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THE UNFOLDING CODE SYSTEM FOR THE NE213 LIQUID SCINTILLATOR

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The unfolding code system for the NE213 liquid scintillator was described, including the system architecture and input instructions. This system consists of (1) the conversion code of pulse height distributions, (2) the code to generate response matrix and (3) unfolding codes. The feasibility of the system was certified by unfolding the source neutrons emitted by the spontaneous fissions of ^{252}Cf.

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NE 213 液体シンチレータに対する アンフォールディングコードシステム

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NE 213液体シンチレータに対するアンフォールディングコードシステムについてその構造と入力形式を示した。本コードシステムは3種類のコードからなり，それらは(1)波高分布変換コード，(2)応答行列作成コード，(3)アンフォールディングコードである。システムの妥当性は，$^{252}C_f$から放出される自発核分裂中性子のアンフォールディングにより確かめた。

CONTENTS

1. Introduction

The liquid scintillator, NE213, has been used for fast neutron spectrum measurements, since the scintillator has good discrimination property between neutrons and gamma rays. The NE213, however, cannot be an easy neutron detector for general purposes because the users are required to have a fundamental knowledge of the detector system. That is, the unfolding procedure is needed for obtaining a neutron spectrum from the measured pulse height distribution. Though the unfolding method has widely been used in many countries, the difficulties involved in the unfolding method including the problem of response matrix are left to be solved in the future. In the Seminor-workshop held on radiation energy spectra unfolding on April 12-13, 1976, the decided solutions were not given.

We have developed and improved our NE213 neutron spectroscopy system including the unfolding procedure for the purpose of applying them to neutron spectrum measurement of the shielding benchmark experiments. The procedure of obtaining the neutron spectrum by the unfolding method is :

a) data conversion of the pulse height distribution from count per channel to count per light unit,
b) generation of the response matrix of the NE213 scintillator,
c) unfolding of the converted pulse height distribution to obtain the neutron spectrum using the response matrix.

In this paper, the procedure of the code system and the input data instructions are described.

Feasibilty of the present system was also examined by unfolding the ^{252}Cf fission neutron sources.

Library data used in the present study are responses of the 2"x 2"$^{\phi}$ NE213 scintillator setup so that its scintillator axis is parallel with the direction of incident neutrons. The data are, of course, replaceable with other data for different experimental setups.

2. Description of the Code System

2.1 Architecture

The present system consists of the three kinds of computer codes. A diagram of the system is shown in Fig.1. The pulse height distribution measured in unit of count per channel is first converted to that in Na light unit. Coupling of the low and high gain data follows the data conversion. On the other hand, a response matrix of a NE213 scintillator to neutrons is prepared by smearing the Monte Carlo calculation. In order to obtain the neutron spectrum using this response matrix and the converted pulse height distribution, the unfolding is made by using two different kinds of unfolding codes, FERDOS and ITEM-II. FERDOS is a modified version of the well-known code FERDO [1), and ITEM-II by iterative method was developed by the present authors. It is important to avoid systematic error in the unfolded neutron spectrum, two independent types of unfolding codes are required, such as are just mentioned. The successive steps in the procedure cannot be performed automatically, because users must select the input data for the next step run after examining the calculated results of the preceding step run. Therefore, the code system should be considered as a collection of the separate codes.

2.2 Data Conversion

The pulse height distribution is measured in unit of count per channel. For unfolding, however, the unit of the pulse height distribution must be matched to that of the response matrix. The Na light unit has generally been used as a measure of the pulse height of NE213 scintillator, so this unit is used in the present system. The relationship between the channel number and the light unit is given in linear expression. The coefficients of the linear expression are determined by pulse height calibration. A new calibration method was proposed by the present authors,[2] which utilizes the relations between the values of the light unit for the energy of the Compton peak and the corresponding channel number of the gamma-ray sources. The relations between the Na unit and the Compton peak location for some standard gamma-ray sources of both 2" x 2"$^{\phi}$ and 5"x 5"$^{\phi}$ NE213 scintillators are tabulated in Table I. In Fig.2 is illustrated the data conversion from unit of count per channel to unit of count per Na unit. The data conversion is made by a proportional allotment. The pulse height data y_j and its standard deviation σ_j for the j-th mesh interval corresponding to the interval of the response matrix are obtained by the eqs.(1) and (2).

$$y_j = (c_i \cdot \frac{u_i - p_1}{u_i - u_{i-1}} + c_{i+1} \cdot \frac{p_2 - u_i}{u_{i+1} - u_i}) \cdot \frac{1}{p_2 - p_1} , \quad (1)$$

$$\sigma_j = \{ \sqrt{s_i^2 \cdot \frac{u_i - p_1}{u_i - u_{i-1}} + s_{i+1}^2 \cdot \frac{p_2 - u_i}{u_{i+1} - u_i}} \} \cdot \frac{1}{p_2 - p_1} , \quad (2)$$

where

c_i : the pulse height data for the i-th channel in unit of count per channel

s_i : the standard deviation for the i-th channel

u_i : the pulse height corresponding to the i-th channel mesh

p_1 : the lower boundary of the j-th mesh interval required

p_2 : the upper boundary of the j-th mesh interval required.

The pulse height for the j-th mesh x_j is assigned as

$$x_j = (p_1 + p_2)/2.0$$

The background subtraction is also possible by option during the data conversion process. We denote by T_s the counting time for the pulse height distribution from the neutrons and by T_b that for the background data. Using T_s and T_b, the background-subtracted pulse height data for the i-th channel c_i and its corresponding standard deviation s_i are obtained as follows :

$$c_i = a_i(T_b/T_s) - d_i , \qquad (T_s \geqq T_b) \qquad (3)$$

$$c_i = a_i - d_i(T_s/T_b), \qquad (T_s < T_b) \qquad (3')$$

$$s_i = \sqrt{a_i(T_b/T_s)^2 + d_i} . \qquad (T_s \geqq T_b) \qquad (4)$$

$$s_i = \sqrt{a_i + d_i(T_s/T_b)^2}, \qquad (T_s < T_b) \qquad (4')$$

where a_i and d_i are the pulse height distribution by the neutrons and that of the background for the i-th channel, respectively. If the background subtraction is not necessary, c_i and s_i become a_i and $\sqrt{a_i}$, respectively, in the above equations. These c_i and s_i are used for data conversion by substituting them into eq.(1).

2.3 Generation of the Response Matrix

The response matrix of a NE213 is obtained by smearing the results of the response functions calculated by the Monte Carlo method. In this study, the response functions to 47 neutron energies calculated by the Monte Carlo method[3] were prepared; calcualtions were made using the neutron cross sections from ENDF/B-IV libraries and the light output data evaluated by Verbinski et al.[4] Energies of the responses considered are listed in Table II. The pulse height meshes are arranged at equal spaces in logarithmic scale from 0.001 to 10.0 Na light unit, with 60 mesh points in each decade pulse height interval.

Information about the resolution of NE213 detector system necessary for smearing must be assigned by the user in the subroutine RESL. We used Burrus et al.'s pulse height resolution,[5] that is,

$$\sigma(L) = 0.138\ L^{0.827}, \qquad (L<0.082 \text{ Na unit}) \qquad (5)$$

$$\sigma(L) = 0.060\ L^{0.494}, \qquad (L\geq 0.082 \text{ Na unit}) \qquad (5')$$

where L is the pulse height variable in Na unit and $\sigma(L)$ the width of the resolution at L.

Pulse height meshes of the smeared response matrix are the same as those for the Monte Carlo results.

And the system involves an interpolation routine of the smeared responses to obtain any desired neutron energies. However, it is desirable to construct the response matrix without aid of the interpolation procedure, using only the response functions obtained by Monte Carlo calculation.

2.4 Unfolding Procedure

In the present system, two kinds of unfolding codes, FERDOS and ITEM-II, are available, whose principles of the unfolding algorithm are different. As already described, it is important to employ two or more kinds of unfolding codes to avoid the systematic error in the unfolded spectrum.

For users' convenience, the response matrix and almost all the input data are arranged to be common to both the codes. A feature of the codes is that both the lower and upper limit of the pulse height region for unfolding can be selected in parametric manner. Occasionally, a slite change of the number of the neutron energy meshes in the matrix causes large differences among the unfolded spectra, especially the spectra unfolded by FERDOS. Therefore, the most reliable solution can be selected among the series of unfolded spectra obtained by changing step by step the lower limit of the neutron mesh of the response matrix.

It is recommended that the user should measure the pulse height distributions by both the lower and high gain measurements and couple them together. This is because the coupled data spread the energy region of the unfolded spectrum and also the smoothly coupled data ensure that the pulse height distribution is prevented from the contamination of gamma rays and that the pulse height calibration is correctly made.

3. Input Data Instruction

The card number is followed by data format, array dimension in bracket and, if necessary, optional condition in parentheses.

3.1 Input Data for the Data Conversion Code "CHNTLU"

*Card 1 Format(2I6,E12.5) [3]

1. NPT — number of data points per unit decade of pulse height intervals ($\leq$60)
2. NDEC — number of decade in the pulse height region ($\leq$4)
3. SINIT — pulse height of initial mesh in Na unit ($\geq$0.001)

   Using these variables, the j-th mesh y_j is obtained as,

$$y_j = \mathrm{SINIT}*10^n, \quad n = \frac{1.0}{\mathrm{NPT}} * (j-2)$$
$$y_1 = 0.0$$

*Card 2 Format(20A4) [20]

1. AL — title card

*Card 3 Format(10I6) [4]

1. NMAX — number of channels in the measured pulse height distribution ($\leq$1024)
2. JMAX — = 0
3. JSUB — 0 - no effect

   1 - enter background data
4. JPUNCH — 0 - no effect

   1 - punch converted data

*Card 4 Format(6E12.5) [3]

1. AF — first-order coefficient of calibration curve
2. BF — constant term of the calibration curve

y = AF*(x + BF)   (in Na unit)

3. ANRM   normalization factor, normally 1.0

*Card 5 Format(6E12.5) [1]

1. TMS   counting time in second

*Card 6 Format(10I8) [NMAX]

1. ND(N,1) pulse height distribution in count per channel

*Card 7 Format(6E12.5) [1] (JSUB=1)

1. TMB   background counting time in second

*Card 8 Format(10I8) [NMAX] (JSUB=1)

1. ND(N,2) pulse height distribution of the background in count per channel

If background data are entered, both TMS and TMB are unified to the smaller value of them. So the pulse height distributions are then properly adjusted according to the counting time.

In the successive runs following the first case, only the Cards 2 to 8 are required.

3.2 Input Data for the Response Matrix Generating Code "SYSMTRIX"

The response matrix obtained by the code is stored on a disk in a data format suitable for the computation with FERDOS and ITEM-II. The response functions to 47 neutron energies calculated by the Monte Carlo method are read from the disk file which is assigned as F01,J2370.MCRESPB4.

*Card 1 Format(20A4) [20]

1. AL   title card

*Card 2 Format(E12.5) [1]

1. SS   multiplicity factor for resolution data, usually 1.0

*Card 3 Format(4I6,2E12.5) [6]

1. NPTO number of mesh points per unit decade of Na unit interval of the referred response matrix (=60)
2. NDECO number of decade between lower and upper pulse height boundaries of the referred response matrix (=4)
3. NPTN number of mesh points per unit decade of Na unit interval of the required response matrix ($\leq$60) (suggested value, NPTN=40)
4. NDECN number of decade in between lower and upper pulse height boundary of the required response matrix
5. SINITO pulse height of initial mesh in Na unit of the referred response matrix (=0.001)
6. SINITN pulse height of initial mesh in Na unit of the required response matrix ($\geq$0.001) (suggested value, SINIT=0.01)

*Card 4 Format(10I6) [3]

1. NMAX number of neutron energy meshes of the required response matrix
2. NPUNCH 0 - no effect
   1 - punch response matrix
3. NDISK 0 - no effect
   1 - store response matrix on disk
   (suggested option) (File No. = 3)

*Card 5 Format(6E12.5) [NMAX]

1. X neutron energy in MeV for which the smeared response function be calculated

In addition to these input data, users must also define in the subroutine RESL the detector resolution as a function of pulse height for smearing procedure. For example, the subroutine RESL for the resolution given by eq.(2) is the following:

```
      SUBROUTINE RESL(P,REN)
      IF(P-0.082) 11,12,12
   11 AQ=0.138
      BQ=0.827
      GO TO 13
   12 AQ=0.060
      BQ=0.494
   13 CONTINUE
      REN=AQ*(P**BQ)
      RETURN
      END
```

where variable P is the pulse height in Na unit and variable REN is the required resolution at P. When the response matrix stored on the disk by the file name J2370.MCRESPB4 is used as the reference data, the variables NPTO, NDECO and SINITO must be fixed to the values indicated in the above input data instructions.

3.3 Input Data for the Unfolding Codes "FERDOS" and "ITEM-II"

3.3.1 FERDOS

*Card 1 Format(I6,18A4) [19]

1. ILOOP number of unfolding repetition
2. IDENT problem identification

*Card 2 Format(12I6) [6]

1. IMAX number of data points of the pulse height distribution ($\leq$150)

2. ILM1 mesh number of lower limit of pulse height

3. ILM2 mesh number of upper limit of pulse height

4. JLM1 mesh number of lower limit of neutron energy

5. JLM2 mesh number of upper limit of neutron energy

6. NGO = 1005

*Card 4 Format(10I8) [IMAX]

1. ND pulse height distribution data

*Card 4 Format(10I8) [IMAX]

1. LSG standard deviation of ND

Once all the input data from Card 1 through 4 are entered, only Card 2's are required (ILOOP-1) times more. This repetition routine is for changing the response matrix domain for the unfolding.

ILM1 must correspond to the cutoff pulse height mesh of the response function to JLM1'th neutron energy. A similar relation must hold between ILM1 and ILM2. The above relations are illustrated in Fig.3. Here, marks * in the matrix indicate the nonzero element and no marks the zero element. When the variables ILM1, ILM2, JLM1 and JLM2 are defined, the matrix domain surrounded by the dotted lines is arranged to be used for unfolding the pulse height distribution in the pulse height region of ILM1 to ILM2. Since there is no relations between JLM1 and JLM2, JLM1 may be selected independently of JLM2. But it is necessary that JLM2 agrees with the cutoff pulse height of the data or its vicinity.

Window functions for FERDOS are fixed independently of the user's own detector resolution, following the width given by

Verbinski et al.[6] as follows :

$$\sigma(E) = 0.2161 \cdot E^{0.93} \quad , \qquad (E<0.766)$$

$$\sigma(E) = 0.1907 \cdot E^{0.46} \quad , \qquad (0.766 \leq E \leq 11.98)$$

$$\sigma(E) = 0.0499 \cdot E^{1.00} \quad , \qquad (E>11.98)$$

3.3.2 ITEM-II

Almost all the input data for ITEM-II are common to FERDOS. So, detail instructions of these input data are omitted.

*Card 1 Format(I6,18A4) [19]

1. ILOOP number of unfolding repetition
2. TITLE problem identification

*Card 2 Format(10I6) [9]

1. IMAX number of data points (same as for FERDOS)
2. NLM1 same as ILM1 for FERDOS
3. NLM2 same as ILM2 for FERDOS
4. NEM1 same as JLM1 for FERDOS
5. NEM2 same as JLM2 for FERDOS
6. ITMAX iteration maximum
7. NPRNT print results every "NPRNT" times of iteration. If "NPRNT" equals to unity, results are printed for every iterations.
8. NGUESS option of initial guess spectrum
   0 - enter guess spectrum
   1 - use fission spectrum
   2 - use 1/E spectrum
   3 - use constant spectrum (flat spectrum)

*Card 3 Format(10I8) [IMAX]

1. NAEXP pulse height distribution data

*Card 4 Format(10I8) [IMAX]

1. NDAEXP standard deviation of NAEXP

*Card 5 Format(6E12.5) [NE] (NGUESS=0)

1. FAI initial guess spectrum
NE must agree with NMAX in SYSMTRIX code, the number of neutron energy meshes.

Repetition control for ITEM-II is the same as for FERDOS. Only the data in Card 2 are necessary for repetition routine.

The required response matrix for both FERDOS and ITEM-II is always read from the disk file stored by SYSMTRIX code and never read from cards.

4. Sample Calculations and Discussion

It is generally difficult to estimate accuracy of the unfolded spectrum by the unfolding method itself. So it was suggested recently that the unfolded fission spectrum from a ^{252}Cf neutron source should always be given as a criteria for accuracy of the unfolded spectrum when the unfolding technique is used. Therefore, the spectrum of the neutrons emitted by spontaneous fissions of ^{252}Cf was measured for verification of feasibility of the present system. Measurements were made with a 2"x 2"$^{\phi}$ NE213 scintillator of which the axis was in parallel to the direction of incident neutrons. Both the low and high gain data were measured, which are presented in Fig.4. The data conversion of count per channel to count per Na light unit is then made. Calibration curves for the data conversion are as follows.

$$y = 2.318\times10^{-3}(\ x + 12\ )\ , \qquad \text{(high gain)}$$
$$y = 1.070\times10^{-2}(\ x + 12\ )\ , \qquad \text{(low gain)}$$

where x and y are the channel number and the pulse height in Na unit, respectively. The converted data obtained by both the high and low gain measurements are shown in Fig.5. As seen in the figure, the converted high and the low gain data overlap within statistical uncertainty in the region of about 0.35 to 0.80 Na unit. This good agreement shows validity of the measured pulse height distributions.

The response matrix used in this study is composed of 121 rows (pulse height mesh) and 34 columns (neutron energy mesh). The pulse height of the matrix covers the region of 0.01 to 10.0 Na unit, and 40 mesh points are involved in each decade of pulse height. The mesh points are equally spaced in logarithmic scale. The 34 neutron energies considered are listed in Table III. The energy meshes are so chosen that the matrix involves about 2.5 $\sim$ 3.0 meshes in the width of the resolution (full width at half maximum) at the neutron energy of interest. With this criterion, the energies are so selected that one of them will agree with any one of the neutron energies of the unsmeared response functions. So only smearing was made , and interpolation was not made.

The unfolded fission spectrum from ^{252}Cf is plotted in Fig.6. The unfolded spectrum well fits to the Maxwellian function expressed as

$$N(E) = C\sqrt{E}\cdot\exp(-E/T) \quad , \qquad (MeV^{-1})$$

with the maxwellian energy T as 1.36 which is slightly smaller than 1.38 by Sarkar et al.[6]

In Appendix A, B, C and D are presented lists of the input data for sample calcualtion and control cards for the system codes, i.e. CHNTLU, SYSMTRIX, FERDOS and ITEM-II.

References

1) W. R. Burrus and V. V. Verbinski, "Recent Developments in the Proton-Recoil Scintillation Neutron Spectrometer," Proc. Am. Nucl. Soc., Special Session on Fast Neutron Spectroscopy (San Francisco, Dec. 1964) ; Shielding Division Report ANS-SD-2

2) S. Tanaka and N. Sasamoto, to be published in Nucl. Instr. and Meth.

3) H. Tokumaru, private communication

4) V. V. Verbinski et al., "Calibration of an Organic Scintillator for Neutron Spectrometry," Nucl. Instr. and Meth. 65 (1968) 8.

5) W. R. Burrus and V. V. Verbinski, "Fast-Neutron Spectroscopy with Thick Organic Scintillators," Nucl. Instr. and Meth. 67 (1969) 181.

6) P. K. Sarkar et al., "A Proton Recoil Scintillation Technique for Estimating Neutron Energy Spectra," Nuclear Technology Vol. 28 Feb. 1976.

Table I. The relations between the pulse height in Na unit and the Compton peak energy of the specified monoenergetic gamma-rays for both 2" x 2"$^{\phi}$ and 5" x 5"$^{\phi}$ NE213

(2" x 2"$^{\phi}$ NE213)

isotope	gamma-ray energy (MeV)	Compton peak energy (MeV)	pulse height (Na unit)
^{22}Na	0.511	0.296 ± 0.008	0.237
	1.274	0.985 ± 0.013	0.788
^{137}Cs	0.662	0.426 ± 0.009	0.341
^{54}Mn	0.835	0.580 ± 0.010	0.464
^{88}Y	1.836	1.517 ± 0.015	1.214

(5"x 5"$^{\phi}$ NE213)

isotope	gamma-ray energy (MeV)	Compton peak energy (MeV)	pulse height (Na unit)
^{22}Na	0.511	0.306 ± 0.006	0.245
	1.274	1.003 ± 0.008	0.802
^{137}Cs	0.662	0.435 ± 0.007	0.348
^{54}Mn	0.835	0.593 ± 0.007	0.474
^{88}Y	1.836	1.541 ± 0.010	1.233

Table II. The neutron energies to which the response functions are provided by the Monte Carlo calculation

No.	E_n (MeV)	No.	E_n (MeV)	No.	E_n (MeV)	No.	E_n (MeV)
1	0.100	13	1.900	25	7.250	37	10.250
2	0.150	14	2.233	26	7.500	38	10.500
3	0.201	15	2.750	27	7.750	39	11.000
4	0.322	16	3.238	28	8.029	40	11.500
5	0.427	17	3.750	29	8.250	41	11.980
6	0.617	18	4.236	30	8.500	42	12.500
7	0.760	19	4.600	31	8.750	43	13.000
8	0.904	20	4.919	32	9.000	44	13.500
9	1.000	21	5.450	33	9.250	45	14.007
10	1.205	22	6.017	34	9.500	46	14.500
11	1.400	23	6.500	35	9.750	47	15.000
12	1.613	24	7.037	36	10.000		

(in MeV unit)

Table III. The neutron energies adopted in the (34 x 121) size response matrix

No.	E_n (MeV)	No.	E_n (MeV)	No.	E_n (MeV)	No.	E_n (MeV)
1	0.100	10	1.613	19	5.450	28	10.000
2	0.150	11	1.900	20	6.017	29	10.500
3	0.201	12	2.233	21	6.500	30	11.000
4	0.322	13	2.750	22	7.037	31	11.500
5	0.427	14	3.238	23	7.500	32	12.500
6	0.617	15	3.750	24	8.029	33	13.000
7	0.760	16	4.236	25	8.500	34	14.000
8	1.000	17	4.600	26	9.000		
9	1.205	18	4.919	27	9.500		

(in MeV unit)

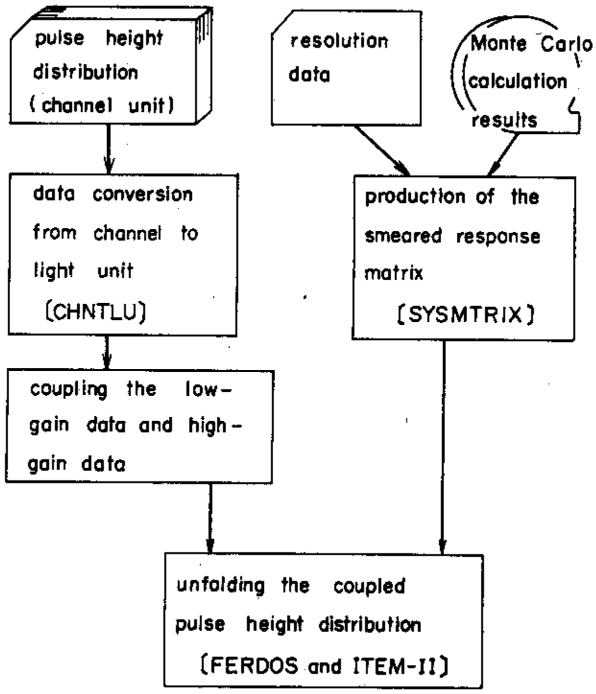

Fig. 1 Unfolding code system for the NE213 neutron spectroscopy

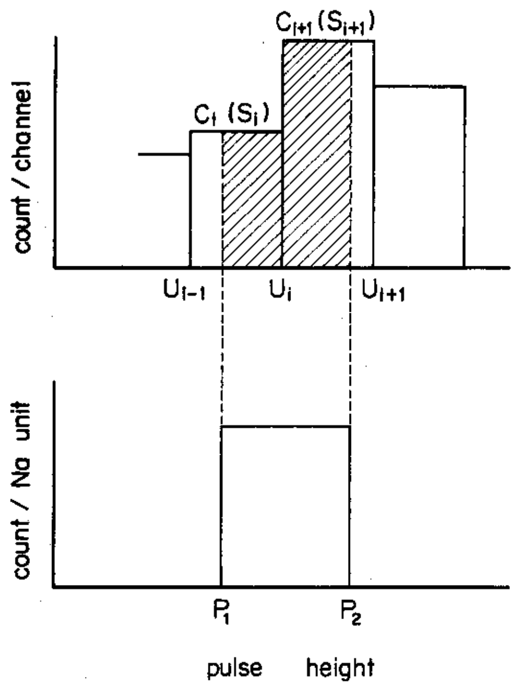

Fig. 2 Illustration of the pulse height data conversion from unit of count per channel to unit of count per Na light unit

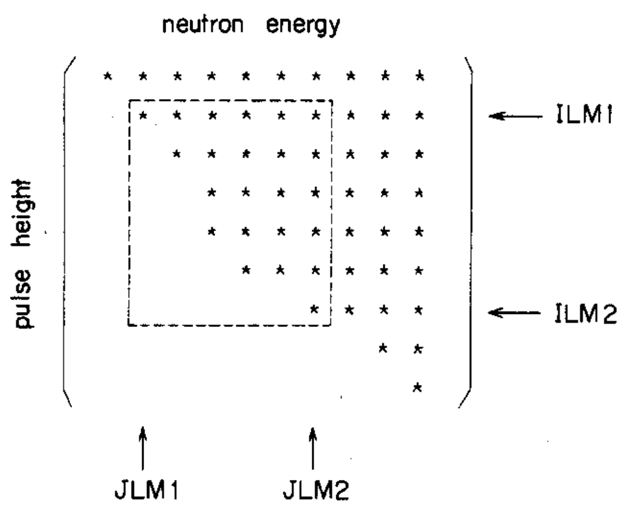

Fig. 3 Definition of the response matrix domain for unfolding the pulse height distribution in the region from ILM1 to ILM2

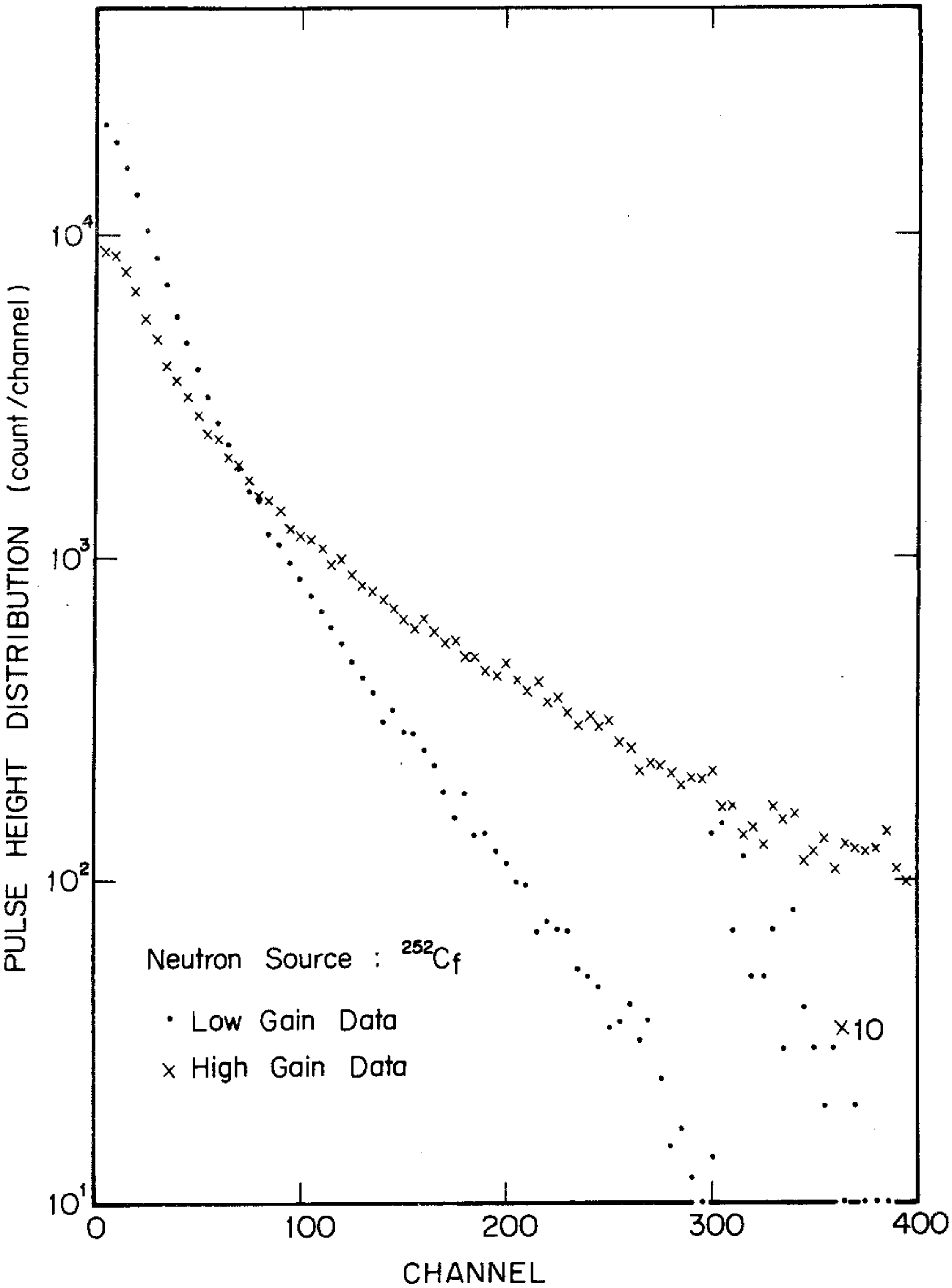

Fig. 4 The measured pulse height distribution in unit of count per channel of the neutrons emitted from ^{252}Cf

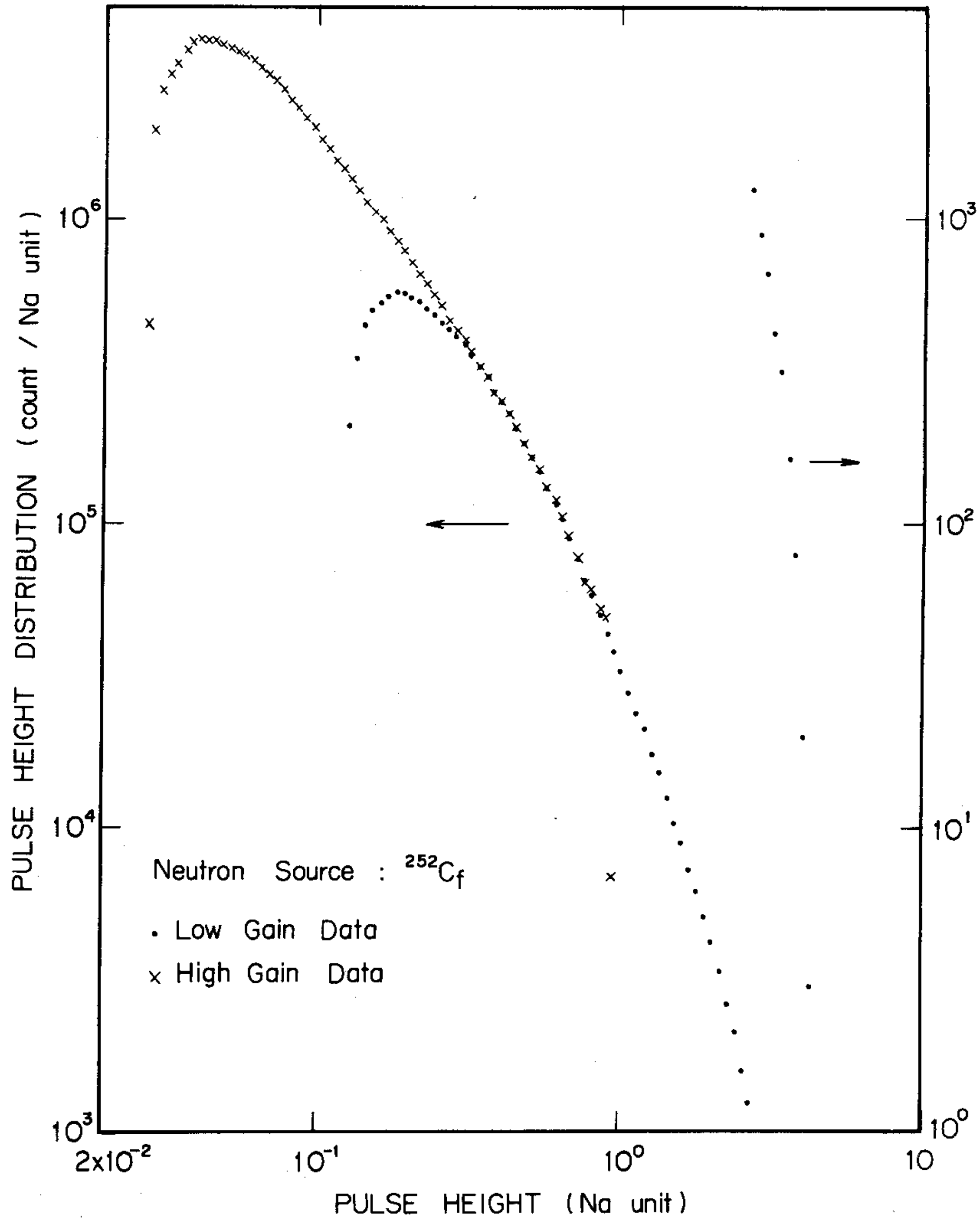

Fig. 5 The converted pulse height distribution in unit of count per Na unit of the neutrons emitted from ^{252}Cf

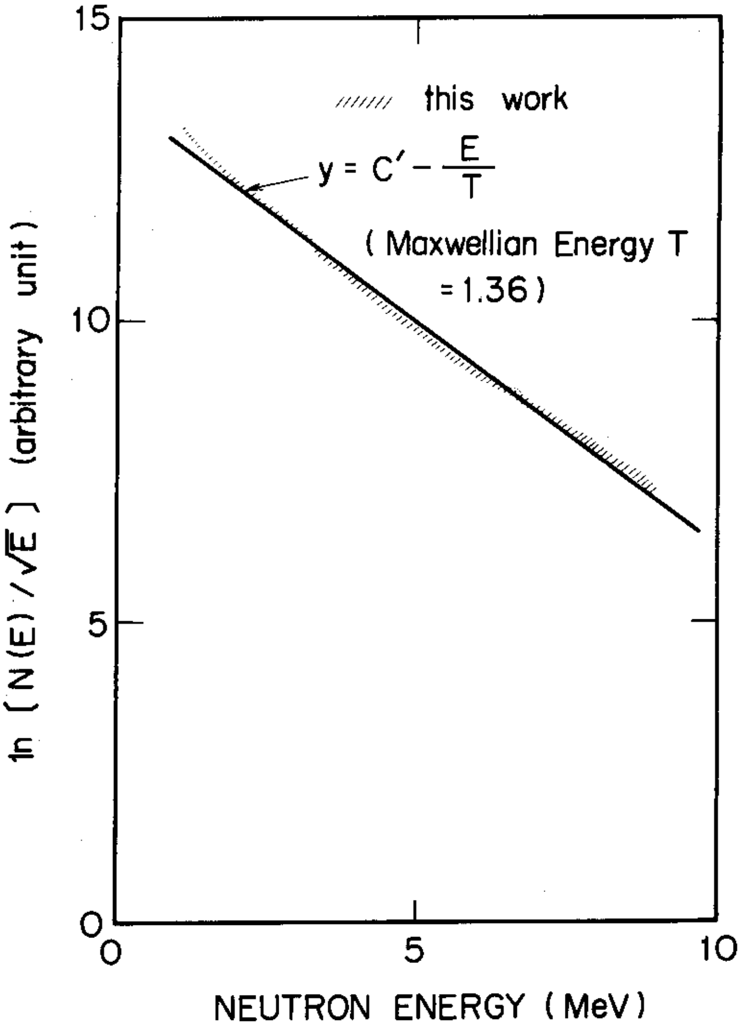

Fig. 6 The unfolded neutron spectrum emitted by the spontaneous fissions of ^{252}Cf

Appendix A

```
....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

*DLIEDRUN   RFNAME=J2370,CHNTLU
*DATA
   40      3  0,01
NO,31 CF252 SOURCE / LOW GAIN / 1976-2-11 /
  399      0      0      0
 1,0695  -02  12.0        0,2777778
 3600,0
   12067    17304    19514    20872    21861    22131    21503    21001    20598    19424
   18763    18050    17379    17136    16179    15391    14884    14252    13688    13155
   12559    12100    11362    10892    10395    10126     9686     9311     8911     8439
    8094     7656     7493     7159     6995     6681     6273     6241     5792     5596
    5397     5127     5017     4635     4624     4557     4337     4203     4000     3806
    3616     3519     3434     3174     3149     2997     2879     2838     2728     2606
    2517     2462     2360     2298     2251     2198     2106     2021     1991     1917
    1791     1743     1766     1754     1596     1590     1533     1552     1492     1505
    1353     1376     1334     1284     1190     1225     1199     1092     1121     1101
    1085      986     1020      975      959      929      871      881      901      864
     862      879      809      755      763      796      728      678      651      688
     605      667      610      619      611      614      616      530      575      547
     504      486      493      514      479      456      435      499      402      428
     413      380      419      384      383      374      363      371      311      312
     365      315      342      352      339      317      275      295      285      291
     277      270      254      269      237      283      250      237      229      204
     223      251      213      222      226      189      211      222      203      187
     189      190      172      196      158      163      176      178      175      187
     164      156      134      132      139      156      159      137      123      140
     131      120      132      111      122      117      122      101      122      113
     115      115       84       97       99       96      102       81       96       96
      94       76       87       97       69       75       91       96       87       74
      74       74       60       63       70       77       78       59       57       69
      49       38       62       59       53       64       63       65       65       50
      59       50       43       50       46       45       45       36       48       35
      41       39       37       41       36       35       34       30       35       41
      36       40       24       31       32       34       31       23       27       37
      26       32       23       27       24       29       21       26       23       15
      27       23       26       26       17       23       22       23       17       12
      16       16       14       14       10       19       22       10       12       14
      14       13       24        7       15       20        8       18       18        7
       8       12       11       11       12       14        9       11        9        5
      11        9        4        6        5        6        4        7       14        7
       9        5        7        7        3        1        5        7        3        8
       2        4        0        2        4        6        8        3        3        3
       3        2        3        2        2        2        1        3        3        3
       0        3        0        0        0        0        1        2        1        2
       1        1        0        0        0        0        2        0        1        0
       2        1        1        0        1        0        0        1        0        0
       0        0        0        0        0        0        0        0        0        0
NO.32 CF252 SOURCE / HIGH GAIN / 1976-2-11 /
  399      0      0      0
 2.3180  -03 12,0        1.0
 1000,0
    4531     6465     7292     8136     8830     9083     8979     8966     8806     8594
    8376     8188     8237     7918     7698     7477     7262     6984     6785     6672
    6338     6249     5887     5708     5523     5425     5115     4966     4798     4743
    4496     4358     4244     4226     4031     3938     3780     3674     3457     3534
    3487     3269     3163     3205     3147     3090     2889     2853     2812     2773
    2698     2591     2479     2494     2404     2420     2378     2347     2348     2333
    2164     2120     2190     2086     2045     2069     1967     1948     1868     1940
    1834     1886     1765     1782     1728     1725     1689     1677     1625     1561
    1531     1592     1511     1476     1512     1519     1457     1410     1331     1407
    1350     1379     1363     1292     1223     1330     1264     1301     1184     1169
    1196     1244     1152     1120     1133     1079     1073     1067     1035     1060
    1054     1067     1005     1002      950      968     1019     1004      959      987
     937      895      859      867      891      850      909      871      869      812
     877      815      857      777      795      744      739      750      768      742
     724      767      735      701      694      725      729      689      677      648
     682      645      655      647      601      599      635      589      617      654
     589      616      604      586      592      607      608      578      544      545
     571      542      578      536      550      520      541      553      499      497
     503      498      497      504      490      494      503      529      459      447
     435      460      453      461      430      426      458      426      402      477
     443      370      409      388      414      381      422      398      374      388
     393      385      374      391      411      359      365      369      393      355
     338      383      354      358      370      351      366      316      350      333
     312      325      348      339      302      310      313      309      315      323
     291      264      294      271      301      307      272      325      266      315
     264      259      261      300      269      279      292      269      272      257
     265      269      282      261      219      244      247      234      241      230
     238      229      246      257      227      233      207      240      231      215
     207      220      224      224      198      215      202      205      218      209
     198      211      211      190      206      182      178      178      192      217
     212      170      176      184      168      157      179      179      174      158
     132      152      186      156      136      140      147      164      154      145
     152      151      144      142      129      150      162      132      145      168
     120      156      167      169      155      145      144      153      140      161
     146      129      133      153      113      123      117      126      121      122
     158      128      146      138      133      115      122      119       95      106
     124      115      123      117      129      112      142      122      133      125
     105      132      105      114      122      101      122      103      128      125
     124      133      127      136      141      116      110       97      106      107
     117      105      111      110       93       89      104      111      111
```

Appendix B

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....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

*DLIEDRUN  RFNAME=J2370.SYSMTRIX
*DISKTO  F01.J2370,MCRESPB4
*DISK    F02
*DISKTN  F03.J2370,MASTER
*DATA
 PRODUCTION OF RESPONSE MATRIX (34*121)
 1,00
    60      4     40     3 0,001        0,01
    34      0      1
  0,100       0,150       0,201       0,322       0,427       0,617
  0,760       1,000       1,205       1,613       1,900       2,233
  2,750       3,238       3,750       4,236       4,600       4,919
  5,450       6,017       6,500       7,037       7,500       8,029
  8,500       9,000       9,500      10,000      10,500      11,000
 11,500      12,500      13,000      14,007
```

Appendix C

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....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

*DLIEDRUN  RFNAME=J2370,FERDOS
*DISKTO  F01.J2370.MASTER
*DATA
    2  CF252 SOURCE UNFOLDING BY ITEM-II
  121     28    105      3     25  1005
      0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0 1015081 2084613
2833662 3134582 3430768 3722297 3921311 3959845 3932558 3885221 3786586 3656623
3598958 3497080 3333060 3180946 3008543 2855242 2675138 2474307 2312104 2128823
1977559 1845013 1701832 1554030 1444220 1362551 1238572 1130221 1053612  993737
 920455  841846  783744  716211  666718  608215  567411  514206  467101  434980
 394488  367561  326303  299990  270334  252670  227565  205299  182621  165676
 145155  129485  116123   99603   86327   74857   64891   57121   48809   42725
  37483   31391   27222   23482   20574   16872   14623   12183   10040    8565
   7126    5825    4891    4031    3185    2436    2034    1544    1113     847
    619     391     261     138      62      19       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       0       0       0       0   25374   35330
  40023   40900   41575   42077   41962   40971   39671   38313   36750   35089
  33824   32396   30730   29168   27562   26089   24536   22928   21535   20077
  18802   17645   16466   15288   14320   13515   12519   11620   10902   10286
   9619    8938    8379    7783    7296    6771    6354    5877    5443    5103
   4722    4429    4054    3777    3484    3272    3017    2785    2552    2361
   2148    1971    1813    1632    1476    1335    1208    1101     989     899
    818     727     658     594     540     475     430     381     336     302
    267     235     209     184     159     136     120     101      84      71
     59      45      36      25      16       9       0       0       0       0
      0       0       0       0       0       0       0       0       0       0
      0
  121     35    105      4     25  1005
```

Appendix D

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....*....1....*....2....*....3....*....4....*....5....*....6....*....7....*....8

*DLIEDRUN  RFNAME=J2370,ITEMII
*DISKTO  F01.J2370.MASTER
*DATA
    2  CF252 SOURCE UNFOLDING BY ITEM-II
  121     28    105      3     25    100    105      1
      0       0       0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0 1015081 2084613
2833662 3134582 3430768 3722297 3921311 3959845 3932558 3885221 3786586 3656623
3598958 3497080 3333060 3180946 3008543 2855242 2675138 2474307 2312104 2128823
1977559 1845013 1701832 1554030 1444220 1362551 1238572 1130221 1053812  993737
 920455  841846  783744  716211  666718  608215  567411  514206  467101  434980
 394488  367561  326303  299990  270334  252670  227565  205299  182621  165676
 145155  129485  116123   99603   86327   74857   64891   57121   48809   42725
  37483   31391   27222   23482   20574   16872   14623   12183   10040    8565
   7126    5825    4891    4031    3185    2486    2034    1544    1113     847
    619     391     261     138      62      19       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       0       0       0       0   25374   35330
  40023   40900   41575   42077   41962   40971   39671   38313   36750   35089
  33824   32396   30730   29168   27562   26089   24536   22928   21535   20077
  18802   17645   16466   15288   14320   13515   12519   11620   10902   10286
   9619    8938    8379    7783    7296    6771    6354    5877    5443    5103
   4722    4429    4054    3777    3484    3272    3017    2785    2552    2361
   2148    1971    1813    1632    1476    1335    1208    1101     989     899
    818     727     658     594     540     475     430     381     336     302
    267     235     209     184     159     136     120     101      84      71
     59      45      36      25      16       9       0       0       0       0
      0       0       0       0       0       0       0       0       0       0
      0
  121     35    105      4     25    100    105      1
```