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DROSG-2000: Neutron Source Reactions

Data files with computer codes
for 60 accelerator-based two-body neutron source reactions

prepared by

M. Drosg
University of Vienna

Summary documentation

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 can be downloaded from http://www-nds.iaea.org.

Citation guideline:
This database should be cited as follows:
M. Drosg, DROSG-2000, Codes and database for 60 neutron source reactions, documented in the IAEA report IAEA-NDS-87 Rev. 10 (January 2016), downloaded from the homepage of IAEA Nuclear Data Section.

DROSG-2000
Neutron Source Reactions

Data files with the computer codes
for 60 accelerator-based two-body neutron source reactions

0. History

UPGRADE to DROSG2000 v. 12.00 Based on the mass.mas12 file: atomic masses published in: "The Ame2012 atomic mass evaluation (I)" by G.Audi, M.Wang, A.H.Wapstra, F.G.Kondev, M.MacCormick, X.Xu, and B.~Pfeiffer, Chin. Phys. C36, 1287, Dec.2012 the MASS.TAB file of the codes was modified to provide the latest mass information. Observe that this table uses nuclear masses as appropriate for nuclear collisions at higher energy.

UPDATE information
20170210:
calculation of collimated emitted particles was overhauled
20160101:
in ENINPO: conditional change of sequence of input energies. Now, in case of kinematic collimation the half-opening angle is given at all energies.
in RELKIN: output messages changed (Format 100 and 110)
20110805:
added warning in WHIYIE for total specific neutron output: outside the double valued angular range value might be too low

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 NDEFLT 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: 9Be(d,n)10B
g) A new target type (LiF) was added for the 7Li(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 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

CONVERSION 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-7Li 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 3He 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

6 (alpha,n) reactions.
Including the inverse reactions a total of 60 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 (*.exe) are provided to run under under any MS-WINDOWS platform (both 32- bit and 64-bit machines). The source codes should be ready for FORTRAN95 compilers under LINUX and UNIX, too. 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 sketched in MAKEF77.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 2012 [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. Observe that the threshold energy is not 0.5000 of the absolute value of the Q-value for projectile and target having the same mass because some of the kinetic energy is consumed by the relativistic

mass increase! Thus, if the calculated value is higher than values found in the literature or somewhere else indicates that those values where obtained nonrelativistically.

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 35 *.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,n0)7Be, 7Li(p,n1)7Be*, 9Be(p,n0)9B, 11B(p,n0)11C, 13C(p,n0)13N, 15N(p,n0)15O,2H(d,n)3He, 3H(d,n)4He, 3H(4He,n0)6Li
b) Differential cross sections at 0 deg AND/OR 180 deg.
In several cases just isotropic approximation from integrated cross sections:
6Li(p,n0)6Be, 10Be(p,n0)10B, 10B(p,n0)10C, 14C(p,n0)14N, 36Cl(p,n)36Ar, 39Ar(p,n0)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 file (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,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
491	T2O target		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
61	9Be(4He,n)12C	isotropic approx.	multiline	1.5-7.9
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  2012 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   41.000002 INT. CROSS SECT.= 1.44121E+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= 4709.05369 MeV,Momentum of projectile=   235.2041,Q= 17.5892473

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


INCIDENT LAB ENERGY    0.999999 INT. CROSS SECT.= 2.31585E+02 mb
INTEGRAL YIELD with a 10 keV SPREAD at 0 Deg=   4.337E+00 n/pC
Total energy= 4685.13318 MeV,Momentum of projectile=    36.7250,Q= 17.5892473

       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
```

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 file (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
   491  T2O target                        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
 61   9Be(4He,n)12C  isotropic approx.    multiline       1.5-7.9
 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  2012 mass table
```

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

Between   1.880770 and   1.920462 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
 If chosen angle is outside double valued range above value
 might be too small!

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
If chosen angle is outside double valued range above value
 might be too small!
 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    4.670882 INT. CROSS SECT.= 3.21120E+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.= 3.07136E+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.= 2.94491E+02 mb
        LABORATORY SYSTEM                9.918E+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 4.717E+01 2.7641E+00                          3.438E+00
 INCIDENT LAB ENERGY    4.373264 INT. CROSS SECT.= 2.81484E+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+002.962128E+00 0.00000E+00 4.67088E+00 0.00E+00 0.00000E+00 0.00000E+00
 1.5000E+012.962128E+00 4.12134E+00 4.67088E+00 1.00E-01 2.42554E+02 3.21120E+02
 1.5000E+012.863122E+00 3.74616E+00 4.57163E+00 1.00E-01 2.27927E+02 3.07136E+02
 1.5000E+012.764119E+00 3.43759E+00 4.47242E+00 1.00E-01 2.14614E+02 2.94491E+02
```

```
 1.5000E+012.665115E+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+00,3.7836E+08
 2.9621E+00,4.1627E+08

!: p7li    4.670880 MeV 15.00 deg, beam exits w/    4.373260 MeV
!: Units are: neutrons/MeV/sr/microCoulomb vs. MeV
!: High energy group: av. energy=  2.821575, av. dbl. diff. yield= 3.645E+08
!: Average energy of all neutrons=  2.821575, 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 file (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.
 60   15O(n,d0)14N     isotropic approximation            5.974 - 20.348
 38   16O(n,d0)15N     isotropic approximation            10.53 - 16.137/20.
 40   19F(n,d0)18O     isotropic approximation            7.    - 8.165/20.
 50   6Li(n,t)4He                                         0.0001- 1.000/20.
 49   6Li(n,4He)3H                                        0.0001- 1.000/20.
 51   10B(n,4He0)7Li   isotropic approximation            0.0001 - 0.79
 61   12C(n,4He)9Be    isotropic approximation            7.308 - 12.115
 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  2012 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  31.0133874 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
```

3.3.2 Sample output (FOR002.DAT):

```
 REACTION 3He(n,p)3H

 REST MASSES: INCIDENT   939.5653261  CALCULATED Q=     0.7638038
               TARGET  2808.3913240
                    C   938.2719964
                    D  2808.9208499
 INCIDENT LAB ENERGY 30.0000000   INCIDENT LAB MOMENTUM  239.3197
 PROJ. ENERGY FOR RECIPR. REACTION: 31.0133874 INTEGR. CROSS SECTION:  50.570350
 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  956.32598 MOM   178.25931
 PART B:TOT EN 2814.04304 MOM   178.25931
 PART C:TOT EN  955.60945 MOM   181.20453 BETA  0.1896 GAM 1.0185 MQ    0.193
 PART D:TOT EN 2814.75957 MOM   181.20453 BETA  0.0644 GAM 1.0021 MQ    0.065
```

PARTICLE C:					PARTICLE D:			
CM ANGLE	LAB ANGLE	KINETIC ENERGY	SOLID ANGLE	labCROSS SECTION	LAB ANGLE	KINETIC ENERGY	SOLID ANGLE	labCROSS 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. Drosg, 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, M.Wang, A.H.Wapstra, F.G.Kondev, M.MacCormick, X.Xu, and B.~Pfeiffer, "The Ame2012 atomic mass evaluation (I)", Chin. Phys. C36, 1287, Dec.2012

[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. Drosg: "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)

[6] M. DROSG, N. Otuka, “Evaluation of the absolute angle-dependent differential neutron production cross sections by the reactions ^{3}H(p,n)^{3}He, ^{1}H(t,n)^{3}He, ^{2}H(d,n)^{3}He, ^{3}H(d,n)^{4}He, and ^{2}H(t,n)^{4}He and of the cross sections of their time-reversed counterparts up to 30 MeV and beyond”, Report INDC(AUS)-0019(2015)
https://www-nds.iaea.org/publications/indc/indc-aus-0019.pdf

Appendices:

Appendix 1: List of files:

a) Introductory information (2 files):
IAEA-NDS-0087v12.01.pdf
README.TXT
b) Example of compiling and linking commands:
makef77.bat
c) 9 source files:
ANGCAL.F95
ANGINP.F95
CHKANG.F95
ENINPO.F95
LEGINT.F95
NEUYIE.F95
The output subroutines for the 3 codes are in one of the following files:
NYIOUT.F95 (monoenergetic neutron production)
WHIOUT.F95 (white source, i.e. thick target application)
RECOUT.F95 (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 LAHEY Fortran LF95
NEUYIE.exe
TIMREV.exe
WHIYIE.exe
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 (35 files):
A11BGS.KOE
A13CGS.KOE
A22NEX.KOE
A7LIGS.KOE
A9Bexx.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 (55 files):
AONB.ELS
AONBe.ELS
AONC.ELS
AONH.ELS
AONH2o.ELS
AONLI.ELS
AONNE.ELS
AONO.ELS
AR9ONH.ELS
B11HE.ELS
B11ONH.ELS
Be0ONH.ELS
C12ONH.ELS
C13HE.ELS
C13ONH.ELS
C14ONH.ELS
Cl6ONH.ELS
CO9ONH.ELS
DONB.ELS
DONBE.ELS
DONC.ELS
DONLI.ELS
DONLIH.ELS
DONMG.ELS
DONN.ELS
DONNE.ELS
DONO.ELS
DONS.ELS
DONSI.ELS
LI7HE.ELS
LI7ONH.ELS
MG4ONH.ELS
N15ONH.ELS
NE0ONH.ELS
NE22HE.ELS
PONAR.ELS
PONB.ELS
PONBE.ELS
PONC.ELS
PONCL.ELS
PONCO.ELS
PONLI.ELS
PONLIF.ELS
PONLIH.ELS
PONLiOH.ELS
PONN.ELS
PONO.ELS
S32ONH.ELS
SI8ONH.ELS
TOCTAN.ELS
TONH.ELS
TONH2O.ELS

TONHE.ELS
TONLIH.ELS
TONLiOH.ELS

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

M. DROSG, and N. Otuka: “Evaluation of the absolute angle-dependent differential neutron production cross sections by the reactions 3H(p,n)3He, 1H(t,n)3He, 2H(d,n)3He, 3H(d,n)4He, and 2H(t,n)4He and of the cross sections of their time-reversed counterparts up to 30 MeV and beyond”, Report INDC(AUS)-0019 https://www-nds.iaea.org/publications/indc/indc-aus-0019.pdf

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 1H(t,n)3He 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 >=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
UNIVERSITY OF VIENNA
Boltzmanngasse 5
A-1090 WIEN
AUSTRIA / Europe
for his personal use.

Neither the author nor anybody else makes any warranty, express
or implied, or assumes any legal liability or responsibility for
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infringe privately owned rights.

The author will appreciate any comment that will allow to improve
this program:
E-mail "Manfred.Drosg@UNIVIE.AC.AT"

Vienna, 2017-03-02