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DROSG-2000: Neutron Source Reactions

Data files with computer codes for 59 accelerator-based two-body neutron source reactions

prepared by

M. Drogg

Institute for Experimental Physics, University of Vienna

May 2005

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Abstract

This package contains data and three computer codes to calculate:

- -neutron energies, differential cross-sections and differential yields;
- -thick-target yields and white neutron spectra from monoenergetic neutron producing reactions;
- -differential cross sections and energies of (n,p), (n,d), (n,t) and (n,4He) reactions which are time-reversed neutron production reactions (using detailed balance calculations)

The package is available on PC diskette from the IAEA Nuclear Data Section or can be downloaded <http://www-nds.iaea.org>.

This package supersedes the package DROSG-96.

! : v. 2.21: 15-MAY-2005

IAEA-NDS-87
Rev. 9, May 2005

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Summary documentation

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DROSG-2000
Neutron Source Reactions

Data files with the computer codes
for 59 accelerator-based two-body neutron source reactions

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0. UPDATE history

UPDATES:

!: VERSION 2.21: 15-MAY-2005
 changed MASS.TAB from 1995 nuclear masses to 2003 nuclear masses
 removed some mistakes in text files
 only 1 executable for MS operating systems

!: VERSION 2.2: 02-JAN-2003

Database:

rearranged SETYIE.TAB to accomodate two new reactions:
 18O(p,n)18F and 14N(d,n)15O; and five new targets: 202 d-octane target,
 203 LiD target, 702 7LiH target, 902 7LiH target, 313 LiD target.
 extended differential cross section energy range for p-7Li using
 ENDF/B-VI MOD 1 Evaluation, July 1999 by M.B. Chadwick,P.G.Young.
 Code:
 in file NEUYIE: rearranged input in subr. RDSTUP to match new SETYIE.TAB
 in files ANGCAL,ANGINP,ENINPO,LEGINT,NEUYIE,NYIOUT,RECOUT and
 WHIOUT variable HANGSA now in COMMON /masse/
 in file ENINPO: in subr. WHISUM: now output of 1st angle
 in files ANGINP,LEGINT and NEUYIE added BLANK='NULL' in all OPEN
 statements for files that are read
 in file ANGCAL: increased number of digits of ENT in FORMAT 100 (display)
 in file RECOUT: increased number of digits in printout
 in file WHIOUT: in subroutine PLDTIN: changed FORMAT 100

!: VERSION 2.1: 02-JAN-2002

Minor changes in data files D2HAGS.koe, D3HAGS.koe, D9BEGS.koe, P3HAGS.koe,
 P7LIGS.koe and P7LIES.koe; changes of the source code in 6 of the 9 *.f90
 files as indicated:
 ANGINP.F90 Added exit on error for angle input by file option
 CHKANG.F90 changed format of threshold output
 ENINPO.F90 changed wording of 2 messages
 NYIOUT.F90 added output of Q-value
 RECOUT.F90 changed FORMAT # 87
 WHIOUT.F90 added output of exit energy of beam in *.spc

!: VERSION 2.0: 17-NOV-2000

Code was made compatible with LAHEY-FORTRAN for LINUX and for DEC-UNIX

- a) Major changes were necessary to maintain "default" capabilities.
Subroutine NDEFULT has now 5 arguments so that it can handle an input pair.
- b) All commas (used for data separation) in data files (*.KOE, *.tab) were removed. As a consequence a few FORMAT changes were necessary.
- c) To avoid warnings during compilation none of the COMMON blocks (in all the subroutines) is truncated any more and dummy variables were removed.
- d) Two COMMON blocks were changed to avoid misalignment messages.
- e) No capital letters for file names (UNIX!) in the calling routines any more.
- f) A new reaction was added: ${}^9\text{Be}(d,n){}^{10}\text{B}$
- g) A new target type (LiF) was added for the ${}^7\text{Li}(p,n)$ reactions.

!

!: VERSION 1.01: 19-MAR-2000

- a) Clean-up of COMMON blocks: CHARACTER variables put together
- b) Several redundancies removed, e.g. in ANGSET: redundancy concerning 'LOW energy group OPTION= 1:' removed
- c) Several FORMATS changed to allow much smaller values, e.g. in OUTPUT of NYIOUT.F90: FORMAT 185 and 186
- d) in BELTHR check for $\text{XXC}=0.$ before /XXC
- e) introduced minimum energy step number for WHIYIE
- f) new flag LGERR avoids output of negative cross sections
- g) added subroutine SPCAVG for WHIYIE

From DROSG-87 to DROSG-2000:

The original package named DROSG-87 [1] provided energy and differential cross section data of p-T, d-D, d-T, p- ${}^7\text{Li}$ and their inverse counterparts. The first source code was just about three pages of FORTRAN-IV [1].

Soon it was clear that differential neutron yield data were of much interest so that neutron sources could be compared. After this feature had been included (in the code NEUYIE, "neutron yield") it was straightforward to provide thick-target neutron yield information by way of the code WHIYIE ("white yield"). When a need arose to predict the differential yields and energies of (n, charged particle) reactions in ${}^3\text{He}$ counters, it was easy to introduce the necessary detailed balance calculations into NEUYIE to generate the code TIMREV which gives the energy and cross section data of the time reversed reactions covered by NEUYIE.

When heavy ion acceleration became more common, inverse (p,n) and (d,n) reactions had to be considered. In general, inverse reactions have very desirable properties: wider monoenergetic range and, for endothermic reactions, kinematic neutron collimation with enhanced laboratory cross sections.

Therefore, a revised package (DROSG-96) took care of this development:

it included the three codes and provided data bases for 15 (p,n) reactions and 7 (d,n) reactions, so that together with inverse reactions 33 neutron source reactions were covered.

The latest package, DROSG-2000, supersedes DROSG-96 and DROSG-87. It is a major revision.

- 1) All iteration routines were changed. They are based now on physical properties so that convergence is guaranteed under any input condition. Besides any iteration occurs within about 25 steps increasing the speed in some cases considerably.
- 2) All calculations are done now with double precision.

3) Some relevant physical properties (thresholds, double valued range and opening angle of kinematically collimated sources) are made available right after the selection of the desired source reaction, and energy, resp..

4) Some (exotic) monoenergetic (d,n) reactions and (alpha,n) reactions and their inverse reactions were added so that the data base comprises

- 15 (p,n) reactions
- 11 (d,n) reactions and
- 5 (alpha,n) reactions.

Including the inverse reactions a total of 57 neutron producing reactions are presently provided.

1. Introduction

The package contains 3 codes:

- 1) NEUYIE: Accelerator-based mononenergetic neutron production
This program calculates neutron energies, differential cross sections and (for isotopic pure targets) differential neutron yields for monoenergetic neutron sources using internal tables. The Legendre coefficients of the differential cross sections are stored in the files *.KOE, the energy loss tables needed for the neutron yield calculations in the files *.ELS. The neutron yields are given for an energy loss of the projectile that results in a 10 keV neutron energy spread at 0 degree.
- 2) WHIYIE: White neutron yields from two-body reactions
This program calculates angular differential thick-target neutron yields of white neutron sources that are based on the two-body reactions covered under 1). As an option, a white spectrum at a chosen angle ready for plotting is produced.
- 3) TIMREV: Differential cross sections and energies of (n,p), (n,d), (n,t) and (n,alpha) reactions
This program calculates differential cross sections and energies of some (n,p), (n,d), (n,t) and (n,alpha) reactions by detailed balance from the time reversed reactions covered under 1).

As these codes have much in common (a good deal of the source code, data files) they are joined together in this package. The source code is written in FORTRAN which is fully compatible with FORTRAN-95. Executables are provided to run under OPEN-VMS (*.exe for VAXes, *.e90 for ALPHAs) under LINUX (PCs), under DECUNIX and under MS-WINDOWS (*.exe, compiled with a LAHEY F90 compiler, requires at least a 386 processor).

For those who want to adjust the source code to their needs or who are using a different computer platform the COMPILATION and LINKING procedures (under OPEN-VMS: xxxLINK.COM and xxxLI90.COM, under MSDOS for the LAHEY compilers: MAKEF77.BAT and MAKEF90.BAT) should be helpful.

The regular O U T P U T of all three codes is put in File FOR002.DAT.

It will be overwritten for each run.

The neutron source reactions in NEUYIE were either chosen because of their practical importance or because of some distinct personal interest of the author in that source. Adding a further reaction is **straight-forward**: add the corresponding data in the files MASS.TAB and SET*.TAB and add the cross section table (xxx.KOE)

and energy loss table (yyy.ELS).

Interpolation in the cross section tables is done by SPLINE fitting. If the data show narrow structures a sufficient number of points are needed to give reasonable interpolated data. The interpolation is checked internally for necessary conditions and an error message (see Appendix) is given when this check fails. For the generation of excitation functions the use of the tabulated energies is preferred. Therefore, such a provision is included into NEUYIE (see there).

2. Accuracies

2.1 Kinematics:

The kinematic properties are calculated with the 2003 [2] (nuclear) masses using relativistic expressions. In most cases (not near thresholds) the mass uncertainty can be disregarded. It is assumed that the interacting nuclei are completely stripped which need not be true under special circumstances. The mass data (given in MeV) are stored in MASS.TAB.

All energies are in MeV unless given otherwise, all angles are in degrees.

2.2 Cross sections:

The accuracy of the differential cross sections stored in the 34 *.KOE data files must be dealt with individually. Observe the comments in the comment section at the end of each file. Only p-T, d-D and d-T differential cross sections are based on measurements of this author. The error discussion for these reactions and for p-7Li given in [1] is still valid, even if the recommended cross section values have changed. The evaluated integrated data of d-D above 2.34 MeV and of d-T above 6 MeV which were taken over by the LLNL group in their 1991 evaluation [3](without giving credit!), might be more accurate than given in [1]. For unknown reasons this group assigned errors to these data which are about a factor of two smaller than obtained from the original work.

Some more information on the accuracy of the cross sections can be found in the literature given in the Appendix.

Three classes of cross section data are used in the code:

a) Complete angular distributions of differential cross sections in some energy range for:

3H(p,n)3He, 7Li(p,n)7Be, 7Li(p,n)7Be*, 9Be(p,n)9B,
11B(p,n)11C, 13C(p,n)13N, 15N(p,n)15O,
2H(d,n)3He, 3H(d,n)4He, 3H(4He,n)6Li

b) Differential cross sections at 0 deg AND/OR 180 deg.

In several cases just isotropic approximation from integrated cross sections:

6Li(p,n)6Be, 10Be(p,n)10B, 10B(p,n)10C, 14C(p,n)14N,
36Cl(p,n)36Ar, 39Ar(p,n)39K, 59Co(p,n)59Ni, 7Li(d,n)8Be, 9Be(d,n)10B,
11B(d,n)12C, 13C(d,n)14N, 15N(d,n)16O, 18O(d,n)19F,
7Li(4He,n)10B, 11B(4He,n)14N, 13C(4He,n)16O, 22Ne(4He,n)25Mg

c) Dummy data:

12C(p,n)12N, 20Ne(d,n)21Na, 24Mg(d,n)25Al, 28Si(d,n)29P,
32S(d,n)33Cl

In several cases (n,p), (n,d) and (n,4He) data were taken from

the neutron data files (e.g. ENDF) and converted to (p,n), (d,n) and (4He,n) data. The use of such integrated data is indicated in the menu by the REMARK "isotropic approximation". Special care must be taken in cases in which the cross section includes those of reactions to excited states. If only such data are available this is indicated by the omission of "0" [(x,n) instead of (x,n0)]. Mixed data files, i.e. data files that contain data of more than one class, can be recognized in the menu by the slash (/) in the "X-section range". For class a) data ONLY, there will be a warning when there are no complete angular distributions: "ENERGY OUT OF RANGE OF LEGENDRE TABLE, check validity"

WARNING:

Be aware that the answer you get may be seriously off, because it is only as good as the input cross sections are. If you must rely on the answer for a specific reaction, check first the data file and improve it if necessary. Changing the data base in any *.KOE file is straightforward.

All cross sections are in millibarns or millibarns/steradian resp..

2.3 Yields:

Yields are calculated assuming such a target thickness that at 0 deg the neutron energy spread is 10 keV (the corresponding target thickness is given by the energy loss of the projectiles in output file FOR002.DAT). The electronic stopping power needed for this calculation is stored in the *.ELS data files. These are usually based on data of ZIEGLER [4] unless shown otherwise at the end of each file. For energies which are moderately higher than the low energy maximum of the stopping power the solutions of different authors differ by typically 5 to 10%. Using the values of Ziegler [4] appeared to be the best in several cases. Therefore, these data were finally chosen for this code. However, anybody can easily change any *.ELS file to use his/her own favorite energy loss data.

The data in these files are in units of MeV/(g/sqcm) vs. MeV.

In the DOUBLE-VALUED region (of endothermic reactions) the predicted angular differential thick-target neutron yield (vanishing solid angle) cannot always be taken to be a good approximation of the measured thick-target yield, because of the possibility of a (very) strong nonlinear angular dependence which requires an integration over the opening angle of the detector.

In NEUYIE the differential neutron yield is given in units of: neutrons/(sr*pC) for a 10 keV neutron energy spread at 0 degree.

In WHIYIE the units in the *.SPC files are: neutrons/MeV/sr/microCoulomb vs. MeV.

2.4 Time reversed data:

The spins needed for the detailed balance calculations are stored in MASS.TAB.

The degeneracy factor of the d-D reaction [5] is put into SETREC.TAB.

Time reversal is done relativistically. The conversion of data at very low energies to those near threshold and vice versa is

strongly dependent on the accurate knowledge of the nuclear masses (and the energies) and consequently less accurate.

3. Description of codes

3.1 NEUYIE (Mononenergetic neutron production)

This program calculates neutron energies and differential cross sections for monoenergetic neutron sources from internal tables of the Legendre coefficients.

For isotopic pure targets (and others) it also can calculate the neutron yield using energy loss tables. The neutron yields are for an energy loss of the projectile that results in a 10 keV neutron energy spread at 0 degree.

The main menu is shown below together with a sample input. The interactive program is self-explaining, the main menu more or less, too, except for 'En0 RANGE' which means the monoenergetic neutron energy range at 0 degree available by that reaction, and the slash (/) in the X-SECTION RANGE column which indicates mixed classes of cross sections in the *.KOE table (see 2.2). If there is no truly monoenergetic range like in some exothermic reactions the numbers of neutron lines at 0 MeV incoming energy is indicated by '>=n lv', meaning that n levels are exited at zero incoming energy.

If "-2" is chosen as "number of energy steps" (see below) the actual energies from the Legendre tables are selected to avoid interpolation errors (which is essential when generating plot files of excitation functions in cases with a strong structure in the cross sections).

3.1.1 Main menu and sample terminal responses:

MONOENERGETIC NEUTRON PRODUCTION (isotopically pure targets)

ID	REACTION TYPE	REMARKS	En0 RANGE	X-SECTION RANGE [MeV]
Traditional Sources				
1	3H(p,n)3He	gas target	0.064-7.585	1.0191-32.80/318.
	101 T2O target			
2	2H(d,n)3He	gas target	2.449-7.706	0.02 - 39.80/85.
	201 D2O target	/ 202 d-octane target / 203 LiD target		
3	1H(t,n)3He	gas target	0.574-17.64	3.051 - 98.19
	301 water target / 302 octane target			
4	3H(d,n)4He	gas target	14.03-20.46	0.01 - 40.00/400.
	401 T2O target			
5	2H(t,n)4He	gas target	14.03-23.01	0.015- 59.9/599.
	501 D2O target			
7	7Li(p,n0)7Be		0.030-0.650	1.8807-23.00/494.
	701 7LiF target / 702 7LiH target			
8	1H(7Li,n0)7Be		1.441-3.842	13.097- 160.165
9	7Li(p,n1)7Be*	(0.429 MeV level)	0.038-1.557	2.40 - 150.
	901 7LiF target / 902 7LiH target			
10	1H(7Li,n1)7Be*	(0.429 MeV level)	1.816-7.231	16.713-1044.56
LESS COMMON (p,n)-SOURCES				
11	6Li(p,n0)6Be	isotropic approx.	0.122-1.172	6.00 - 7.874/200.
12	9Be(p,n0)9B		-	2.20 - 30.0
13	10Be(p,n0)10B	isotropic approx.	0.002-0.310	0.251 - 1.040/20.247
14	1H(10Be,n0)10B	isotropic approx.	.2068-3.012	2.495 - 10.337/201.2

15	10B(p,n)10C	isotropic approx.	0.041-4.055	4.94 - 8.571/17.1
16	11B(p,n)11C		0.021-2.388	3.020/3.5 - 5.49/26.
17	1H(11B,n)11C		2.538-11.88	33.-59.989/284.1
18	12C(p,n)12N	zero degree only	0.119-1.200	25.8
19	13C(p,n)13N		0.017-2.278	3.239 - 12.86/30.6
20	1H(13C,n)13N		2.792-12.18	41.803/112.28-165.97
21	14C(p,n)14N	isotropic approx.	0.003-2.522	0.6714 - 3.151/20.67
22	1H(14C,n)14N	isotropic approx.	0.586-9.782	9.332 - 43.795/287.2
23	15N(p,n)15O		0.015-5.742	3.94 - 15.62
24	1H(15N,n)15O		3.319-25.73	58.659 -232.549
59	18O(p,n)18F	isotropic approx.	0.008-1.199	2.58 - 20.
25	36Cl(p,n)36Ar	isotropic approx.	.0001-2.028	0.878 - 2.103
26	1H(36Cl,n)36Ar	isotropic approx.	0.074-7.826	31.35 - 75.08
27	39Ar(p,n)39K	isotropic approx.	.0002-2.593	1.225 - 1.300/20.224
28	1H(39Ar,n)39K	isotropic approx.	0.214-10.28	47.367 - 50.28/782.1
29	59Co(p,n)59Ni	isotropic approx.	.0006-0.363	1.8897 - 2.240/11.89
30	1H(59Co,n)59Ni	isotropic approx.	1.830-4.198	110.534 - 131./695.5

LESS COMMON (d,n)-SOURCES

31	7Li(d,n)8Be	isotropic approx.	>=3 lv	0.01 - 10.957
	313 LiD target			
32	2H(7Li,n)8Be	isotropic approx.	>=3 lv	0.035 - 38.5
33	9Be(d,n)10B	isotropic approx.	>=5 lv	0.05 - 0.121/16.89
34	11B(d,n)12C	isotropic approx.	>=10 lv	0.411 - 2.513/5.564
35	2H(11B,n)12C	isotropic approx.	>=10 lv	2.247 - 13.82/30.6
36	13C(d,n)14N	isotropic approx.	>=5 lv	0.312 - 3.568
37	2H(13C,n)14N	isotropic approx.	>=5 lv	2.028 - 23.04
60	14N(d,n)15O	isotropic approx.	4.765-4.997	1. - 15.
38	15N(d,n)16O	isotropic approx.	>=8 lv	2.13E-4 - 5.979/10.1
39	2H(15N,n)16O	isotropic approx.	>=8 lv	0.0016 - 44.53/75.2
40	18O(d,n)19F	isotropic approx.	>10 lv	0.975 - 2.204/14.696
41	20Ne(d,n)21Na	dummy data	0.197-0.344	1.E-5 - 0.140
42	2H(20Ne,n)21Na	dummy data	0.197-0.644	1.E-4 - 1.390
43	24Mg(d,n)25Al	dummy data	0.044-0.483	1.E-5 - 0.650
44	2H(24Mg,n)25Al	dummy data	0.044-1.192	1.2E-4 - 7.740
45	28Si(d,n)29P	dummy data	0.505-1.445	1.E-5 - 1.000
46	2H(28Si,n)29P	dummy data	0.505-3.208	1.4E-4 - 13.891
47	32S(d,n)33Cl	dummy data	0.049-0.855	1.E-5 - 0.900
48	2H(32S,n)33Cl	dummy data	0.049-2.207	1.6E-4 - 14.286

(alpha,n)-SOURCES

49	3H(4He,n)6Li		0.913-4.916	11.134-13.128/51.0
50	4He(3H,n)6Li		0.519-3.794	8.3906-9.893/38.4
51	7Li(4He,n)10B	isotropic approx.	0.146-1.528	4.3821-5.5106
52	4He(7Li,n)10B	isotropic approx.	0.449-2.429	7.6815-9.6596
53	11B(4He,n)14N	isotropic approx.	0.148-2.885	0.167-2.9396
54	4He(11B,n)14N	isotropic approx.	0.148-4.412	0.460-8.086
55	13C(4He,n)16O	isotropic approx.	2.084-7.024	0.0559-5.025
56	4He(13C,n)16O	isotropic approx.	2.084-10.54	0.1816-16.325
57	22Ne(4He,n)25Mg	isotropic approx.	0.004-0.700	0.5671 - 3.0
58	4He(22Ne,n)25Mg	isotropic approx.	0.103-1.504	3.1159 - 16.483

Enter ID, negative for YIELD calculation - blank continues table:

-4

Uses 2003 mass table

NEUTRONS from the REACTION 3H(d,n)4He

PROJECTILE energy or NEGATIVE 0-deg NEUTRON energy in MeV or <enter> for END:

1.

Energy steps OPTION: + or - step size, nr. of steps;

OR using tabulated energy values: MAXIMUM energy, -2;
 40.,2
 NUMBER of ANGLES, NEGATIVE if C.M., blank for FILE:
 -3
 INPUT of ANGLE values: LINE-BY-LINE or "<enter>" for other OPTIONS
 <enter>
 Constant SPACING options: COSINE= 2, DEF.= degrees:
 <enter>
 Enter MIN. and MAX. angle of RANGE, DEFAULT= full range:
 10.,20.
 Const. spacing OPTION: RANGE from 10.00 to 20.00 is divided into 2
 portions
 ! Energy out of range of LEGENDRE table, check validity
 PROJECTILE energy or NEGATIVE 0-deg NEUTRON energy in MeV or <enter> for END:
 <enter>
 Stopped because of BLANK energy INPUT
 COMMENT: cross section and yield data depend on data base in file: d3hags.koe
 FORTRAN STOP

3.1.2 Output (FOR002.DAT):

NEUTRONS FROM THE REACTION 3H(d,n)4He

INCIDENT LAB ENERGY 0.999999 INT. CROSS SECT.= 2.316E+02 mb
 INTEGRAL YIELD with a 10 keV SPREAD at 0 Deg= 4.337E+00 n/pC
 Total energy= 4685.1332 MeV, Momentum of projectile= 36.7250, Q= 17.5892470

LABORATORY SYSTEM			CENTER-OF-MASS 5.962E+00 keV target		
thickness	ANGLE	CROSS ENERGY	ANGLE	CROSS	neutrons/(sr*pC) for a
10		SECTION		SECTION	keV neutron energy
spread	DEGREE	mb/sr MeV	DEGREE	mb/sr	at 0 D due to energy
loss					
	9.30	21.971 16.72144	10.00	19.036	4.114E-01
	13.96	21.908 16.68052	15.00	19.027	4.102E-01
	18.62	21.826 16.62368	20.00	19.019	4.087E-01

NEUTRONS FROM THE REACTION 3H(d,n)4He

INCIDENT LAB ENERGY 41.000002 INT. CROSS SECT.= 1.441E+01 mb
 ! Energy out of range of LEGENDRE table, check validity
 INTEGRAL YIELD with a 10 keV SPREAD at 0 Deg= 9.985E+00 n/pC
 Total energy= 4709.0537 MeV, Momentum of projectile= 235.2041, Q= 17.5892470

LABORATORY SYSTEM			CENTER-OF-MASS 1.033E+01 keV target		
thickness	ANGLE	CROSS ENERGY	ANGLE	CROSS	neutrons/(sr*pC) for a
10		SECTION		SECTION	keV neutron energy
spread	DEGREE	mb/sr MeV	DEGREE	mb/sr	at 0 D due to energy
loss					
	7.55	23.363 57.80428	10.00	13.367	1.619E+01

11.34	22.397	57.40395	15.00	12.893	1.552E+01
15.13	21.091	56.84776	20.00	12.245	1.461E+01

3.2 WHIYIE (White neutron yields from two-body reactions)

This program calculates angular differential thick-target yields of white neutron sources that are based on the two-body reactions covered in 3.1.1. (See above warning with regard to yields in the double-valued region!)

As an option, a white spectrum ready for plotting is produced. The main menu is shown below together with a sample input. The interactive program is self-explaining, the main menu more or less, too, except, like in NEUYIE, for En0max which means the maximum clean monoenergetic neutron energy available by that reaction, and the slash (/) in the X-SECTION RANGE column indicating mixed classes of cross sections in the *.KOE table (see 2.2).

The main difference to NEUYIE is as follows:

INPUT:

- a) energy steps are NEGATIVE only
- b) energy steps are NEUTRON energy at 0 deg, even if the starting energy is projectile energy!
- c) angles are lab only

OUTPUTS:

a) FOR002.DAT:

- no c.m. data
- Additional summary data (in parallel to display) as follows:
ENERGY integr. Yield at 0 deg = xxxx n per sr.picoCoul.
abs. TOTAL neutron output = yyyy neutrons per picoCoul.

b) FOR001.DAT: This output can be used to generate one's own white neutron spectrum.

- 7 data per line for each energy step (and angle): angle, neutron energy, yield per 10 keV at 0 deg, beam energy, 0-deg neutron energy step size, integrated yield/MeV, integrated cross section

c) aaaann.SPC:

- neutron energy - double differential yield pairs, intended for plotting (intrinsic white neutron spectrum).

WARNING: This output file will be overwritten in a following run if the complete filename is equal.

3.2.1 Main Menu and sample terminal responses:

WHITE NEUTRON PRODUCTION (isotopically pure targets)

ID	REACTION TYPE	REMARKS	En0 RANGE	X-SECTION RANGE [MeV]
		Traditional Sources		
1	3H(p,n)3He	gas target	0.064-7.585	1.0191-32.80/318.
	101 T2O target			
2	2H(d,n)3He	gas target	2.449-7.706	0.02 - 39.80/85.
	201 D2O target	/ 202 d-octane target / 203 LiD target		
3	1H(t,n)3He	gas target	0.574-17.64	3.051 - 98.19

301	water target	/	302	octane target		
4	3H(d,n)4He	gas target			14.03-20.46	0.01 - 40.00/400.
401	T2O target					
5	2H(t,n)4He	gas target			14.03-23.01	0.015- 59.9/599.
501	D2O target					
7	7Li(p,n0)7Be				0.030-0.650	1.8807-23.00/494.
701	7LiF target	/	702	7LiH target		
8	1H(7Li,n0)7Be				1.441-3.842	13.097- 160.165
9	7Li(p,n1)7Be*	(0.429 MeV level)			0.038-1.557	2.40 - 150.
901	7LiF target	/	902	7LiH target		
10	1H(7Li,n1)7Be*	(0.429 MeV level)			1.816-7.231	16.713-1044.56
LESS COMMON (p,n)-SOURCES						
11	6Li(p,n0)6Be	isotropic approx.			0.122-1.172	6.00 - 7.874/200.
12	9Be(p,n0)9B				-	2.20 - 30.0
13	10Be(p,n0)10B	isotropic approx.			0.002-0.310	0.251 - 1.040/20.247
14	1H(10Be,n0)10B	isotropic approx.			.2068-3.012	2.495 - 10.337/201.2
15	10B(p,n0)10C	isotropic approx.			0.041-4.055	4.94 - 8.571/17.1
16	11B(p,n0)11C				0.021-2.388	3.020/3.5 - 5.49/26.
17	1H(11B,n0)11C				2.538-11.88	33.-59.989/284.1
18	12C(p,n)12N	zero degree only			0.119-1.200	25.8
19	13C(p,n0)13N				0.017-2.278	3.239 - 12.86/30.6
20	1H(13C,n0)13N				2.792-12.18	41.803/112.28-165.97
21	14C(p,n0)14N	isotropic approx.			0.003-2.522	0.6714 - 3.151/20.67
22	1H(14C,n0)14N	isotropic approx.			0.586-9.782	9.332 - 43.795/287.2
23	15N(p,n0)15O				0.015-5.742	3.94 - 15.62
24	1H(15N,n0)15O				3.319-25.73	58.659 -232.549
59	18O(p,n)18F	isotropic approx.			0.008-1.199	2.58 - 20.
25	36Cl(p,n)36Ar	isotropic approx.			.0001-2.028	0.878 - 2.103
26	1H(36Cl,n)36Ar	isotropic approx.			0.074-7.826	31.35 - 75.08
27	39Ar(p,n0)39K	isotropic approx.			.0002-2.593	1.225 - 1.300/20.224
28	1H(39Ar,n0)39K	isotropic approx.			0.214-10.28	47.367 - 50.28/782.1
29	59Co(p,n)59Ni	isotropic approx.			.0006-0.363	1.8897 - 2.240/11.89
30	1H(59Co,n)59Ni	isotropic approx.			1.830-4.198	110.534 - 131./695.5
LESS COMMON (d,n)-SOURCES						
31	7Li(d,n)8Be	isotropic approx.	>=3 lv			0.01 - 10.957
313	LiD target					
32	2H(7Li,n)8Be	isotropic approx.	>=3 lv			0.035 - 38.5
33	9Be(d,n0)10B	isotropic approx.	>=5 lv			0.05 - 0.121/16.89
34	11B(d,n)12C	isotropic approx.	>=10 lv			0.411 - 2.513/5.564
35	2H(11B,n)12C	isotropic approx.	>=10 lv			2.247 - 13.82/30.6
36	13C(d,n)14N	isotropic approx.	>=5 lv			0.312 - 3.568
37	2H(13C,n)14N	isotropic approx.	>=5 lv			2.028 - 23.04
60	14N(d,n)15O	isotropic approx.	4.765-4.997			1. - 15.
38	15N(d,n)16O	isotropic approx.	>=8 lv			2.13E-4 - 5.979/10.1
39	2H(15N,n)16O	isotropic approx.	>=8 lv			0.0016 - 44.53/75.2
40	18O(d,n)19F	isotropic approx.	>10 lv			0.975 - 2.204/14.696
41	20Ne(d,n)21Na	dummy data			0.197-0.344	1.E-5 - 0.140
42	2H(20Ne,n)21Na	dummy data			0.197-0.644	1.E-4 - 1.390
43	24Mg(d,n)25Al	dummy data			0.044-0.483	1.E-5 - 0.650
44	2H(24Mg,n)25Al	dummy data			0.044-1.192	1.2E-4 - 7.740
45	28Si(d,n)29P	dummy data			0.505-1.445	1.E-5 - 1.000
46	2H(28Si,n)29P	dummy data			0.505-3.208	1.4E-4 - 13.891
47	32S(d,n)33Cl	dummy data			0.049-0.855	1.E-5 - 0.900
48	2H(32S,n)33Cl	dummy data			0.049-2.207	1.6E-4 - 14.286

(alpha,n)-SOURCES

49	3H(4He,n)6Li		0.913-4.916	11.134-13.128/51.0
50	4He(3H,n)6Li		0.519-3.794	8.3906-9.893/38.4
51	7Li(4He,n)10B	isotropic approx.	0.146-1.528	4.3821-5.5106
52	4He(7Li,n)10B	isotropic approx.	0.449-2.429	7.6815-9.6596
53	11B(4He,n)14N	isotropic approx.	0.148-2.885	0.167-2.9396
54	4He(11B,n)14N	isotropic approx.	0.148-4.412	0.460-8.086
55	13C(4He,n)16O	isotropic approx.	2.084-7.024	0.0559-5.025
56	4He(13C,n)16O	isotropic approx.	2.084-10.54	0.1816-16.325
57	22Ne(4He,n)25Mg	isotropic approx.	0.004-0.700	0.5671 - 3.0
58	4He(22Ne,n)25Mg	isotropic approx.	0.103-1.504	3.1159 - 16.483

Enter ID - blank continues the table:

7

Uses 2003 mass table

NEUTRONS from the REACTION 7Li(p,n0)7Be

Between 1.880769 and 1.920461 MeV LAB cross sections are double valued
If starting energy is in the double valued range, the LOW-energy branch
is automatically included.

BEAM energy or NEGATIVE maximum 0-deg NEUTRON energy in MeV or <enter> for
END:

-3.

Neutron energy SPACING at 0 deg, Nr. of energy STEPS:

0.1,4

NUMBER of ANGLES (lab.); if 1, a yield vs. energy file *.SPC is generated

1

INPUT of ONE angle:

15.

abs. TOTAL neutron output= 6.645E+02 neutrons per pC

BEAM energy or NEGATIVE maximum 0-deg NEUTRON energy in MeV or <enter> for
END:

<enter>

Stopped because of BLANK energy INPUT

Opens INPUT file: for001.dat

Number of projectiles lost by two-body nuclear reactions per pC 664.52

Opens OUTPUT file: p7li04.spc

: p7li 4.670880 MeV 15.00 deg, beam exits w/ 4.373260 MeV

AVERAGE neutron energy at 15.0 deg 2.824 MeV, using 3. scans

COMMENT: cross section and yield data depend on data base in file: p7ligs.koe

3.2.2 Sample outputs:

a) FOR002.DAT:

INCIDENT LAB ENERGY	4.670881	INT. CROSS SECT.=	3.211E+02 mb
LABORATORY SYSTEM		9.928E+00 keV target thickness	
ANGLE	CROSS	ENERGY	neutrons/(sr*pC) for a 10
	SECTION		keV neutron energy spread
DEGREE	mb/sr	MeV	at 0 D due to energy loss
15.000	5.456E+01	2.9621E+00	4.121E+00

INCIDENT LAB ENERGY	4.571630	INT. CROSS SECT.=	3.071E+02 mb
LABORATORY SYSTEM		9.923E+00 keV target thickness	
ANGLE	CROSS	ENERGY	neutrons/(sr*pC) for a 10
	SECTION		keV neutron energy spread
DEGREE	mb/sr	MeV	at 0 D due to energy loss
15.000	5.048E+01	2.8631E+00	3.746E+00

INCIDENT LAB ENERGY	4.472423	INT. CROSS SECT.=	2.945E+02 mb
LABORATORY SYSTEM		9.918E+00 keV target thickness	
ANGLE	CROSS	ENERGY	neutrons/(sr*pC) for a 10


```

SECTION
DEGREE      mb/sr      MeV
15.000 4.717E+01 2.7641E+00
INCIDENT LAB ENERGY 4.373264 INT. CROSS SECT.= 2.815E+02 mb
LABORATORY SYSTEM 9.914E+00 keV target thickness
ANGLE      CROSS      ENERGY      neutrons/(sr*pC) for a 10
SECTION      keV neutron energy spread
DEGREE      mb/sr      MeV      at 0 D due to energy loss
15.000 4.427E+01 2.6651E+00      3.167E+00
abs. TOTAL neutron output= 6.645E+02 neutrons per pC

```

b) FOR001.DAT:

```

0.0000E+00 2.962128E+00 0.00000E+00 4.67088E+00 0.00E+00 0.00000E+00
0.00000E+00
1.5000E+01 2.962128E+00 4.12134E+00 4.67088E+00 1.00E-01 2.42554E+02
3.21119E+02
1.5000E+01 2.863123E+00 3.74616E+00 4.57163E+00 1.00E-01 2.27926E+02
3.07136E+02
1.5000E+01 2.764119E+00 3.43759E+00 4.47242E+00 1.00E-01 2.14614E+02
2.94481E+02
1.5000E+01 2.665116E+00 3.16743E+00 4.37326E+00 1.00E-01 2.01400E+02
2.81484E+02

```

c) P7LI04.SPC:

```

@@@
2.6651E+00,3.1991E+08
2.7641E+00,3.4719E+08
2.8631E+00,3.7837E+08
2.9621E+00,4.1627E+08

```

```

!: p7li 4.670810 MeV 15.00 deg, beam exits w/ 4.373260 MeV
!: Units are: neutrons/MeV/sr/microCoulomb vs. MeV
!: High energy group: av. energy= 2.821576, av. dbl. diff. yield= 3.645E+08
!: Average energy of all neutrons= 2.821576, angular diff. yield= 1.083E+08

```

3.3 TIMREV (Differential cross sections and energies of (n,p), (n,d), (n,t) and (n,4He) reactions)

These are calculated by detailed balance from the time reversed reactions.

The main menu is shown below together with a sample input. The interactive program is self-explaining, the main menu more or less, too, except for the slash (/) in the X-SECTION RANGE column, which indicates mixed classes of cross sections in the *.KOE table (see 2.2).

The output FOR002.DAT contains kinematic information on both the ingoing and the outgoing particles and on the differential LABORATORY cross section of both outgoing particles together with the solid angle factors needed for a conversion into c.m..

3.3.1 Main Menu and sample terminal responses:

```

Cross sections of (n,p), (n,d), (n,t) and (n,alpha) REACTIONS
ID REACTION TYPE      REMARKS      X-SECTION RANGE [MeV]
1   3He(n,p)3H          0.001 - 31.786
2   3He(n,d)2H          REACTION CROSS SECTIONS! 4.38 - 30.945
3   3He(n,t)1H          0.001 - 31.786
4   4He(n,d)3H          22.08 - 52.2

```

5	4He(n,t)2H		22.08 - 52.2
7	7Be(n,p)7Li		1.07e-5 -21.118
13	10B(n,p0)10Be	isotropic approximation	0.001 - 20.
15	10C(n,p)10B	isotropic approximation	.0626 - 3.692/12.22
16	11C(n,p)11B		0.678 - 2.471
19	13N(n,p)13C		5.462 - 9.622
21	14N(n,p0)14C	isotropic approximation	1.44e-6 - 20.
23	15O(n,p0)15N		0.165 - 1.85/11.843
25	36Ar(n,p0)36Cl	isotropic approximation	0.7 - 0.733/20.
27	39K(n,p0)39Ar	isotropic approximation	1. - 1.075/20.
29	59Ni(n,p)59Co	isotropic approximation	3.71e-5 - 20.
33	10B(n,d)9Be	isotropic approximation	4.846 - 4.910/20.
34	12C(n,d0)11B	isotropic approximation	15.272 - 17.201/20.
36	14N(n,d0)13C	isotropic approximation	6. - 20.
38	16O(n,d0)15N	isotropic approximation	10.53 - 16.137/20.
40	19F(n,d0)18O	isotropic approximation	7. - 8.165/20.
49	6Li(n,t)4He		0.0001- 1.000/20.
51	10B(n,4He0)7Li	isotropic approximation	0.0001 - 0.79
53	14N(n,4He0)11B	isotropic approximation	0.30 - 2.48
55	16O(n,4He0)13C	isotropic approximation	2.40 - 6.44
57	25Mg(n,4He)22Ne	isotropic approximation	3.e-5 - 2.141

Enter ID:

1

Uses 2003 mass table

REACTION 3He(n,p)3H

Incoming NEUTRON energy in MeV or <enter> for END:

30.

NUMBER of ANGLES, NEGATIVE if C.M., blank for FILE:

3

INPUT of ANGLE values: LINE-BY-LINE or "<enter>" for other OPTIONS

0.

90.

180.

The CROSS SECTIONS were calculated by using 31.0133866 MeV proj. energy

Incoming NEUTRON energy in MeV or <enter> for END:

<enter>

Stopped because of BLANK energy INPUT

COMMENT: cross section and yield data depend on data base in file: p3hags.koe

FORTRAN STOP

3.3.2 Sample output (FOR002.DAT):

REACTION 3He(n,p)3H

REST MASSES: INCIDENT 939.5653261 CALCULATED Q= 0.7638032

TARGET 2808.3913232

C 938.2719963

D 2808.9208498

INCIDENT LAB ENERGY 30.0000000 INCIDENT LAB MOMENTUM 239.3197

PROJ. ENERGY FOR RECIPR. REACTION: 31.0133866 INTEGR. CROSS SECTION:

50.570351

Center of Mass Parameters:

TOTAL ENERGY 3770.3690 BETA(C.M.)0.0633 GAMMA(C.M.) 1.0020 S= 1.421568E+07

PART A:TOT EN 956.3260 MOM 178.2593

PART B:TOT EN 2814.0430 MOM 178.2593

PART C:TOT EN 955.6094 MOM 181.2045 BETA 0.1896 GAM 1.0185 MQ 0.193

PART D:TOT EN 2814.7596 MOM 181.2045 BETA 0.0644 GAM 1.0021 MQ 0.065

PARTICLE C:					PARTICLE D:			
CM	LAB	KINETIC	SOLID	labCROSS	LAB	KINETIC	SOLID	
labCROSS	ANGLE	ANGLE	ENERGY	ANGLE	SECTION	ANGLE	ENERGY	ANGLE
SECTION	0.00	0.00	30.762	0.5596	63.0585	180.00	0.0023889	0.0769
0.0091	109.52	90.00	15.418	1.0631	1.7629	35.51	15.346	0.3117
6.0131	180.00	180.00	7.759	2.2459	2.1924	0.00	23.005	0.2530
19.4597								

References:

- [1] M. Drogg, O. Schwerer: "Production of Monoenergetic Neutrons Between 0.1 and 23 MeV: Neutron Energies and Cross Sections", in Handbook on Nuclear Activation Data, K. Okamoto, Ed., IAEA Tech. Rep. Ser. 273, Vienna 1987
- [2] G. Audi, A.H. Wapstra, and C. Thibault. "The AME2003 atomic mass evaluation (II). Tables, graphs, and references", Nuclear Physics A729, 337 (2003).
- [3] Fusion Evaluated Data File, FENDL, MAY91, R. M. WHITE & D. A. RESLER, JULICH 91 CONFERENCE
- [4] J. F. ZIEGLER, ed., "The Stopping and Ranges of Ions in Matter", Vol.3 "HYDROGEN, Stopping Powers and Ranges in All Elements", Vol.5, "Heavy Ions, Stopping Powers and Ranges", Pergamon, 1977, 1980.
- [5] M. Drogg: "Unified Absolute Cross Sections for the Neutron Production by the Hydrogen Isotopes for Charged Particle Energies Between 6 and 17 MeV", Nucl.Sci.Eng. 67, 190 (1978)

Appendices:

Appendix 1: List of files:

a) Introductory information (4 files):

0-README.TXT
IAEANDS.TXT
README.TXT

b) 6 OPEN-VMS-compatible compiling and linking commands:

for VAXes (FORTRAN77)	for ALPHAs (FORTRAN90)
RECLINK.COM	RECLI90.COM
WHILINK.COM	WHILI90.COM
YIELINK.COM	YIELI90.COM

c) 9 source files:

ANGCAL.F90
ANGINP.F90
CHKANG.F90
ENINPO.F90
LEGINT.F90
NEUYIE.F90

The output subroutines for the 3 codes are in one of the following files:

NYIOUT.F90 (monoenergetic neutron production)
WHIOUT.F90 (white source, i.e. thick target application)
RECOUT.F90 (reciprocal reactions)

d) 3 parameter files (for INCLUDE statement):
PARAM.MON
PARAM.REC
PARAM.WHI
(PARAM.NEU is not included, it is a temporary file only!)

e) 3 executables (compiled with either Fortran-90 or Fortran-95)
NEUYIE.xxx
TIMREV.xxx
WHIYIE.xxx

f) 3 general data files:
SETYIE.TAB General menu for NEUYIE and WHIYIE
SETREC.TAB General menu for TIMREV
!!!! ATTENTION: In case that there is no complete display of
the main menu remove all " + " symbols from the SET*.TAB files.
MASS.TAB Table of nuclear masses and spins

g) Cross sections and Legendre coefficients (34 files):
A11BGS.KOE
A13CGS.KOE
A22NEX.KOE
A7LIGS.KOE
D9BEGS.KOE
D11BGS.KOE
D13CGS.KOE
D14NGS.KOE
D15NGS.KOE
D18OGS.KOE
D20NEX.KOE
D24MGX.KOE
D28SIX.KOE
D2HAGS.KOE
D32SGS.KOE
D3HAGS.KOE
D7LIGS.KOE
P10BEX.KOE
P10BGS.KOE
P11BGS.KOE
P12CGS.KOE
P13CGS.KOE
P14CGS.KOE
P15NGS.KOE
P18OGS.KOE
P36CLX.KOE
P39ARX.KOE
P3HAGS.KOE
P59COX.KOE
P6LIGS.KOE
P7LIES.KOE
P7LIGS.KOE
P9BEGS.KOE
T4HEGS.KOE

h) Energy loss data (50 files):
AONH.ELS
AONLI.ELS
AONB.ELS
AONC.ELS
AONNE.ELS
TONHE.ELS
LI7HE.ELS

B11HE.ELS
C13HE.ELS
NE22HE.ELS
DONLI.ELS
DONLIH.ELS
DONB.ELS
DONBE.ELS
DONC.ELS
DONN.ELS
DONO.ELS
DONNE.ELS
DONMG.ELS
DONSI.ELS
DONS.ELS
LI7ONH.ELS
B11ONH.ELS
C13ONH.ELS
N15ONH.ELS
NE00NH.ELS
MG4ONH.ELS
SI8ONH.ELS
S32ONH.ELS
PONLI.ELS
PONLIF.ELS
PONLIH.ELS
PONBE.ELS
Be00NH.ELS
PONB.ELS
PONC.ELS
C12ONH.ELS
C14ONH.ELS
PONN.ELS
PONO.ELS
PONCL.ELS
C16ONH.ELS
PONAR.ELS
AR9ONH.ELS
PONCO.ELS
CO9ONH.ELS
TONH.ELS
TONH2O.ELS
TONLIH.ELS
TOCTAN.ELS

Appendix 2: List of papers on neutron sources by the same author:

- M. DROSG: "Monoenergetic neutron production by two-body reactions in the energy range from 0.0001 to 500 MeV. An overview." TCM-Meeting of IAEA, Debrecen, Hungary, October 1999
- M. DROSG: "Monoenergetic neutrons in the energy range from 100 eV to 200 MeV from two-body reactions with the hydrogen nuclei." Proc. 5th International Conf. on Applications of Nucl. Techniques "Neutrons in Research and Industry", Sissi, Crete, June 1996
- M. DROSG: "Sources of fast monoenergetic neutrons. More recent developments." Proc. 4th International Conf. on Applications of Nucl. Techniques "Neutrons and their

Applications", Sissi, Crete, June 1994.

M. DROSG, D.M. DRAKE, J. Mazarik: "Calibration of a Li-glass detector for neutron energies above 50 keV by the $1\text{H}(t,n)^3\text{He}$ reaction." Nucl. Instr. Meth. Phys. Res. B (1994)

M. DROSG, D.M. DRAKE: "Fast neutron yield from 20-MeV tritons on water. Part I. Triton interaction with light water." Nucl. Instr. Meth. Phys. Res. B73, 387(1993)

M. DROSG, D.M. DRAKE, R.C. HAIGHT, R.O. NELSON: "Fast neutron yield from 20-MeV tritons on water. Part II. Triton interaction with heavy water." Nucl. Instr. Meth. Phys. Res. B73, 392(1993)

M. DROSG, D.M. DRAKE, R.C. HAIGHT, Ron NELSON: "A 'one-step' Method for Measuring Neutron Detector Efficiencies up to 40 MeV", p.135, Report NEANDC-305 "U", NEA, OECD, Paris 1991

M. DROSG: "Some Accurate Neutron Cross Sections in the 4He and 5He Systems above 20 MeV", p.196, Report NEANDC-305 "U", NEA, OECD, Paris 1991

M. DROSG: "On Shibata-san's "Evaluation of Neutron Nuclear Data for 3He and 4He " published in Journal of NUCLEAR SCIENCE and TECHNOLOGY, 27,81(1990)", Nucl. Sci. Techn., 28(4), 70(1991).

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Appendix 3: List of ERROR messages with /explanations/:

WARNINGS:

' Input ERROR, repeat input'/ Formal input error/.
' ATTENTION: sqrt of negative value avoided'/ /
' ATTENTION: negative value might be serious'/ /
' PROJ. ENERGY TO GET nnn.nnnn MeV NEUTRONS IS NOT ACCESSIBLE, Below THRESHOLD of: nnn.nnnnn MeV'//
' BELOW THRESHOLD of nnnn.nnnnn MeV'/ Projectile energy is below threshold./
' Neutron energy below ',engnmin,' MeV encountered'//
' Minimum allowed neutron energy spacing is 0.001 MeV'/Lower limit for WHIYIE is 1 keV./
' At E= nnn.nnnnn MeV ALL nnn ANGLES OUTSIDE OF THE CONE'/ For endothermic reactions in the double-valued regime./
' ENERGY OUT OF RANGE OF LEGENDRE TABLE, check validity'/ Definitely NO information on angular distributions at this energy in file *.KOE./
' INTERPOLATION ERROR: sum of coeff. deviates $\geq 0.1\%$ '/ It is necessary, that the sum of the coefficients deviates not more than 0.001 from 1.0000/.
' SPLINE Interpolation failed!! Neg. cross section of -nnn.nnn at Eproj nnnn.nnnn set to zero!'/Uses zero cross section instead of calculated negative one./
' ATTENTION: step size was 0., replaced by 0.1 MeV'/ In WHIYIE only; provision to overcome problem when generating differential yield spectra (should never happen!)/
' Possibility of a GAP! after nn'/In WHIYIE only; detects an energy gap in differential yield spectra. Unavoidable in double-valued data./
' Possible offset in Ethr of: ',df,' MeV'/ Calculation of threshold energy incomplete. (Should never happen!)/
' Conversion into projectile energy failed. Possible offset of: ',df,' MeV'/ (Should never happen!)/

FATAL ERRORS:

' ERROR in connection with SETUP table'/ ID chosen does not occur in the main menu/.
' STOPPED BECAUSE OF BLANK energy INPUT'/ <enter> is the preferred regular exit from the program/.
' STOP: Zero neutron energy (end of data) encountered!'/ No *.SPC output for plotting because only one data point is available./
' ERROR IN PROJECTILE ENERGY'/' NEUTRON ENERGY LIMITS CANNOT BE CONVERTED INTO PROJECTILE ENERGY VALUES'/.
' ITERATION of reciprocal energy was NOT successful'/ TIMREV cannot find the charged particle energy that matches the neutron energy/.
' No cross section data'/ /
' DESIRED ENERGIES OUTSIDE OF LEGENDRE TABLES'/ Only in option "-2" of

NEUYIE, i.e. if a *.KOE table is scanned/
' EMINL - EMAXL mess up'/ Indicates an error in the first line of
the *.KOE table/
' >=5% Interpolation ERROR of Legendre coefficients!'/ If the sum of the
coefficients deviates more than 0.05 from 1.0000. NEUYIE and TIMREV stop
conditionally. WHIYIE gives the ERROR message and terminates the energy chain.
' Yield and cross section values are meaningless!'/ If sum of
Legendre coefficients deviates by more than 5 %; see above./
' STOP in subroutine LEGINT, file LEGINT.F90'/ Error in SPLINE
interpolation vector/
' NOT ENOUGH DATA FOR SPLINE'/ /
' STOP: bad cross section input for ',en,' MeV'/ Error in SPLINE:
two data points are equal/
' RETURN: ANGLE mismatch!'/In WHIYIE only; error in FOR001.DAT
from which the white spectrum *.SPC for plotting is prepared/.
' Consecutive neutron energies are equal!'/ In WHIYIE only; error in
FOR001.DAT from which the white spectrum *.SPC for plotting is prepared/.

Appendix 4: Disclaimer:

Previous versions of these programs have been distributed under
the acronyms DROSG-87 and DROSG-96 by the IAEA since 1987.

The codes DROSG-2000 were written by
M. DROSG
INST. F. EXP. PHYSICS
UNIVERSITY OF VIENNA
Boltzmannngasse 5
A-1090 WIEN
AUSTRIA / Europe
for his personal use.

Neither the author nor anybody else makes any warranty, express
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The author will appreciate any comment that will allow to improve
this program:
E-mail "Manfred.Drosg@UNIVIE.AC.AT"

Vienna, 2005-05-11

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: nds.contact-point@iaea.org
fax: (43-1)26007
telephone: (43-1)2600-21710
web: <http://www-nds.iaea.org/>
