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ERRORJ : A Code to Process Neutron-nuclide Reaction Cross Section Covariance, Version 2.3

Go CHIBA

Reactor Physics Analysis and Evaluation Group
Advanced Nuclear System Research and Development Directorate

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For the evaluation of the uncertainties of nuclear parameters which are induced by uncertainties in neutron-nuclide reaction cross sections with deterministic procedures, covariance data for energy-averaged cross sections are necessary. ERRORJ is a processing code to transform cross section covariance given in the ENDF format into energy-averaged cross section covariance. ERRORJ can process the covariance data of cross sections including resonance parameters, angular and energy distributions of secondary neutrons.

Since the release of the previous version, ERRORJ has been modified in order to reduce calculation time and to make it easy to incorporate ERRORJ into the NJOY code system. The version 2.3 is developed with these modifications.

Keywords: Covariance, Multi-group, Resonance Parameters, Processing

JAEA-Data/Code 2007-007

ERRORJ：中性子核反応断面積共分散処理コード バージョン2.3

日本原子力研究開発機構
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中性子と原子核との反応断面積の不確かさに起因する核特性パラメータの不確かさを決定論的手法に基づいて評価する際に、エネルギー平均された核反応断面積の共分散が必要となる。ERRORJは、ENDFフォーマットで格納されている核反応断面積の共分散を読み込み、多群形式に変換するコードである。ERRORJは従来の共分散処理コードでは不可能であった、共鳴パラメータを含む断面積、二次中性子の角度およびエネルギー分布の共分散処理が可能である。

今回、計算時間の短縮を目的とした計算アルゴリズムの改良、及び核データ処理コードシステムNJOYのモジュールとして利用しやすいように修正を実施し、バージョン2.3として整備した。

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1. Introduction

It is important to evaluate uncertainties of nuclear parameters, such as the neutron multiplication factor and reactivity coefficients, in the field of reactor physics and reactor core design. For the uncertainty analyses, covariance data of neutron-nuclide reaction cross sections are essential. The evaluated nuclear data files, such as JENDL, ENDF/B and JEF(F), contain covariance data of the cross sections for several important nuclides.

When the uncertainties of the nuclear parameters are evaluated in a deterministic manner, covariances of the energy-averaged (multi-group) cross sections are necessary. The original ERRORJ code was developed by K. Kosako[1) 2)] in 1999 based on the ERRORR module of the NJOY code[3)] to generate the covariances of multi-group cross sections from the covariance data given in the nuclear data files. ERRORJ can process the covariances of the cross sections including Breit-Wigner and Reich-Moore resonance parameters, angular and energy distributions of secondary neutrons and the number of neutrons generated by the fission reaction. ERRORJ can also process the covariances of the resonance parameters contained in the 'compact format' recently proposed.

ERRORJ had been the only code to process such covariance data in the world. Recently, the PUFF-IV[4)] code has been developed at the Oak Ridge National Laboratory. The PUFF-IV code can process the covariances of all the kinds of resonance parameters, and it can read the covariance in the compact format. However, the PUFF-IV code cannot treat the covariance of angular and energy distributions of secondary neutrons.

2. Development of ERRORJ

The original version of ERRORJ was developed based on the ERRORR module in NJOY. Thus, all the functions implemented in the ERRORR module are available also in ERRORJ. ERRORJ produces a COVFIL format file which stores the covariance data of the multi-group cross sections (multi-group covariance data). The COVFIL format file can be converted to a COVERX format file by a conversion program named NJOYCOVX. The COVERX format has been proposed as a standard file format of multi-group covariance data in the FORSS system[5]. The original version of ERRORJ and NJOYCOVX were developed by K. Kosako in 1999[1].

In 2002, the author of the present document fixed a bug found in a subroutine to process covariances of the average cosine of the elastic scattering angle, and released ERRORJ version 2[6].

After the release of version 2, the author added the capability to calculate the non-diagonal elements of covariance matrices in the resonance energy range, and optimized perturbated amount in numerical calculations for derivatives of energy-averaged cross sections to resonance parameters. After these modifications, version 2.2 was released in 2004[7].

Since the release of version 2.2, ERRORJ has been modified in order to reduce calculation time and to make it easy to incorporate ERRORJ into the NJOY code system. The version 2.3 was developed with these modifications.

3. Methods added to ERRORR

3.1 Numerical calculations for derivatives of multi-group cross sections to resonance parameters

The covariance of multi-group cross sections V_{σ_g,σ_h} are calculated from the covariance of resonance parameters V_{Γ_i,Γ_j} as

$$V_{\sigma_g,\sigma_h} = \sum_i \sum_j \left(\frac{\partial \sigma_g}{\partial \Gamma_i}\right) \cdot \left(\frac{\partial \sigma_h}{\partial \Gamma_j}\right) \cdot V_{\Gamma_i,\Gamma_j} \tag{3.1}$$

where the indices g and j refer to the energy group, and i and j the resonance parameter.

The ERRORR module in NJOY calculates analytically the derivative $\frac{\partial \sigma_g}{\partial \Gamma_i}$ under an assumption that each resonance exists in one energy group, not over a few energy groups. This assumption loses its validity when a width of energy group is narrow. This procedure can be applied only to the resolved resonance parameters expressed by the single- and the multi-level Breit-Wigner theory. In addition, only the capture and fission reactions can be treated.

On the other hand, The ERRORJ code calculates the derivative numerically without any approximations. In the version 2.2, the derivative is calculated as

$$\frac{\partial \sigma_g}{\partial \Gamma_i} = \frac{\sigma'_g - \sigma_g}{\Delta \Gamma_i} \tag{3.2}$$

where σ_g is calculated from a set of resonance parameters, and σ'_g is calculated from another set of resonance parameters in which the i-th resonance parameter is perturbated ($\Gamma_i \rightarrow \Gamma_i + \Delta\Gamma_i$).

When covariance data are given for N resonance parameters in a nuclear data file, the version 2.2 calculates one unperturbated cross section (σ_g) and N perturbated cross sections (σ'_g). Calculations of group-wise cross sections are not small tasks since point-wise cross sections have to be generated from resonance parameters, and energy-integrations of these point-wise cross sections have to be carried out.

In the present version, this algorithm is revised as [1]

$$\frac{\partial \sigma_g}{\partial \Gamma_i} = \frac{1}{\Delta E}\int_{E\in g} \frac{\partial \sigma(E)}{\partial \Gamma_i} dE = \frac{1}{\Delta E}\int_{E\in g} \frac{\sigma^+(E) - \sigma^-(E)}{2\Delta\Gamma_i} dE \tag{3.3}$$

where $\sigma^+(E)$ ($\sigma^-(E)$) is calculated from a set of resonance parameters in which the i-th parameter is perturbated as $\Gamma_i + \Delta\Gamma_i$ ($\Gamma_i - \Delta\Gamma_i$) [2] . In an energy range which is far from the resonance energy (E_r) to which the i-th resonance parameter belongs, a difference between

[1] A weight function is assumed to be flat.

[2] When the resonance parameters are defined with the Reich-Moore formalism, point-wise cross sections are calculated as a sum of cross sections which are determined from resonance parameters of specific neutron orbital

'positive-perturbated' cross section ($\sigma(E)^+$) and 'negative-perturbated' cross section ($\sigma(E)^-$) can be negligible. Hence, we do not have to apply a fine energy grid into such energy range. It enables us to reduce calculation time. To survey an optimal energy grid, we process covariance data of U-238 in JENDL-3.3 with a 'reference' energy grid (E_{n+1}/E_n = 1.00002) and with several sets of energy grids. The obtained optimal energy grid is shown in **Table 3.1.1**.

Table 3.1.1 Energy grid for point-wise derivative calculation

		E_{n+1}/E_n
E < 0.1eV		1.05
E > 0.1eV	$E < 0.7E_r \cup E > 1.3E_r$	1.02
	$0.7E_r < E < 0.8E_r \cup 1.2E_r < E < 1.3E_r$	1.005
	$0.8E_r < E < 0.9E_r \cup 1.1E_r < E < 1.2E_r$	1.0003
	$0.9E_r < E < 1.1E_r$	1.00002

Figure 3.1.1 shows relative standard deviations of U-238 capture cross sections in JENDL-3.3, which are processed with the reference grid and with the defined grid in fine group structure (ign=11, lanl-70) and a weight function (iwt=6). Differences between two results are negligible even if the processing is performed in a fine group structure.

We compare a calculation time between the version 2.2 and the version 2.3. The result with ign=3 and iwt=6 is shown in **Table 3.1.2** [3].

Table 3.1.2 Processing time with the previous and the revised versions

Processed nuclide	Version 2.3	Version 2.2
U-235 (JENDL-3.2)	41.3 Min.	128.0 Min.
U-238 (JENDL-3.3)	8.8 Min.	12.0 Min.
Pu-239 (JENDL-3.3)	48.2 Min.	187.8 Min.

Next, we process covariance data of U-233 given in the preliminary version of ENDF/B-VII. This covariance data are very huge since variance and full-correlation matrix are given for 770 resonances. Leal of ORNL reported that it took about five days to process it with the version 2.2. With the version 2.3, the processing terminated in about five hours (SCALE-44 group structure and iwt=3). To process U-233 in ENDF/B-VII, maximum size of 'a' array in errorr.f

angular momentum and specific spin of the resonance. Hence, $(\sigma^+(E) - \sigma^-(E))$ in Eq.(3.3) depends only on the resonance parameters which have the same neutron orbital angular momentum and the same spin as the i-th resonance. It means that we can neglect contributions from resonances of different neutron orbital angular momentum and different spin to the i-th resonance to Eq.(3.3). This can reduce calculation time taken in the generation of point-wise cross sections from resonance parameters in Eq.(3.3).

[3] A processing time depends on target group structure and used weight functions.

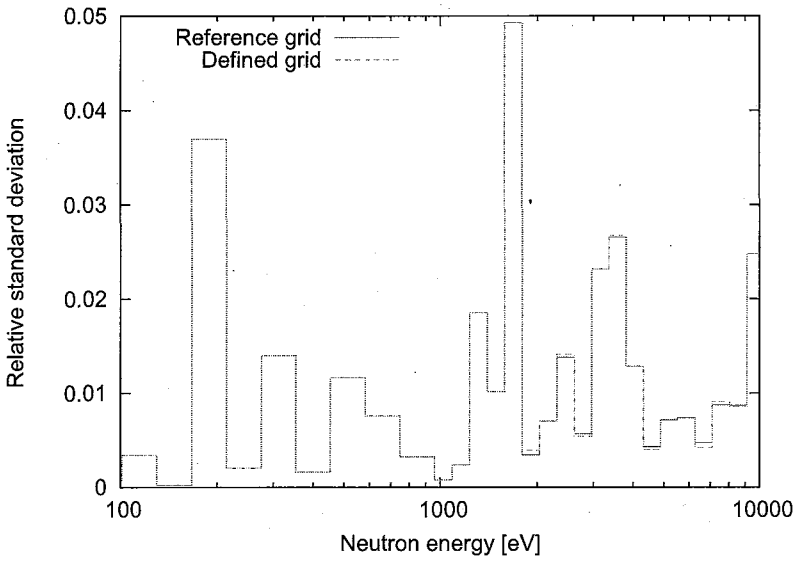

Fig. 3.1.1 Relative standard deviation of capture cross sections of U-238 in JENDL-3.3

has to be increased to 8,500,000, and 'nwds' in covout.f has to be set to 8,000,000.

3.2 Processing average cosine of elastic scattering angle

ERRORJ can process the covariance of the average cosine of the elastic scattering angle, $\bar{\mu}$. The procedure is described below.

① Legendre expansion coefficients of the elastic scattering cross section in a union group structure are prepared from the angular distribution of the elastic scattering.

② The covariance of $\bar{\mu}$ in the laboratory system is obtained from the covariance given in MF=34 as

$$Cov.(\bar{\mu}_g, \bar{\mu}_{g'}) = Cov.(a_{1,g}^{Lab.}, a_{1,g'}^{Lab.}) = Cov.(\sum_m U_{1m} a_{m,g}^{C.M.}, \sum_l U_{1l} a_{l,g'}^{C.M.}) \tag{3.4}$$

where $a_{l,g}^{Lab.}$ and $a_{l,g}^{C.M.}$ are the l-th order coefficients of Legendre expansion of the elastic scattering in the laboratory system and the center mass system, respectively. U_{1m} is a component of transformation matrix $\vec{U}$ from the center mass system to the laboratory system. If $\vec{U}$ is not defined in the nuclear data file, a module named `matrixin` is used to calculate it. The module was prepared by T. Nakagawa of Japan Atomic Energy Research Institute[8].

Conventionally, the covariance of the elastic scattering angle is defined only for the first order coefficient of Legendre expansion. Thus,

$$Cov.(\bar{\mu}_g, \bar{\mu}_{g'}) = U_{11} U_{11} Cov.(a_{1,g}^{C.M.}, a_{1,g'}^{C.M.}) \tag{3.5}$$

③ The covariance in a user group structure is calculated as below.

$$Cov.(\bar{\mu}_G, \bar{\mu}_{G'}) = \sum_{g \in G, g' \in G'} Cov.(\bar{\mu}_g, \bar{\mu}_{g'}) \cdot \frac{\phi_g \sigma_g^{Ela.}}{\phi_G \sigma_G^{Ela.}} \cdot \frac{\phi_{g'} \sigma_{g'}^{Ela.}}{\phi_{G'} \sigma_{G'}^{Ela.}} \tag{3.6}$$

The current ERRORJ code cannot treat the covariance of the higher order coefficients. Therefore, users should set input value `legerd` to 1 in card 7 of an input file. Results are given as MT=251. It is not necessary for users to prepare the group-averaged $\bar{\mu}$ in a user group structure because it can be calculated in ERRORJ.

4. How to use ERRORJ

4.1 How to run

The following files are necessary in order to run the ERRORJ code.

- Input file,
- Evaluated nuclear data file including covariance data,
- Point-wise cross section data file (PENDF) or group-wise cross section data file (GENDF).

ERRORJ produces a standard output file and a covariance file in COVFIL format including multi-group cross sections and relative covariance data. The standard output file named 'output' is automatically updated.

Relationship between the tape number and the file name is the same as the NJOY code. ERRORJ uses tapes 10-19 as scratch files, therefore users should not use tapes 10-19. Tapes 1-9 are conventionally not used.

To transform the COVFIL format file to the COVERX format file, a utility program NJOYCOVX is used. Users should name the COVFIL format file `cvf.+nuclide name(NN)`. For example, if users want to process U-238, the name of the COVFIL format file must be `cvf.u238`. In addition, users should prepare a directory named `exc-d` to contain correlation matrix files before running NJOYCOVX. .

NJOYCOVX needs one input parameter, which is a nuclide name, as below.

```
/home/user1/errorj/njoycovx/njoycovx_ld u238
```

In this example, NJOYCOVX realizes that `cvf.u238` is the file which should be transformed to a COVERX format file. Files created by NJOYCOVX are

- multi-group covariance file in the COVERX format, `cvx.(NN)`,
- relative standard deviation file, `rsd.(NN)`,
- multi-group cross section and relative standard deviation file, `rxs.(NN)`,
- multi-group cross section and correlation matrix file, `corr.matrix`,
- correlation matrix in each reaction, `mt XXX-XXX`, which is made in `exc-d` directory.

An example of the shell script to run ERRORJ is as follows.

```
#! /bin/csh
#
set NUCL=cr0
set MAT=2400
rm tape* output input
cp /home/endf/cov/${NUCL} tape20
cp /home/pendf/${NUCL} tape22
#
cat>input <<EOF
errorr
 20 22 0 24 0 /
 $MAT 1 1 1 0 6 300.0 /
 0 300.0/
 0 33 1 /
 4/
 1e-5 10.0 1e+3 1e+5 1e+7/
errorr
 20 22 0 23 24 0 /
 $MAT 20 1 1 /
 0 34 1 1 /
stop
EOF
#
/home/usr1/errorj/src/errorj < input
if ( -e tape23 ) then
   if ( -z tape23 ) exit
else
   exit
endif
cp tape23 cvf.${NUCL}
#
if ( -d exc-d ) then
   rm -f exc-d/*
else
   mkdir exc-d
```

```
endif
/home/usr1/errorj/njoycovx/njoycovx_ld ${NUCL}
mv corr.matrix cor.${NUCL}
rm -fR excd-${NUCL}
mv exc-d excd-${NUCL}
exit
```

4.2 Detail description about input file

In this section, detail information about the input file is described. `nout` in card1 is the tape number on which multi-group covariance created by ERRORJ is written. If users set `nout` to 23, the multi-group covariance are written in tape 23. `nin` is the tape number which is read as the existing multi-group covariance file and new multi-group covariance data are added.

`irelco` in card 2 is an option to define a form of output covariance matrix, absolute (`irelco=0`) or relative (`irelco=1`).

`mfcov` in card 7 is an option to determine covariance data to be processed.

- mfcov=31: covariance of the average number of neutrons per fission (reaction type is restricted, MT=452, 455 and 456)
- mfcov=33: covariance of the neutron cross section and the resonance parameters
- mfcov=34: covariance of the angular distribution of the secondary neutron (reaction type is restricted, MT=2)
- mfcov=35: covariance of the energy distribution of the secondary neutron (reaction type is restricted, MT=18)

4.3 Incorporation of ERRORJ into NJOY

It is convenient for users to use ERRORJ as a part of NJOY. Users can incorporate ERRORJ into the NJOY code system very easily. It is attained by replacing the 'errorr.f' of NJOY by the 'errorr.f' of ERRORJ.

4.4 Input sample

The format of input file is slightly modified since there is redundancy in choice of weight function in version 2.2. Hence, input files for version 2.2 should not be used for the version 2.3. Header of the version 2.3 is shown in **Fig. 4.4.1**.

In the following, we show three examples to process covariance data of Pu-239 in JENDL-3.3 with the ERRORJ-incorporated NJOY. **Figure 4.4.2** is an input data with utilizing point-wise cross sections. Group-averaging is performed in the ERRORR module.

When users want to process MF31 or MF35 covariance data, they have to prepare group-averaged cross sections by GROUPR. **Figure 4.4.3** is an input data with utilizing group-wise cross sections.

In some cases, covariance data between different nuclides are given. In these cases, users have to prepare group-averaged cross sections for all-correlated nuclides. **Figure 4.4.4** is an example of input data for such cases.

```
      subroutine errorr
c     ***************************************************************
c     *                                                             *
c     * produce cross section covariances from error files in endf/b*
c     * format                                                      *
c     *                                                             *
c     * first, the union energy grid of the users group structure   *
c     * and the endf covariance energies is determined.  the array  *
c     * of coefficients for derived cross sections is also constructed.*
c     * then multigroup cross sections are computed on the union    *
c     * grid (see grpav), or they are read from a multigroup cross  *
c     * section library and then collapsed to the union grid.  the  *
c     * methods of groupr are used for cross section averaging.  endf*
c     * covariances and the group cross sections are then combined  *
c     * to get the basic covariance matrices (see covcal).  finally,*
c     * the basic matrices are combined to get covariances for      *
c     * derived reactions, the matrices are collapsed to the user-s *
c     * group structure, and the results are printed and/or written *
c     * onto an output gendf tape for later use (see covout).       *
c     *                                                             *
c     *---input specifications (free format)-----------------------*
c     *                                                             *
c     *  card 1                                                     *
c     *    nendf   unit for endf/b tape                             *
c     *    npend   unit for pendf tape                              *
c     *    ngout   unit for input group xsec (gendf) tape           *
c     *            (if zero, group xsecs will be calculated)        *
c     *            (if iread eq 2 or if mfcov eq 31 (see card 7),   *
c     *            ngout cannot be zero)                            *
c     *            (if mfcov eq 35                (see card 7),     *
c     *            ngout cannot be zero)                            *
c     *            (default=0)                                      *
c     *    nout    unit for output covariance tape (default=0)      *
c     *    nin     unit for input covariance tape (default=0)       *
c     *            (nin and nout must be both coded or both binary) *
c     *    nstan   unit for ratio-to-standard tape (default=0)      *
c     *  card 2                                                     *
c     *    matd    material to be processed                         *
c     *    ign     neutron group option                             *
c     *            (ign definition same as groupr, except ign=19,   *
c     *            which means read in an energy grid, as in ign=1, *
c     *            and supplement this with the endf covariance grid*
c     *            within the range of the user-specified energies) *
c     *            (default=1)                                      *
c     *    iwt     weight function option (default=6)               *
c     *    iprint  print option (0/1=minimum/maximum) (default=1)    *
c     *    irelco  covariance form (0/1=absolute/relative) (default=1) *
c     *            (if mfcov=34, irelco must be 1)                  *
c     *  card 3    (omit if ngout.ne.0)                             *
c     *    mprint  print option for group averaging (0=min., 1=max.)*
c     *    tempin  temperature (default=300)                        *
c     *                                                             *
c     *---for endf/b version 4 (iverf=4) only----------------------*
c     *                                                             *
c     *  card 4                                                     *
c     *    nek     number of derived xsec energy ranges             *
c     *            (if zero, all xsecs are independent)             *
c     *  card 5    (omit if nek=0)                                  *
c     *    ek      nek+1 derived xsec energy bounds                 *
c     *  card 6    (omit if nek=0)                                  *
c     *    akxy    derived cross section coefficients, one row/line *
c     *                                                             *
c     *---for endf/b version 5 or 6 (iverf=5 or 6) only------------*
c     *                                                             *
c     *  card 7                                                     *
c     *    iread   0/1/2=program calculated mts/input mts and eks/  *
c     *            calculated mts plus extra mat1-mt1 pairs from input *
c     *            (default=0)                                      *
```

Fig. 4.4.1 Header of the new ERRORR module

```
c     *     mfcov    endf covariance file (31, 33, 34 or 35) to be       *
c     *              processed (default=33).                             *
c     *              note--contribution to group cross section           *
c     *              covariances from resonance-parameter uncertainties  *
c     *              (mf=32) is included when mfcov=33 is specified.     *
c     *              (mf=-33) high speed Calc. for test case             *
c     *              (mf=333) high speed Calc. for test case(faster)     *
c     *     irespr   processing option of resonance parameter covariance *
c     *              (mf=32) (default=1)                                 *
c     *              0 = area sensitivity method                         *
c     *              1 = 1% sensitivity method                           *
c     *     legord   legendre order calculating covariance (default=1)   *
c     *              (if mfcov is not 34, legord is ignored)             *
c     *     ifissp   processing energy range number of fission energy    *
c     *              spectrum (default=-1)                               *
c     *              (if mfcov is not 35, ifissp is ignored)             *
c     *              n>0 = energy range number                           *
c     *              -1  = fast neutron reactor (average energy = 2 MeV) *
c     *                                                                  *
c     *   following cards only if iread eq 1                             *
c     *   card 8                                                         *
c     *     nmt      no. mts to be processed                           *
c     *     nek      no. derived cross section energy ranges           *
c     *              (if zero, all xsecs are independent)              *
c     *   card 8a                                                        *
c     *     mts      nmt mts                                           *
c     *   card 8b    (omit if nek=0)                                   *
c     *     ek       nek+1 derived cross section energy bounds         *
c     *   card 9     (omit if nek=0)                                   *
c     *     akxy     derived cross section coefficients, one row/line  *
c     *                                                                *
c     *   following card only if iread eq 2                            *
c     *   card 10                                                      *
c     *     mat1     cross-material reaction to be added to            *
c     *     mt1          covariance reaction list.                     *
c     *              repeat for all mat1-mt1 pairs desired             *
c     *              terminate with mat1=0.                            *
c     *                                                                *
c     *   following card only if nstan ne 0                            *
c     *   card 11                                                      *
c     *     matb     standards reaction referenced                     *
c     *     mtb          in matd.                                      *
c     *     matc     standards reaction to be                          *
c     *     mtc          used instead.                                 *
c     *              repeat for all standard reactions to be redefined.*
c     *              terminate with matb=0.                            *
c     *   note.  if matb(1) and mtb(1) are negative, then matc(1) and  *
c     *     mtc(1) identify a third reaction, correlated with matd thru*
c     *     the use of the same standard.  covariances of all reactions*
c     *     in matd (which reference the standard) with the reaction   *
c     *     matc(1)-mtc(1) will be produced.  the standard reaction    *
c     *     must be identified on card 10 and repeated as the negative *
c     *     entries on card 11.  the group xsec tape ngout must include*
c     *     all covariance reactions in matd, plus matc(1)-mtc(1).     *
c     *----------------------------------------------------------------*
c     *                                                                *
c     *   card 12a (for ign eq 1 or ign eq 19)                         *
c     *     ngn      number of groups                                  *
c     *              (if negative, group bounds is decending order)    *
c     *   card 12b                                                     *
c     *     egn      ngn+1 group bounds (ev)                           *
c     *   card 13a   tabulated (iwt=1 only)                            *
c     *     wght     weight function as a tab1 record                  *
c     *   card 13b   analytic flux parameters (iwt=4 only)             *
c     *     eb       thermal break (ev)                                *
c     *     tb       thermal temperature (ev)                          *
c     *     ec       fission break (ev)                                *
c     *     tc       fission temperature (ev)                          *
```

Fig.4.4.1 Header of the new ERRORR module (Cont.)

```
c     *---options for input variables-------------------------------------*
c     *                                                                   *
c     *     ign          meaning                                          *
c     *     ---          -------                                          *
c     *      1           arbitrary structure (read in)                    *
c     *      2           csewg 239-group structure                        *
c     *      3           lanl 30-group structure                          *
c     *      4           anl 27-group structure                           *
c     *      5           rrd 50-group structure                           *
c     *      6           gam-i 68-group structure                         *
c     *      7           gam-ii 100-group structure                       *
c     *      8           laser-thermos 35-group structure                 *
c     *      9           epri-cpm 69-group structure                      *
c     *     10           lanl 187-group structure                         *
c     *     11           lanl 70-group structure                          *
c     *     12           sand-ii 620-group structure                      *
c     *     13           lanl 80-group structure                          *
c     *     14           eurlib 100-group structure                       *
c     *     15           sand-iia 640-group structure                     *
c     *     16           vitamin-e 174-group structure                    *
c     *     17           vitamin-j 175-group structure                    *
c     *     18           xmas 172-group structure                         *
c     *     19          read in, supplemented with endf covariance grid   *
c     *                                                                   *
c     *     iwt          meaning                                          *
c     *     ---          -------                                          *
c     *      1           read in smooth weight function                   *
c     *      2           constant                                         *
c     *      3           1/e                                              *
c     *      4           1/e + fission spectrum + thermal maxwellian      *
c     *      5           epri-cell lwr                                    *
c     *      6           (thermal) -- (1/e) -- (fission + fusion)         *
c     *      7           same with t-dep thermal part                     *
c     *      8           thermal--1/e--fast reactor--fission + fusion     *
c     *      9           claw weight function                             *
c     *     10           claw with t-dependent thermal part               *
c     *     11           vitamin-e weight function (ornl-5505)            *
c     *     12           vit-e with t-dep thermal part                    *
c     *                                                                   *
c     *********************************************************************
```

Fig.4.4.1 Header of the new ERRORR module (Cont.)

```
set NUCL=Pu239
set MAT=9437
rm tape* output input
set WHOME=/home/chiba
cp $WHOME/XSDATA/JENDL-3.3/$NUCL tape20

cat>input <<EOF
moder
 20 -21 /
reconr
 -21 -22 /
'test processing of pu-239 of jendl-3.3'  /
$MAT 0 0 /
0.001 /
0 /
broadr
 -21 -22 -23 /
$MAT 1 0 0 0 /
0.001 /
300. /
0 /
errorr
 -21 -23 0 25 0 0 /
$MAT 3 1 1 2 /
 0 300. /
0 33 1 /
errorr
 -21 -23 0 24 25 0 /
$MAT 3 1 1 2 /
 0 300. /
0 34 1 1  /
stop
EOF
#
$WHOME/CODE/njoy99/xnjoy99 < input
```

Fig. 4.4.2 Pu-239 processing with point-wise cross sections

```
set NUCL=Pu239
set MAT=9437

set WHOME=/home/chiba
cp $WHOME/XSDATA/JENDL-3.3/$NUCL tape20
ln -s $WHOME/XSDATA/pendf_j33/$NUCL.t0300.dat tape22

cat>input <<EOF
moder
 20 -21 /
groupr
-21 22 0 91 /
$MAT 3 0 2 1 1 1 0 /
'test' /
300. /
1.0e10 /
3 /
3 251 'mubar' /
3 252 'xi' /
3 452 'nu' /
3 455 'nu' /
3 456 'nu' /
5 18  'xi' /
0 /
0 /
errorr
 -21 0 91 25 0 0 /
$MAT 3 1 1 2 /
0 31 1 1 -1 /
errorr
 -21 0 91 24 25 0 /
$MAT 3 1 1 2 /
0 33 1 1 -1 /
errorr
 -21 0 91 25 24 0 /
$MAT 3 1 1 2 /
0 34 1 1 -1 /
errorr
 -21 0 91 24 25 0 /
$MAT 3 1 1 2 /
0 35 1 1 -1 /
stop
EOF
#
$WHOME/CODE/njoy99/xnjoy99 < input
```

Fig. 4.4.3 Pu-239 processing with group-wise cross sections

```
set WHOME=/home/chiba
cp $WHOME/XSDATA/endf/Pu239 tape20
cp $WHOME/XSDATA/gendf/Pu239 tape91
cp $WHOME/XSDATA/gendf/U233  tape92
cp $WHOME/XSDATA/gendf/U235  tape93
cp $WHOME/XSDATA/gendf/U238  tape94
cp $WHOME/XSDATA/gendf/Pu240 tape95
cp $WHOME/XSDATA/gendf/Pu241 tape96

cat>input <<EOF
moder
 2 99 /
'combine all gendf files' /
 92   9222 /
 93   9228 /
 94   9237 /
 91   9437 /
 95   9440 /
 96   9443 /
 0 /
errorr
 20 0 99 24 0 0 /
 9437 3 1 1 6 /
 33 1  /
 9222 18 /
 9228 18 /
 9237 18 /
 9437 18 /
 9440 18 /
 9443 18 /
 0 /
 0 /
stop
EOF
#
$WHOME/CODE/njoy99/xnjoy99 < input
```

Fig. 4.4.4 Pu-239 processing considering correlation with other nuclides

5. Summary

The ERRORJ code was developed to process the covariance data. ERRORJ has new functions to process covariance data of cross sections including resonance parameters as well as angular distributions and energy distributions of secondary neutrons which could not be processed with by former covariance processing codes.

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国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度（質量密度）	キログラム毎立法メートル	kg/m^3
質量体積（比体積）	立法メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
（物質量の）濃度	モル毎立方メートル	mol/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率	（数の）1	1

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^{9}	ギガ	G	10^{-12}	ピコ	p
10^{6}	メガ	M	10^{-15}	フェムト	f
10^{3}	キロ	k	10^{-18}	アト	a
10^{2}	ヘクト	h	10^{-21}	ゼプト	z
10^{1}	デカ	da	10^{-24}	ヨクト	y

表３．固有の名称とその独自の記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(a)	rad		$m \cdot m^{-1}=1$(b)
立体角	ステラジアン(a)	sr(c)		$m^2 \cdot m^{-2}=1$(b)
周波数	ヘルツ	Hz		s^{-1}
力	ニュートン	N		$m \cdot kg \cdot s^{-2}$
圧力，応力	パスカル	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
エネルギー，仕事，熱量	ジュール	J	N・m	$m^2 \cdot kg \cdot s^{-2}$
工率，放射束	ワット	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
電荷，電気量	クーロン	C		s・A
電位差（電圧），起電力	ボルト	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
静電容量	ファラド	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
電気抵抗	オーム	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
コンダクタンス	ジーメンス	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
磁束	ウエーバ	Wb	V・s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
磁束密度	テスラ	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
インダクタンス	ヘンリー	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
セルシウス温度	セルシウス度(d)	℃		K
光束	ルーメン	lm	cd・sr(c)	$m^2 \cdot m^{-2} \cdot cd=cd$
照度	ルクス	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd=m^{-2} \cdot cd$
（放射性核種の）放射能	ベクレル	Bq		s^{-1}
吸収線量，質量エネルギー分与，カーマ	グレイ	Gy	J/kg	$m^2 \cdot s^{-2}$
線量当量，周辺線量当量，方向性線量当量，個人線量当量，組織線量当	シーベルト	Sv	J/kg	$m^2 \cdot s^{-2}$

(a)ラジアン及びステラジアンの使用は、同じ次元であっても異なった性質をもった量を区別するときの組立単位の表し方として利点がある。組立単位を形作るときのいくつかの用例は表４に示されている。
(b)実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号“１”は明示されない。
(c)測光学では、ステラジアンの名称と記号srを単位の表し方の中にそのまま維持している。
(d)この単位は、例としてミリセルシウス度m℃のようにSI接頭語を伴って用いても良い。

表４．単位の中に固有の名称とその独自の記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa・s	$m^{-1} \cdot kg \cdot s^{-1}$
力のモーメント	ニュートンメートル	N・m	$m^2 \cdot kg \cdot s^{-2}$
表面張力	ニュートン毎メートル	N/m	$kg \cdot s^{-2}$
角速度	ラジアン毎秒	rad/s	$m \cdot m^{-1} \cdot s^{-1}=s^{-1}$
角加速度	ラジアン毎平方秒	rad/s^2	$m \cdot m^{-1} \cdot s^{-2}=s^{-2}$
熱流密度，放射照度	ワット毎平方メートル	W/m^2	$kg \cdot s^{-3}$
熱容量，エントロピー	ジュール毎ケルビン	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
質量熱容量（比熱容量），質量エントロピー	ジュール毎キログラム毎ケルビン	J/(kg・K)	$m^2 \cdot s^{-2} \cdot K^{-1}$
質量エネルギー（比エネルギー）	ジュール毎キログラム	J/kg	$m^2 \cdot s^{-2} \cdot K^{-1}$
熱伝導率	ワット毎メートル毎ケルビン	W/(m・K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
体積エネルギー	ジュール毎立方メートル	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
電界の強さ	ボルト毎メートル	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
体積電荷	クーロン毎立方メートル	C/m^3	$m^{-3} \cdot s \cdot A$
電気変位	クーロン毎平方メートル	C/m^2	$m^{-2} \cdot s \cdot A$
誘電率	ファラド毎メートル	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
透磁率	ヘンリー毎メートル	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
モルエネルギー	ジュール毎モル	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
モルエントロピー，モル熱容量	ジュール毎モル毎ケルビン	J/(mol・K)	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	$kg^{-1} \cdot s \cdot A$
吸収線量率	グレイ毎秒	Gy/s	$m^2 \cdot s^{-3}$
放射強度	ワット毎ステラジアン	W/sr	$m^4 \cdot m^{-2} \cdot kg \cdot s^{-3}=m^2 \cdot kg \cdot s^{-3}$
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2 \cdot sr)$	$m^2 \cdot m^{-2} \cdot kg \cdot s^{-3}=kg \cdot s^{-3}$

表６．国際単位系と併用されるが国際単位系に属さない単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86400 s
度	°	1° =(π/180) rad
分	’	1’ =(1/60)° =(π/10800) rad
秒	”	1” =(1/60)’ =(π/648000) rad
リットル	l、L	1l=1 $dm^3=10^{-3}m^3$
トン	t	1t=10^3 kg
ネーパ	Np	1Np=1
ベル	B	1B=(1/2)ln10(Np)

表７．国際単位系と併用されこれに属さない単位でSI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位であらわされる数値
電子ボルト	eV	1eV=1.60217733(49)×10^{-19}J
統一原子質量単位	u	1u=1.6605402(10)×10^{-27}kg
天文単位	ua	1ua=1.49597870691(30)×10^{11}m

表８．国際単位系に属さないが国際単位系と併用されるその他の単位

名称	記号	SI 単位であらわされる数値
海里		1海里=1852m
ノット		1ノット=1海里毎時=(1852/3600)m/s
アール	a	1a=1 $dam^2=10^2m^2$
ヘクタール	ha	1ha=1 $hm^2=10^4m^2$
バール	bar	1bar=0.1MPa=100kPa=1000hPa=10^5Pa
オングストローム	Å	1 Å=0.1nm=10^{-10}m
バーン	b	1b=100$fm^2=10^{-28}m^2$

表９．固有の名称を含むCGS組立単位

名称	記号	SI 単位であらわされる数値
エルグ	erg	1 erg=10^{-7} J
ダイン	dyn	1 dyn=10^{-5}N
ポアズ	P	1 P=1 dyn・s/cm^2=0.1Pa・s
ストークス	St	1 St =1$cm^2/s=10^{-4}m^2/s$
ガウス	G	1 G ^10^{-4}T
エルステッド	Oe	1 Oe ^(1000/4π)A/m
マクスウェル	Mx	1 Mx ^10^{-8}Wb
スチルブ	sb	1 sb =1cd/$cm^2=10^4cd/m^2$
ホト	ph	1 ph=10^4lx
ガル	Gal	1 Gal =1cm/$s^2=10^{-2}m/s^2$

表10．国際単位に属さないその他の単位の例

名称	記号	SI 単位であらわされる数値
キュリー	Ci	1 Ci=3.7×10^{10}Bq
レントゲン	R	1 R = 2.58×10^{-4}C/kg
ラド	rad	1 rad=1cGy=10^{-2}Gy
レム	rem	1 rem=1 cSv=10^{-2}Sv
X線単位		1X unit=1.002×10^{-4}nm
ガンマ	γ	1γ=1 nT=10^{-9}T
ジャンスキー	Jy	1 Jy=10^{-26}W・m^{-2}.Hz^{-1}
フェルミ		1 fermi=1 fm=10^{-15}m
メートル系カラット		1 metric carat = 200 mg = 2×10^{-4}kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	
ミクロン	μ	1 μ =1μm=10^{-6}m

（第７版，1998年改訂）