65] below 20 MeV and calculated theoretically values are consistent with experimental data between 17 to 20

MeV The recommended data for $^{59}Co(n,x)^{59}Fe$ reaction are shown in Figs 7~8.

4 Summary

At present work, the evaluated cross section around 14 MeV are in good agreement with other evaluated data as shown in the following table:

The comparison of cross sections (in mb) at 14.32 MeV

Reactions	Present work	Other work
$^{59}Co(n,2n)^{58}Co$	732 16± 11	740 3 ± 27.1 [39]
		745 8 ± 9.00[42]
		734.4 ± 12.0 [37]
$^{59}Co(n,\alpha)^{56}Mn$	31 76 ± 0 8	31 46± 1.16[39]
		31 34± 0.80[37]
		31 50± 0.60[42]
$^{59}Co(n,p)^{59}Fe$	50.6 ± 1 4	50 63± 2.34[37]
		48 90± 1.40[42]

The cross sections of $^{59}Co(n,x)^{56,57,58}Co$ reactions were recommended based on the measured data of Vesser[17] using large liquid scintillation method and recently measured data using activation method of Uno[40] between 20 and 40.0 MeV. Therefore, the evaluated data are very useful for guiding the theoretical calculation in higher energy

The present evaluated data of $^{59}Co(n,x)^{56}Mn$ and $^{59}Co(n,p)^{59}Fe$ reactions are higher than the previous evaluated data below 12 MeV and reproduce the new experimental data very well. The inconsistency of evaluated values below 15 MeV has been improved. For $^{59}Co(n,\alpha)$ and $^{59}Co(n,p)$ reactions, each measured data of Mannhart[39] were accompanied with a "gas−out" data in order to subtract parasitic neutron produced in the gas cell structure and breakup neutrons from D(n,np) reaction. The new measured data of Mannhart[39] for $^{59}Co(n,\alpha)$ and $^{59}Co(n,p)$ reaction are higher than those evaluated previously. Therefore, present evaluated data improved the previous evaluated results below 14 MeV and extended energy range up to 100 MeV.

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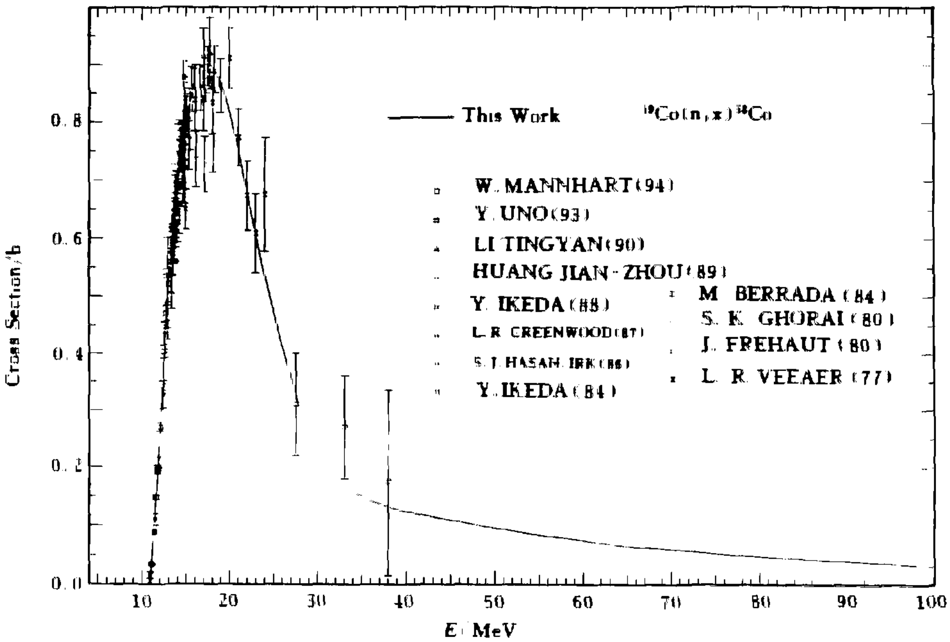

Fig. 1 Comparison of evaluated & measured data for ^{59}Co(n,x)^{58}Co reactions

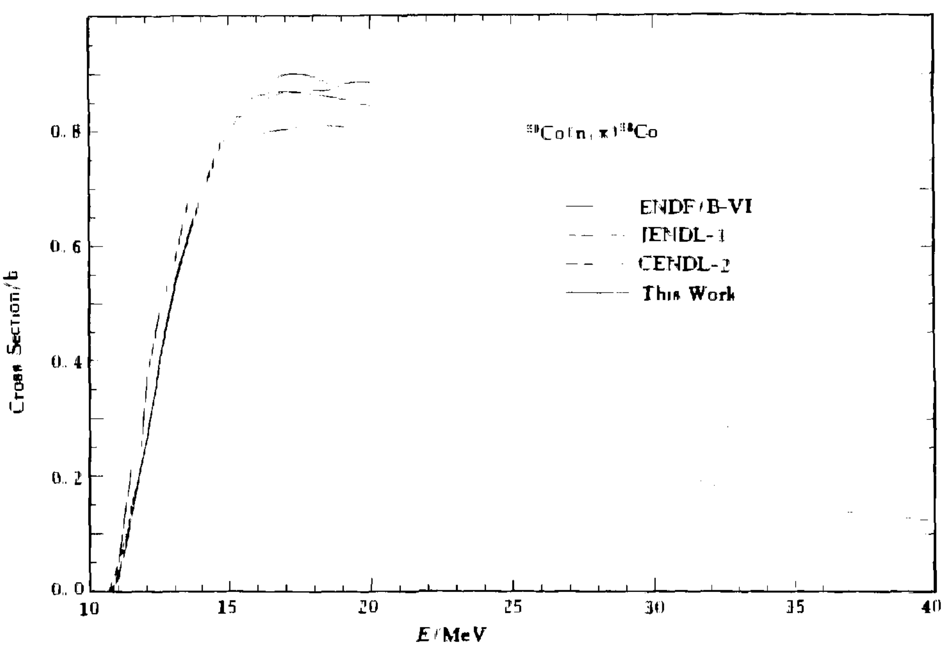

Fig. 2 Comparison of evaluated data for ^{59}Co(n,x)^{58}Co reactions

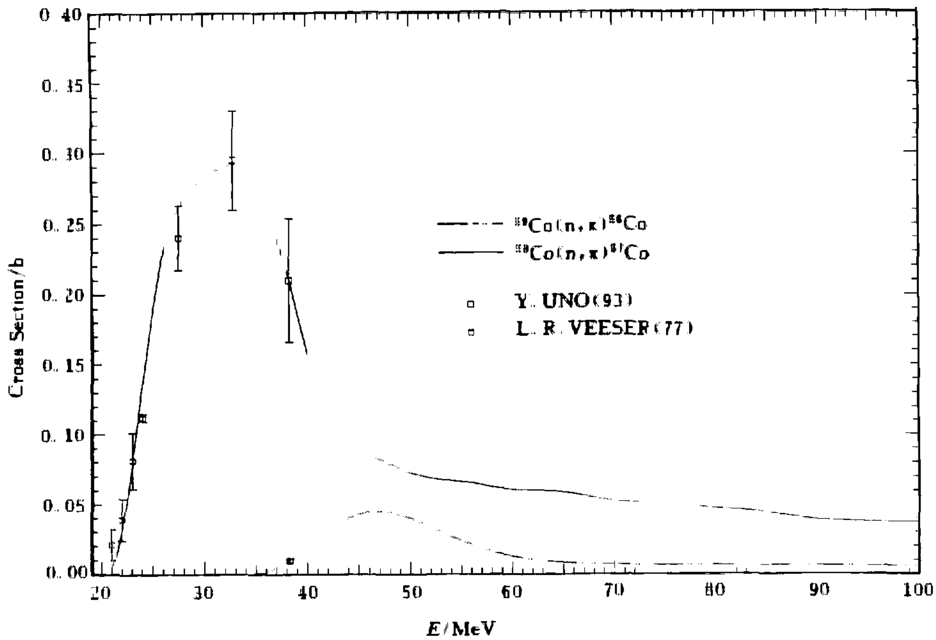

Fig. 3 Evaluated & measured data for ^{59}Co(n,x)^{57,56}Co reactions

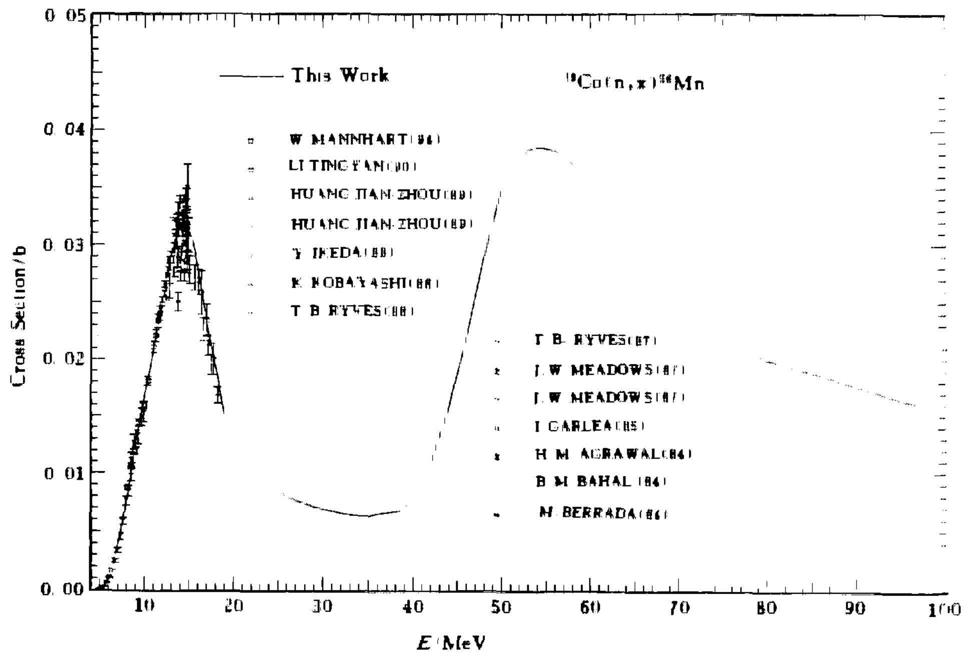

Fig. 4 Comparison of evaluated & measured data for ^{59}Co(n,x)^{56}Mn reactions

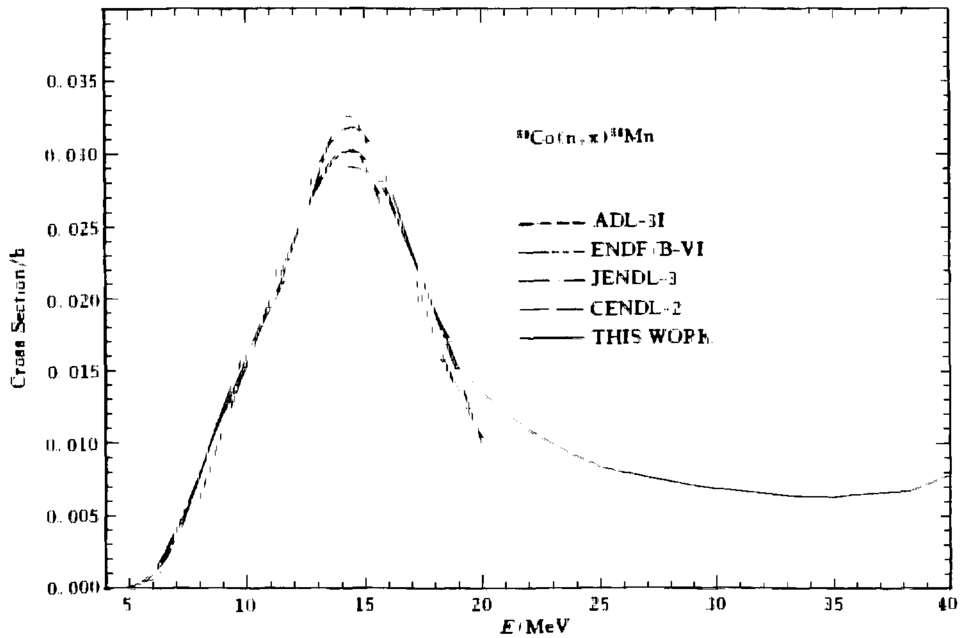

Fig. 5 Comparison of evaluated data for $^{59}Co(n,x)^{56}Mn$ reactions

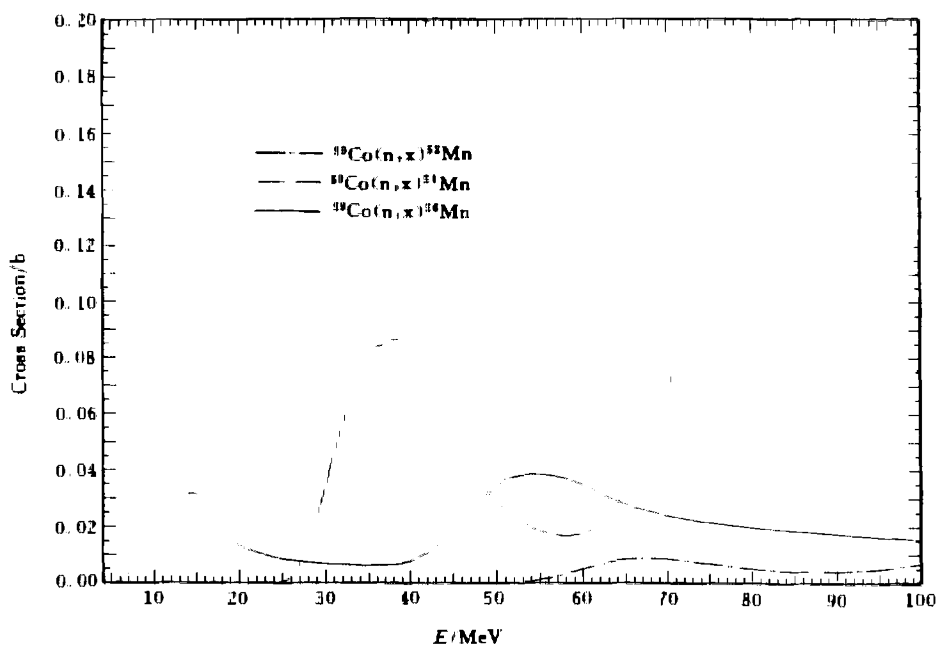

Fig. 6 Evaluated data for $^{59}Co(n,x)^{56,54,52}Mn$ reactions

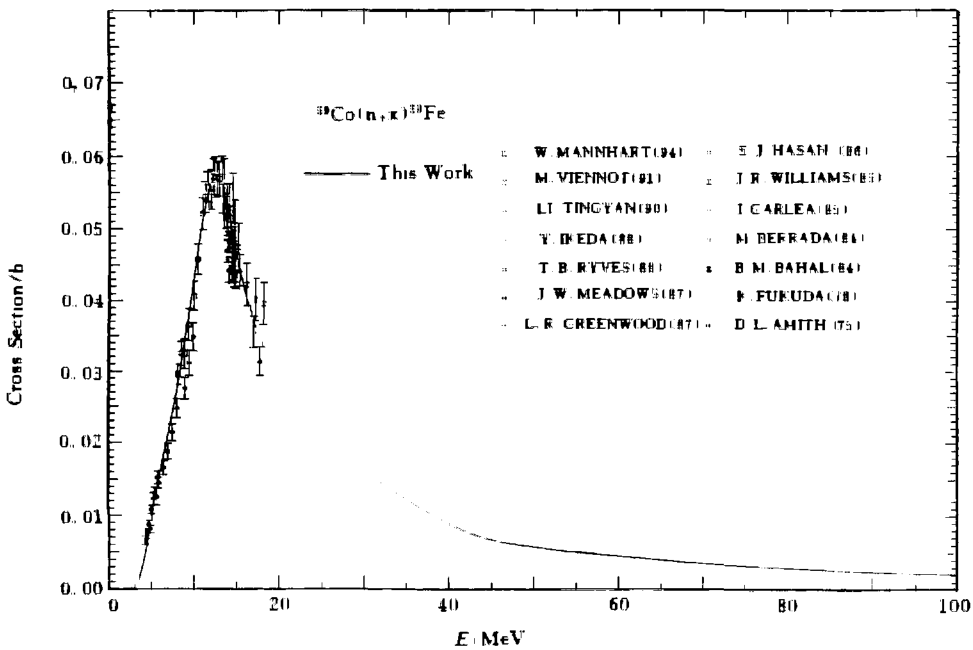

Fig. 7 Comparison of evaluated & measured data for $^{59}Co(n,x)^{59}Fe$ reactions

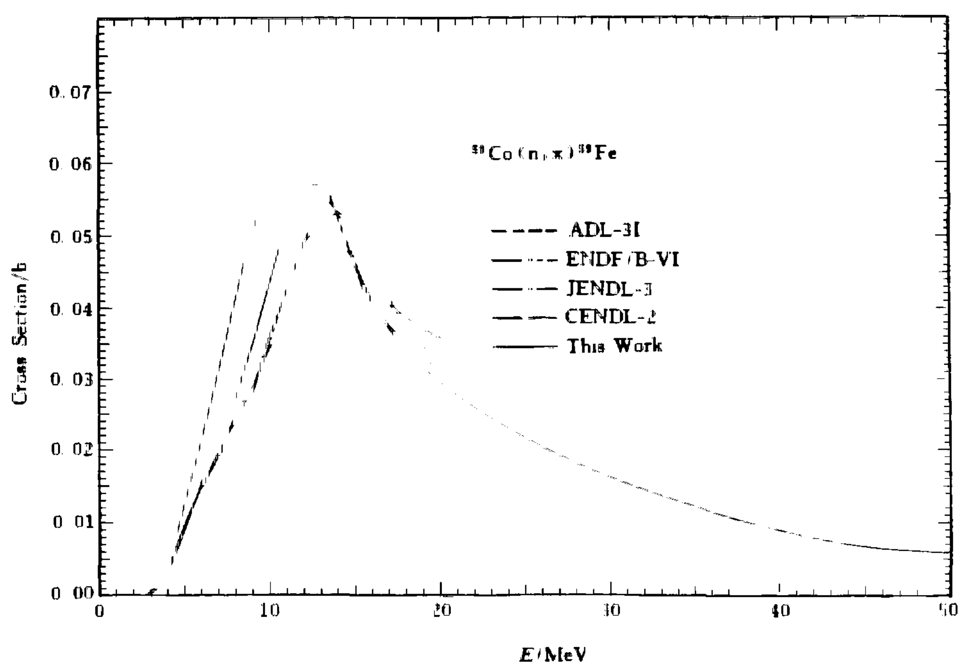

Fig. 8 Comparison of evaluated data for $^{59}Co(n,x)^{59}Fe$ reactions

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