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COVARIANCE MATRICES EVALUATED BY DIFFERENT METHODS FOR SOME NEUTRON-DOSIMETER REACTIONS

Y.Kanda and Y.Uenohara

Department of Energy Conversion Engineering,
Kyushu University, Kasuga, Fukuoka 816, Japan

Abstract : Covariance matrices between neutron-induced activation cross sections depends strongly on an evaluation method. The activation cross sections for neutron dosimeter can be evaluated from experimental data. In order to obtain covariances, differential and integral experiments are used in the evaluation. Correlation is localized in the limited energy regions where the measurements are abundant. In another way, the covariance matrices can be also evaluated by nuclear reaction model calculation in which are used the parameters estimated from experiments. Correlation is not localized but distributed over whole energy regions. These differences influence neutron spectra to be measured in unfolding from dosimeter activities.

(Dosimeter, Covariance, Nuclear Parameters, Hauser-Feshbach model)

Introduction

In current nuclear data evaluation, importance of covariance matrices associated with cross-sections is emphasized as well as accuracy and consistency of evaluated data. Ambiguity for absolute values and shapes of cross-section curves has remained beyond requirement in application in spite of serious endeavors by experimentalists and evaluators. The covariance matrix for evaluated nuclear data is introduced to cope with the difficulty/1/. The covariance matrix estimated for a reaction has diagonal elements representing uncertainties of the absolute values and non-diagonal ones relating to correlation between two energy regions i.e. to the shapes of the cross-sections (hereafter called the covariance for energies). If reactions more than two are simultaneously evaluated, the estimated covariance matrix has the elements expressing the correlations (hereafter, called the covariance for reactions). Especially in neutron dosimetry, the covariance for reactions is demanded.

Methods to estimate the covariance have been developed and applied in various works. Since the basis of covariance deduction is experimental data, it is an essential work to examine in detail and evaluate numerically partial errors of individual measurements. The covariance matrix depends on the method and experiments used in the estimation procedure. In the previous work/2/, the covariances obtained from different method were discussed. In the present study more detail comparison is performed. The results in the other works /3,4/ are applied to evaluate the covariance for energies and for reactions. One is estimation of the optical model parameters and level density parameters in Hauser-Feshbach model formulae /3/. Another is evaluation of cross-sections from differential and integral measurements /4/. The former is called is called the measured-data method. In this work, comparison is done for the four reactions, ^{54}Fe(n,p), ^{56}Fe(n,p), ^{59}Co(n,α) and ^{58}Ni(n,p) which are common in both the works. Since they are main neutron-dosimeter reactions, they are suitable to compare and discuss which covariances are convenient for application to dosimeters.

Covariance Estimation

MODEL-PARAMETER METHOD The parameter estimation for Hauser-Feshbach model is described in ref. 3. The level-density parameters are estimated for forty seven residual nuclides of neutron-induced reactions, and the optical model parameters are also done for a neutron, proton and α-particle including a radius r_0 and a depth V_0 of real potential and a radius r_1 and a depth W_1 of imaginary potential, respectively. The target nuclides are thirteen in Z=22 to 28. The kinds of experimental data referred in the estimation are thirty four including total, (n,p), (n,α), and (n,2n) cross-sections, and energy distribution of protons and α-particles emitted by neutron induced reactions. The parameters are estimated by Bayesian method developed in the previous work /5,6/.

The covariance matrix for energies and reactions, can be calculated from

$$C=SMS^t$$

where the matrix S is a sensitivity matrix of a physical quantity used for the estimation to the parameter and M is the estimated covariance matrix for the parameter. The matrices S and M are prepared and computed in the parameter estimation, respectively.

MEASURED-DATA METHOD The covariance estimation from differential and integral measurements is described in ref. 4 and 7. The six activation cross-sections including the four reactions discussed in this work and their covariances are simultaneously evaluated from experiments in which samples are activated with monoenergetic neutron sources and with ^{235}U(n,f) and ^{252}Cf (spontaneous) fission neutron spectra.

Results and Discussion

The covariance for four reactions ^{54}Fe(n,p), ^{56}Fe(n,p), ^{59}Co(n,α) and ^{58}Ni(n,p) are shown in Figs. 1, 2 and 3, evaluated by only differential measurements, by both differential and integral measurements, and by nuclear model parameters estimated from differential measurements, respectively. A feature found in comparison of these covariances is marked difference between the first two and the last. The covariance elements for the former are almost zero and for the latter are non-zero. This is natural because the model parameters correlate each other so that all the cross-section calculated with a nuclear model has correlation.

In the case of the covariances estimated by the measured-data method, their elements are non-zero near the regions where available measurements are abundant. If ratio measurements are taken into account as the ratio data not as the data normalized with reference data in an evaluation, there must be correlation between the two cross-sections of the ratio. The example is found in Figs.1 and 2. The ratio data of ^{54}Fe(n,p) measured relative to ^{56}Fe(n,p) are used in the evaluation. Their effect appears in the covariance for reactions, in which the large-value elements are found in the cross region between 7-8 MeV for ^{54}Fe(n,p) and 9 MeV for ^{56}Fe(n,p) in Fig. 1. There are negative values in Fig. 2: "-0" is a negative element whose absolute value is less than 1. They come from correlated integral data measured in fission neutron fields.

As seen in the last paragraph, the covariance matrix depends seriously on the experiments and the method used to evaluated it. Since it is primarily introduced in order to represent the uncertainties of the values and shapes of the evaluated cross-sections, it is reasonable to reflect the status of available experiments. In application, the covariances are used to compute the uncertainties for the results calculated by using the evaluated data. In this case, it is not necessary to be directly connected between the result and the measurement which is referred as the basis of the evaluation. Especially in unfolding of neutron spectrum from dosimeter data, correlation of dosimeter reactions is important. Therefore, the model-parameter method is more preferable than the measured-data method, because the former gives good information about the reaction correlation. The Hauser-Feshbach model used in the present work is appropriate to obtain the covariance for reactions, because it takes account of competition among reactions, and it can approximately reproduce the experimental cross-sections by using the parameters estimated from experiments. In Fig. 4, an example of comparison between the calculated and measured cross-sections for ^{59}Co(n,α) reaction.

References

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	Fe-54(n,p)									Fe-56(n,p)									Co-59(n, α)									Ni-58(n,p)								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
* 1 * 20.0[MeV] *	100
* 2 * 19.0[MeV] *	-12	100
* 3 * 17.0[MeV] *	0	5	100
* 4 * 15.0[MeV] *	2	2	34	100
* 5 * 13.0[MeV] *	2	2	28	47	100
* 6 * 11.0[MeV] *	6	7	0	2	3	100
* 7 * 9.0[MeV] *	2	2	3	3	3	2	100
* 8 * 7.0[MeV] *	2	2	3	3	3	2	43	100
* 9 * 5.0[MeV] *	2	2	7	6	8	3	4	3	100
* 10 * 20.0[MeV] *	0	0	1	1	0	0	0	0	0	100
* 11 * 19.0[MeV] *	0	0	0	0	0	0	1	0	0	-10	100
* 12 * 17.0[MeV] *	0	0	1	1	1	0	1	1	0	23	22	100
* 13 * 15.0[MeV] *	0	0	1	1	0	0	1	1	0	27	17	37	100
* 14 * 13.0[MeV] *	0	0	0	0	0	0	3	2	0	16	17	30	34	100
* 15 * 11.0[MeV] *	0	0	0	0	0	0	21	20	1	2	1	3	3	9	100
* 16 * 9.0[MeV] *	1	1	0	0	1	1	85	34	2	2	2	4	3	4	25	100
* 17 * 7.0[MeV] *	1	1	0	1	1	1	35	79	2	3	2	4	3	4	25	42	100
* 18 * 5.0[MeV] *	0	0	0	0	0	0	13	17	0	1	1	2	2	2	13	15	21	100
* 19 * 20.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
* 20 * 19.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	100
* 21 * 17.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	94	99	100
* 22 * 15.0[MeV] *	0	0	0	1	0	0	0	0	0	0	0	1	3	0	0	0	0	0	92	84	87	100
* 23 * 13.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	85	72	72	96	100
* 24 * 11.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	67	67	93	99	100
* 25 * 9.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	64	62	89	97	99	100
* 26 * 7.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	69	50	44	75	89	92	94	100
* 27 * 5.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-44	-43	-53	-67	-60	-57	-54	-25	100
* 28 * 20.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-16	-20	-20	-12	-6	-4	-3	3	7	100
* 29 * 19.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-17	-21	-22	-16	-9	-7	-5	1	11	98	100
* 30 * 17.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-17	-20	-22	-19	-13	-10	-8	-1	17	84	92	100
* 31 * 15.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-16	-16	-19	-18	-14	-12	-10	-3	19	69	80	93	100
* 32 * 13.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2	-1	1	1	0	0	-0	-2	-6	30	21	-6	4	100
* 33 * 11.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	9	9	7	5	3	-1	-13	-3	-19	-51	-57	63	100
* 34 * 9.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	6	6	4	2	0	-3	-11	6	-11	-45	-54	65	99	100
* 35 * 7.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-8	-7	-5	-4	-5	-5	-6	-7	-5	35	19	-18	-30	77	86	92	100
* 36 * 5.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-7	-8	-6	-3	-2	-2	-3	-3	-7	46	31	-5	-25	61	74	83	96	100

Fig. 1 The Covariance of cross-sections for $^{54}Fe(n,p)$, $^{56}Fe(n,p)$, $^{59}Co(n,\alpha)$ and $^{58}Ni(n,p)$ estimated by the measured-data method using only differential experiments.

	Fe-54(n,p)									Fe-56(n,p)									Co-59(n, α)									Ni-58(n,p)								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
* 1 * 20.0[MeV] *	100
* 2 * 19.0[MeV] *	-12	100
* 3 * 17.0[MeV] *	-0	5	100
* 4 * 15.0[MeV] *	1	2	33	100
* 5 * 13.0[MeV] *	1	2	27	47	100
* 6 * 11.0[MeV] *	5	6	-0	2	3	100
* 7 * 9.0[MeV] *	0	1	3	3	2	-0	100
* 8 * 7.0[MeV] *	0	1	3	3	2	-0	34	100
* 9 * 5.0[MeV] *	1	1	3	3	3	-2	13	13	100
* 10 * 20.0[MeV] *	-0	-0	0	0	0	0	-0	-0	-0	100
* 11 * 19.0[MeV] *	-0	-0	0	0	0	0	-0	-0	-0	-14	100
* 12 * 17.0[MeV] *	0	0	1	1	0	0	-0	-0	-0	12	22	100
* 13 * 15.0[MeV] *	-0	-0	-0	-0	-0	-0	1	1	-0	15	16	29	100
* 14 * 13.0[MeV] *	-0	-0	-0	-0	-0	-0	1	1	-0	12	17	29	32	100
* 15 * 11.0[MeV] *	-0	-0	-0	-0	-0	-0	11	10	2	1	1	2	2	8	100
* 16 * 9.0[MeV] *	1	1	-1	-1	-0	-0	72	19	9	1	1	3	1	2	17	100
* 17 * 7.0[MeV] *	1	1	-1	-1	-0	-1	21	65	8	1	2	3	1	2	17	35	100
* 18 * 5.0[MeV] *	-0	-0	-1	-1	-1	-1	14	13	4	1	1	2	1	1	10	22	22	100
* 19 * 20.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	-0	1	-0	0	0	0	0	100
* 20 * 19.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	1	3	1	0	0	0	0	-34	100
* 21 * 17.0[MeV] *	0	0	0	0	0	0	0	0	0	1	1	2	5	1	0	0	0	0	8	22	100
* 22 * 15.0[MeV] *	0	0	0	2	0	0	0	0	0	2	2	5	12	3	0	0	0	0	10	16	29	100
* 23 * 13.0[MeV] *	0	0	0	0	0	0	0	0	0	1	1	2	5	1	0	0	0	0	11	19	30	38	100
* 24 * 11.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	-0	-1	-0	0	0	0	0	-1	-0	-0	1	6	100
* 25 * 9.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	0	0	0	-0	1	2	100
* 26 * 7.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	-0	0	-0	0	0	0	0	-0	-0	1	0	1	-2	-12	100
* 27 * 5.0[MeV] *	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	0	0	0	0	1	2	2	2	2	7	5	19	100
* 28 * 20.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
* 29 * 19.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-26	100
* 30 * 17.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	4	9	100
* 31 * 15.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	7	13	100
* 32 * 13.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	9	9	19	100
* 33 * 11.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	2	0	3	100
* 34 * 9.0[MeV] *	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	0	0	0	0	1	0	1	2	2	-0	100
* 35 * 7.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	0	0	0	0	0	0	1	1	2	-1	24	100
* 36 * 5.0[MeV] *	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	6	7	-2	8	8	100

Fig. 2 The Covariance of cross-sections for $^{54}Fe(n,p)$, $^{56}Fe(n,p)$, $^{59}Co(n,\alpha)$ and $^{58}Ni(n,p)$ estimated by the measured-data method using both differential and integral experiments.

	Fe-54(n,p)									Fe-56(n,p)									Co-59(n, α)									Ni-58(n,p)								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
* 1 * 20.0[MeV]	100																																			
* 2 * 19.0[MeV]	96	100																																		
* 3 * 17.0[MeV]	76	91	100																																	
* 4 * 15.0[MeV]	33	47	72	100																																
* 5 * 13.0[MeV]	-21	-24	-7	55	100																															
* 6 * 11.0[MeV]	-23	-32	-24	24	91	100																														
* 7 * 9.0[MeV]	-2	-18	-22	17	82	94	100																													
* 8 * 7.0[MeV]	51	31	7	5	32	46	71	100																												
* 9 * 5.0[MeV]	64	55	29	-17	-19	4	26	73	100																											
* 10 * 20.0[MeV]	38	32	18	-1	-11	-5	6	30	33	100																										
* 11 * 19.0[MeV]	27	22	13	-1	-8	-3	5	21	24	99	100																									
* 12 * 17.0[MeV]	11	9	6	0	-2	0	4	10	9	94	98	100																								
* 13 * 15.0[MeV]	12	7	-0	2	-0	-3	4	17	5	85	88	93	100																							
* 14 * 13.0[MeV]	47	36	15	-2	-10	-6	13	48	41	54	50	49	72	100																						
* 15 * 11.0[MeV]	64	51	26	-0	-22	-19	6	55	49	6	-4	-14	6	63	100																					
* 16 * 9.0[MeV]	62	50	26	-0	-26	-25	0	51	44	5	-6	-18	-6	38	93	100																				
* 17 * 7.0[MeV]	75	64	38	-7	-32	-19	7	63	76	25	15	-2	-3	37	81	88	100																			
* 18 * 5.0[MeV]	57	54	41	-9	-20	8	17	40	77	27	21	10	-7	21	28	23	62	100																		
* 19 * 20.0[MeV]	-16	-18	-16	-1	22	23	17	-0	-7	-7	-5	-2	-1	-5	-17	-21	-22	-13	100																	
* 20 * 19.0[MeV]	-19	-19	-14	1	19	18	12	-5	-12	-9	-6	-3	-4	-14	-16	-15	-18	-15	-32	100																
* 21 * 17.0[MeV]	-19	-20	-15	2	19	18	12	-5	-14	-9	-6	-2	-3	-12	-16	-15	-18	-16	9	24	100															
* 22 * 15.0[MeV]	-15	-19	-19	-3	24	26	21	5	-7	-5	-4	0	5	3	-15	-23	-24	-11	12	19	33	100														
* 23 * 13.0[MeV]	-10	-16	-19	-5	24	28	25	10	-2	-2	-2	1	7	9	-12	-22	-22	-7	12	21	33	42	100													
* 24 * 11.0[MeV]	-9	-16	-19	-5	24	27	25	12	-1	-2	-1	1	7	8	-9	-18	-18	-6	2	3	5	5	12	100												
* 25 * 9.0[MeV]	-8	-15	-19	-5	23	26	24	12	-0	-1	-1	1	6	6	-7	-14	-14	-5	2	4	6	6	7	24	100											
* 26 * 7.0[MeV]	-3	-10	-16	-6	21	26	25	16	6	1	1	2	9	15	-6	-17	-15	-0	3	5	7	7	8	24	22	100										
* 27 * 5.0[MeV]	8	12	14	4	-13	-13	-11	-2	7	2	2	1	1	5	3	1	5	9	2	3	5	5	6	15	15	27	100									
* 28 * 20.0[MeV]	86	69	38	-2	-26	-17	11	67	67	42	29	12	19	56	75	72	80	50	0	0	0	0	0	0	0	0	0	100								
* 29 * 19.0[MeV]	82	67	37	-3	-26	-17	11	65	66	40	28	12	17	53	71	69	78	49	0	0	0	0	0	0	0	0	0	-25	100							
* 30 * 17.0[MeV]	67	56	33	-4	-23	-12	9	53	62	33	23	10	10	39	54	53	66	50	0	0	4	0	0	0	0	0	0	5	10	100						
* 31 * 15.0[MeV]	48	40	25	2	-16	-11	5	35	33	23	17	8	10	27	41	42	45	27	0	0	0	1	0	0	0	0	0	5	8	16	100					
* 32 * 13.0[MeV]	21	11	-2	12	-1	-18	-5	13	-22	10	5	1	20	26	36	38	8	-44	0	0	0	0	0	0	0	0	0	6	10	13	25	100				
* 33 * 11.0[MeV]	10	7	3	6	4	0	1	0	-8	3	1	-0	4	8	9	7	-0	-6	0	0	0	0	0	0	0	0	0	3	2	2	2	4	100			
* 34 * 9.0[MeV]	17	13	5	4	-1	-4	1	9	2	7	4	1	7	15	18	17	10	-4	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	100		
* 35 * 7.0[MeV]	38	28	10	2	-11	-16	0	31	18	18	11	4	16	34	45	46	35	-4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	34	100	
* 36 * 5.0[MeV]	49	38	15	-4	-17	-17	4	46	41	24	15	5	16	41	53	52	50	12	0	0	0	0	0	0	0	0	0	2	3	5	10	10	2	2	5	100

Fig. 3 The Covariance of cross-sections for ^{54}Fe(n,p), ^{56}Fe(n,p), ^{59}Co(n, α) and ^{58}Ni(n,p) estimated by the model-parameter method.

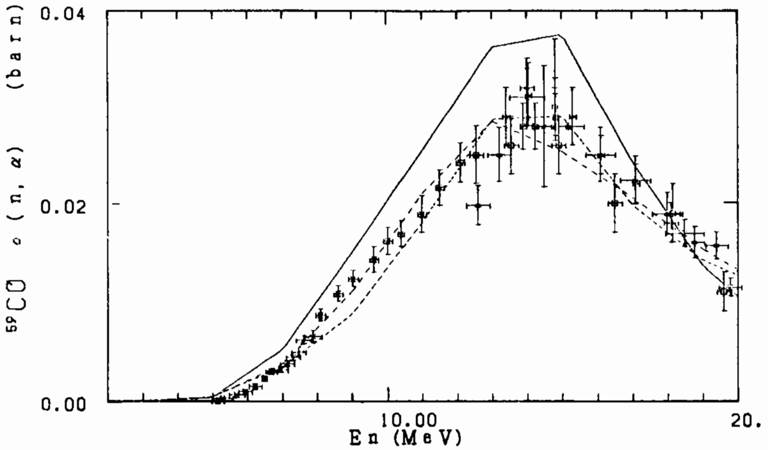

Fig. 4 The cross-section for ^{59}Co(n, α). The solid line is calculated with the original parameters. The dotted line is the curve computed by first-order Taylor expansion of the Hauser-Feshbach model formula.