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NUSTART:
A PC Code for
Nuclear Structure and Radiative Transition
Analysis and Supplementation
Users' Guide

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Abstract

NUSTART is a computer program for the IBM PC/AT. It is designed for use with the nuclear reaction cross-section code STAPLUS, which is a STAPRE-based CRAY computer code that is being developed at the Lawrence Livermore National Laboratory. The NUSTART code was developed to handle large sets of discrete nuclear levels and the multipole transitions among these levels; it operates in three modes. The *Data File Error Analysis* mode analyzes an existing STAPLUS input file containing the levels and their multipole transition branches for a number of physics and/or typographical errors. The *Interactive Data File Generation* mode allows the user to create input files of discrete levels and their branching fractions in the format required by STAPLUS, even though the user enters the information in the (different) format used by many people in the nuclear structure field. In the *Branching Fractions Calculations* mode, the discrete nuclear level set is read, and the multipole transitions among the levels are computed under one of two possible assumptions: (1) the levels have no collective character, or (2) the levels are all rotational band heads. Only E1, M1, and E2 transitions are considered, and the respective strength functions may be constants or, in the case of E1 transitions, the strength function may be energy dependent. The first option is used for nuclei near closed shells; the bandhead option may be used to vary the E1, M1, and E2 strengths for interband transitions. K-quantum number selection rules may be invoked if desired.

Section 1. General Information

NUSTART is a computer program for the IBM PC/AT. It is designed for use with the nuclear reaction cross-section code STAPLUS, which is a STAPRE-based CRAY computer code that is being developed at the Lawrence Livermore National Laboratory. The NUSTART code was developed to handle large sets of discrete nuclear levels and the multipole transitions among these levels; it operates in three modes. The *Data File Error Analysis* mode analyzes an existing STAPLUS input file containing the levels and their multipole transition branches for a number of physics and/or typographical errors. The *Interactive Data File Generation* mode allows the user to create input files of discrete levels and their branching fractions in the format required by STAPLUS, even though the user enters the information in the (different) format used by many people in the nuclear structure field. In the *Branching Fractions Calculations* mode, the discrete nuclear level set is read, and the multipole transitions among

the levels are computed under one of two possible assumptions: (1) the levels have no collective character, or (2) the levels are all rotational band heads. Only E1, M1, and E2 transitions are considered, and the respective strength functions may be constants or, in the case of E1 transitions, the strength function may be energy dependent. The first option is used for nuclei near closed shells; the bandhead option may be used to vary the E1, M1, and E2 strengths for interband transitions. K-quantum number selection rules may be invoked if desired.

Background

The accuracy with which one may calculate nuclear reaction cross sections with the modern codes now in use, particularly codes of the Hauser-Feshbach plus precompound, particle-evaporation type, depends upon the quality and accuracy of a wide variety of input information. Indeed, these modern computer codes may not produce results as dependable as those from the older, less sophisticated codes because the modern codes require large amounts of physics information specific to the problem at hand and rely less on global parameterizations. Limited input information, not to mention input errors, can easily produce misleading and unacceptable results from the modern codes.

An important example of some of the required input is that of large sets of discrete nuclear levels and the multipole transitions among them. Accurate and extensive level sets and their decay branches are extremely important for the calculation of nuclear-reaction cross sections for excitation energies up to a few tens of MeV; they are indispensable if isomer populations are required. In addition to their use in calculating particle and photon cross sections and energy spectra, the discrete level sets provide much needed low-energy physics information. The closeness of the parity fraction of the level set to 0.5 is one indicator of how well the discrete levels will match the continuum level density. Also, a preponderance of one parity may signal possible problems with an isomer population calculation, since M1 and E2 transitions among the levels may be unduly emphasized. The spin cut-off parameter, which governs the angular-momentum distribution as a function of energy, may be computed from the discrete levels and then compared with energy-dependent theoretical expressions. The actual spin distribution of the discrete levels may be fitted, in the least-squares sense, to theoretical expressions, and the spin cut-off parameter extracted in that way also. Comparison of the level density and its variation with energy, as obtained from the level sets, with that obtained from continuum level density expressions can often be useful.

System Requirements

NUSTART runs on IBM PC/AT and AT-compatible machines with 640K of memory. It was written using the Microsoft C Compiler, Microsoft Corp., Bellevue, Washington, and the utility routines from the C UTILITY LIBRARY, Essential Software Inc., Maplewood, New Jersey. It was built on a system using a color monitor with an Enhanced Graphics Adapter (EGA) board; although NUSTART may run on monochrome systems or on a system using Color Graphics Adapter (CGA) or Video Graphics Array (VGA) boards, it has not been tested on such systems. The system must have a 5-1/4-in., high-density floppy disk drive.

The NUSTART Code

NUSTART is designed for use with the nuclear reaction cross-section code STAPLUS, which is a STAPRE-based¹ CRAY computer code in development at the Lawrence Livermore National Laboratory. NUSTART was first written to check for typographical and other errors in our large sets of discrete levels and their multipole transitions.² Some of the sets contain over 900 discrete levels, each of which may decay via up to 30 multipole branches. Some of these

level sets come directly from structure-code calculations, such as for permanent rotors³ or Interacting Boson Approximation (IBA) calculations.⁴ In some of these cases, the modeled discrete-level information can be checked internally by the structure codes themselves. However, many of our level sets are assembled "by hand" from a variety of experimental and theoretical sources. Usually, it is virtually impossible to proof these sets of levels and branches manually.

The NUSTART code was developed to handle these large sets of discrete nuclear levels and the multipole transitions among these levels. It operates in three modes: the *Data File Error Analysis* mode, the *Interactive Data File Generation* mode, and the *Branching Fractions Calculations* mode.

In this report, we show the input formats for nuclear structure information and for nuclear level sets and their decay functions and provide step-by-step instructions for using each mode. In appendices, we derive the energy-dependent E1 multipole strength function, provide sample NUSTART input and output files, and explain error messages.

NUSTART Input

Format for Nuclear Structure Information

The nuclear structure information must be provided in the Fortran format specified by STAPLUS. The nuclear level set consists of a header card, followed by the levels themselves.

Card 1 (I3, A9, I3, A65)

<u>Column</u>		<u>Content</u>
1-3	NDISK	Number of discrete levels
4-12	NAME	Name of nucleus (e.g., IR193)
13-15		Blank
16-80		Comment

Cards 2 (6(F6.3, F4.1, I2))

<u>Column</u>		<u>Content</u>
1-6	ED(1)	Energy of ground state (MeV)
7-10	SD(1)	Spin of ground state
11-12	KPD(1)	Parity of ground state (+1 or -1)
13-18	ED(2)	Energy of first excited state (MeV)
19-22	SD(2)	Spin of first excited state
23-24	KPD(2)	Parity of first excited state
	etc.	

Six levels per card, up to NDISK levels; maximum value of NDISK is 999.

The multipole transitions among the discrete levels are supplied as branching fractions that sum to unity for each radiating level. Cards for the ground state and any isomeric levels are omitted.

Cards 3 (I3, A3, I2, 2X, 10F7.3)

<u>Column</u>		<u>Content</u>
1-3	LEVEL	Number of the radiating level, (e.g., 2 for first excited state).
4-6	ENDS	If ENDS = END, this signals the end of this set of multipole branching information.
7-8	NBR	Number of multipole branches from this level, ≤ 30 . If NBR > 10, another card is read. Three cards (30 branches per radiating level) are maximum. If NBR is blank, only one card is read (number of branches ≤ 10).
9-10		Blank
11-17	TVZD(1)	TVZD(i) are the encoded branching fractions.
18-24	TVZD(2)	
	etc.	

The branching fractions, TVZD(i), are encoded as floating point numbers: III.XXX, starting in column 11. Here, XXX is the branching fraction to final level, III. Use III.000 for a branching fraction of unity (100%). The last card in the set should be blank except for END in columns 4-6. Table 1 shows an example.

Table 1. Example of the format required for the nuclear level sets and their decay branching fractions.^{a,b}

54 IR191											
0.000	1.5+1	0.082	0.5+1	0.129	2.5+1	0.171	5.5-1	0.179	1.5+1	0.342	3.5+1
0.351	2.5+1	0.391	3.5-1	0.503	4.5+1	0.504	3.5+1	0.539	1.5+1	0.557	6.5-1
0.589	2.5+1	0.591	7.5-1	0.625	0.5+1	0.650	1.5-1	0.654	4.5-1	0.686	3.5+1
0.748	2.5+1	0.763	1.5+1	0.787	3.5+1	0.800	2.5-1	0.812	4.5+1	0.832	5.5+1
0.875	4.5+1	0.878	4.5-1	0.902	2.5-1	0.919	5.5-1	0.963	7.5-1	0.977	3.5-1
0.987	4.5+1	0.991	5.5+1	1.004	6.5+1	1.037	8.5-1	1.050	5.5+1	1.092	6.5-1
1.106	5.5+1	1.127	9.5-1	1.136	5.5-1	1.179	3.5-1	1.180	0.5-1	1.211	1.5-1
1.230	5.5-1	1.233	5.5+1	1.253	6.5-1	1.270	4.5+1	1.379	6.5+1	1.397	6.5+1
1.418	7.5+1	1.422	8.5-1	1.424	2.5-1	1.496	6.5+1	1.601	8.5+1	1.694	7.5+1
2	1	1.0									
3	1	1.0									
5	2	1.24		2.76							
6	2	1.59		3.41							
7	3	1.49		3.02	5.49						
8	1	4.0									
9	2	3.59		6.41							
10	3	3.48		5.31	7.21						
11	4	1.45		2.11	3.25	5.19					
12	1	4.0									
13	3	1.74		3.24	6.02						
14	1	4.0									
15	5	1.72		2.19	3.03	5.03	11.03				
16	4	1.02		2.12	3.06	8.80					
17	2	4.10		8.90							
18	3	1.20		3.40	6.40						
19	6	1.02		3.04	5.24	6.05	7.05	11.60			
20	3	3.01		5.06	11.93						
21	3	3.74		6.24	9.02						
22	2	8.56		17.44							
23	3	6.18		7.24	10.58						
24	2	6.23		9.77							
25	3	3.20		6.40	9.40						
26	2	6.10		9.90							
27	2	1.50		3.50							
28	2	8.15		17.85							
29	1	12.0									
30	2	16.10		22.90							
31	3	6.74		9.24	24.02						
32	3	9.33		10.60	23.07						
33	2	9.98		24.02							
34	2	12.10		14.90							
35	5	6.15		9.15	18.53	23.10	24.07				
36	1	26.0									
37	4	6.20		9.35	18.10	24.35					
38	1	14.0									
39	3	8.16		17.45	28.39						
40	1	27.0									
41	1	27.0									

Table 1. (Continued).

42	1	41.0			
43	2	26.83	36.17		
44	3	9.74	24.24	33.02	
45	2	17.73	28.27		
46	4	3.05	9.41	19.22	35.32
47	4	9.20	24.35	25.10	33.35
48	3	23.51	24.22	32.27	
49	2	24.23	33.77		
50	2	12.28	29.72		
51	1	40.0			
52	3	24.74	33.24	49.02	
53	2	33.96	49.04		
54	4	24.20	33.35	37.10	49.35
END					

^a Branching fraction cards 1, 2, and 4 are omitted because LEVEL 1 is the ground state, and LEVELs 2 and 4 are isomers.

^b This example does not show TVZD(i) for $i > 10$.

NUSTART Modes

Data File Error Analysis Mode

In this mode, the NUSTART code examines a set of levels and branches (such as shown in Table 1) for a number of typographical and/or physics errors. Later in this manual, we will enumerate the types of errors subject to diagnosis. The code will write an analysis table similar to Table 2, which actually represents only a portion of the table produced when a level set for the nucleus ^{193}Ir was analyzed. For illustrative purposes, the spin of level 4 was mistyped as 8.5 instead of 2.5, and the multipole decay of level 4 was deliberately incorrectly assigned to level 3 instead of level 1.

Table 2. A portion of the analysis table for ^{193}Ir that contains intentional input errors.

GAMMA-RAY TRANSITIONS AMONG DISCRETE LEVELS									
Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
8	0.362	2.5	1	5	0.180	1.5	1	0.182	0.400
+	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				6.64e+001			2.00e+003	6.05e+004
+	Possible Multipoles			4	0.139	8.5	1	0.223	0.010
+	Possible Multipoles								OTHER
	BR F/EG**(2L+1):			2	0.073	0.5	1	0.289	0.190
+	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):			1	0.000	1.5	1	0.362	0.400
+	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				8.43e+000			6.43e+001	4.91e+002
7	0.358	3.5	1	4	0.139	8.5	1	0.219	0.410
+	Possible Multipoles								OTHER
+	Possible Multipoles			1	0.000	1.5	1	0.358	0.590
	BR F/EG**(2L+1):					E2		M3	
					1.00e+002			7.83e+002	
6	0.299	3.5	-1	3	0.080	5.5	-1	0.219	1.000
+	Possible Multipoles					E2		M3	
5	0.180	1.5	1	2	0.073	0.5	1	0.107	0.760
+	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):				6.20e+002			5.42e+004	
+	Possible Multipoles			1	0.000	1.5	1	0.180	0.240
	BR F/EG**(2L+1):					M1		E2	M3
					4.12e+001			1.27e+003	3.92e+004
4	0.139	8.5	1	3	0.080	5.5	-1	0.059	1.000
+	Possible Multipoles					E3			
3	0.080	5.5	-1	***** ISOMER *****					
2	0.073	0.5	1	1	0.000	1.5	1	0.073	1.000
+	Possible Multipoles					M1		E2	
1	0.000	1.5	1						

The following notation is used in Table 2: N (level number), E (level energy in MeV), J (level spin), P (level parity), EG (transition energy in MeV), and BR F (multipole branching fractions). Because the STAPLUS code considers multipole transitions with $\ell \leq 3$, higher multipole transitions are labeled "other," and a warning is issued to the PC monitor screen as well as being written (as a warning message) at the end of the analysis table. For our purposes, we consider most transitions with $\ell > 3$ to be indicative of isomeric states; therefore, the warning usually represents an input error. In addition to indicating the possible multipole type (M1, E2, etc.) that could give rise to the transition, the analysis table prints, if desired, the value of the branching fraction divided by transition energy raised to the $(2\ell + 1)$ power. If more than one decay branch is present, this information can be related either to relative gamma-ray strength functions or, if several transitions proceed to members of the same rotational band in a rigid rotor, to the Clebsch-Gordon coefficients.

Interactive Data File Generation Mode

Our format for the multipole branching fractions is not in common use. More often, one encounters tables of level energies, spins, and parities, along with the energies of the lower levels and the percentage of the total decay that populates a lower level. To facilitate the conversion of the nuclear structure and decay information to the format required by STAPLUS, a second mode called *Interactive Data File Generation* was added to NUSTART. Format descriptions and options are stated in a subsequent section. While the structure information is being converted to the format in Table 2, some error analyses are made, and the user is given the opportunity to correct the errors. When the level set is completed, the constructed STAPLUS file can be examined in the *Error Analysis* mode to produce an output table like that in Table 1. One or more level sets may be constructed sequentially in this way, each with a header card containing up to 65 characters of descriptive information.

Branching Fractions Calculations Mode

In this third mode of NUSTART, the set of discrete levels minus the branching information is read, and the branching fractions are constructed under one of two possible assumptions: either the levels have no collective character, or the levels are all rotational bandheads with the remaining band members deleted. The strengths of the multipole transitions among the levels are calculated using a relative value for each ℓ -type of transition, multiplied by the transition energy raised to the $2\ell + 1$ power. Only E1, M1, and E2 transitions are permitted. The relative values for the strength functions may be calculated by NUSTART from the Weisskopf assumptions, they may either all be different constants supplied by the user or, in the case of E1 transitions, the E1 strength function may be made energy dependent as in a giant resonance treatment. If the levels are all collective bandheads, the user has the option of using the K-quantum number restrictions. Then, the K-quantum numbers must be supplied when K does not equal J for that level. Also, up to six states may be specified in advance as isomers. The newly constructed STAPLUS input file is then run through the *Data File Error Analysis* mode, and the output table is written.

In the case of permanent rotors, we assume that the intraband transitions are much faster than the interband transitions and that the decay from a band occurs only from the bandhead. Therefore, when the bandhead option is chosen, it is usually for one of the following reasons:

- To test the effect of the modification of the relative multipole strengths of the interband transitions among the discrete levels on a STAPLUS calculation of the population of an isomer.
- To add the possibility of E2 transitions. This would be appropriate when the initial nuclear structure code computed only dipole-type interband transitions.

Because only the bandhead levels are used in the bandhead option, the numbering of the initial and final levels will not correspond to the true level set that includes all band members. In a recent calculation involving ^{176}Lu , there were 291 levels up to 1.497 MeV, of which 62 were bandheads. When the bandhead option was invoked, NUSTART numbered the bandheads as levels with numbers 1 through 62, and the branching fraction calculation identified the parent

and daughter levels accordingly. In the complete set encompassing all band members, the true bandhead level numbers ranged up to 285. Thus, bandhead option level number 62 had to be changed to the true level number 285, bandhead option level number 61 had to be changed to true level number 272, etc. An option in NUSTART makes these changes automatically. The user must supply a table consisting of pairs of bandhead option and true level numbers, either as an input file or interactively via the PC keyboard. The renumbering will not appear in the data-analysis output file; however, the file created as input to STAPLUS will appear as in Table 1—with the addition of the branching fraction information repeated with the true numbering. At this time, the user must himself replace the original bandhead decay cards with the new cards. A possible future modification of NUSTART would have the code read in the complete set of branches and would replace the original bandhead decay cards with the new branch cards.

*** NOTE ***

By mid-December 1989, a version of NUSTART had been run with a variety of level sets and with most of the option combinations listed in this users' guide. Should you notice any hitherto undetected errors, please inform us so that we can make corrections. Direct questions concerning the construction and/or design of the code to G. L. Larsen. Direct questions concerning the basic physics and the approximations incorporated into the code to either D. G. Gardner or M. A. Gardner. We can be reached at the University of California, Lawrence Livermore National Laboratory, Nuclear Chemistry Division, L-234, P. O. Box 808, Livermore, CA 94551, USA.

Using the NUSTART Code

Although the NUSTART program requires some understanding of the physics involved to make effective use of the program, it can be used with minimal computer expertise. With the exception of data or file-name entry, all commands are entered via the function keys f1 through f10 and the ESC key, and all cursor control is done using the arrow keys on the key pad. Data-entry and file-name information are entered by filling out simple forms as they appear on the screen. In all cases, the form displayed on the screen shows what keys to use and what they do. These forms will ask you to type in the pertinent information. If there is more than one item on the form, NUSTART will automatically step you through the form as you fill out each item; alternatively, you can move to any item you wish by using the arrow keys to move the cursor.

Data Entry Termination

When you enter data into the computer through the keyboard, you must let the computer know when you have finished by typing some delimiter as a data terminator. In this manual, we show which delimiter to use by putting it in parentheses at the end of the data-entry instruction. For example, the instruction:

type in filename (Enter)

would mean that you are to type in the name of a disk file with its path and terminate the entry of the name with the Enter key.

Special Keys

Always, the form displayed on the screen shows what keys to use and what they do. Certain keys, however, perform special functions.

Toggle Switches. Several forms use a toggle switch, usually the f1 key, to toggle between a yes/no, 0/1, or on/off response. Pressing the toggle switch will cause the current, displayed setting to be toggled to the opposite setting.

Press f10 to Continue. On most forms and menus, if you do not want to make any changes, but simply want to go on to the next step in the program, pressing the f10 key will generally accomplish this feat. The f10 key also frequently acts as a terminator, letting the program know that you are through with that form.

ESC Key. The ESC key is a special key that is used differently in different situations; however, it always acts as some sort of "get out" key. It may be used to instantly terminate a process without completing the process or, if a number of forms must be filled out to set up and start a process, it allows you to step back through the forms to make corrections.

Arrow Keys. The arrow keys are used when control is needed to move a highlight bar or the cursor.

Input Files

The standard input file for the NUSTART code is the same as the level data input for the STAPLUS code. See Table 1 for the Fortran format required for this input file.

Batch Files

A batch file is a file containing multiple STAPLUS level input data sets concatenated together. Each data set is terminated with an END starting in column four of the last card of the data set, as in the normal STAPLUS level data set.

***** REMINDER *****

NDISK is the variable name for the original number of discrete levels in a level set. This variable name is referred to frequently in this guide.

Data-Analysis File

Enter DATA ANALYSIS file name
or press f10 to default name 'nustart.run'

When executed, the first thing NUSTART does is create a data-analysis file that automatically logs the following information:

- Start date and time.
- Input file name.
- The number of levels for the data set.
- The data-set identification (id) card.
- A listing of the energy, spin, and parity for each level.
- Error messages.
- When the *Data File Error Analysis* mode is selected, the analysis information,

including a table of the multipole transitions and branching ratios, is saved in this log file.

You may either type in the name for the data-analysis file

FILENAME (Enter)

or use the default name "nustart.run" by pressing the f10 key.

The data-analysis file is a cumulative file; that is, the code looks to see if the requested file already exists. If it does, the code opens the file and appends the new data to the end of the existing file. If the requested file does not exist, a new file is created, and the data are written to it.

Main Menu

Select Operating Mode
f1 = Data File Error Analysis
f2 = Interactive Data File Generation
f3 = Branching Fractions Calculations
f4 = Data File Editing
ESC = Terminate

This, the main menu for NUSTART, allows access to the four main functions of the program. You select the option you want by pressing the function key (f1 - f4) corresponding to that option. To end the program, you press the ESC key; this closes all files and gives a normal termination. If you end the program in any other way, i.e., (Ctrl)C or (Ctrl)Break, any open files will not be closed, and the data in those files will be lost. Thus, if you do not care to save any information, using (Ctrl)C or (Ctrl)Break will kill the program at any point.

Section 2. Data File Error Analysis Mode

Select Operating Mode
f1 = Data File Error Analysis f2 = Interactive Data File Generation f3 = Branching Fractions Calculations f4 = Data File Editing ESC = Terminate

Press f1 to select the *Data File Error Analysis* mode.

Introduction

In this mode of operation, an existing STAPLUS input file, such as shown in Table 1, is analyzed for several types of errors. Then, a data-analysis table, illustrated in Table 2, is written, along with certain error messages (if any). As previously mentioned, data sets may be stacked, with a final blank card to signal the end of the stack.

NUSTART verifies the number of discrete levels in a set by determining if the energy of the last level is ≤ 0.000 or if the energy of the (NDISK + 1) level is > 0.000 . If too few or too many levels are in the set, appropriate warnings are issued. Next, NUSTART checks the energies of the sequence of levels to see if any are out of (increasing) order.

The branching fraction cards are then read and checked to ensure that (1) there is no decay from level 1 (the ground state) and (2) that there are no radiating levels with level numbers that exceed NDISK. If the initial level decays 100% to one final level with level number N, the encoded branching is N.000. If a branch is found where the fraction > 0.000 , but $N \leq 0$, an error message is issued. Beginning with the highest energy level, NUSTART determines from the branching fraction card(s) for that initial radiating level the type and, based on the initial and final spins and parities, the multipolarity of each indicated transition to a lower level. The branching fractions are normalized to unity, if necessary. Only E1, M1, E2, M2, E3, and M3 transitions are identified and written into the data-analysis table. Higher multipolarity transitions are labeled "other," and a warning message is issued. If desired, the branching fraction divided by the transition energy raised to the $(2\ell + 1)$ power is printed (ℓ is the multipolarity).

The user is cautioned that NUSTART does not examine the input file for all conceivable errors. The code anticipates that the input will be in the STAPLUS general format, and this file is read in an nearly format-free mode.

*** WARNING ***

Some errors will be accepted by NUSTART, which will then create a data-analysis table that may or may not be correct. These same errors would be detected by STAPLUS, since it has a formatted read. Two examples will illustrate the situation:

- Assume that the level-description format is (F6.3, F4.1, I2), for the level energy, spin, and parity, respectively. If the spin is entered as 7;0 instead of 7.0, the unformatted read in NUSTART will reject the incorrect semicolon character and the following zero, and will understand the spin to be 7. In this example, no incorrect conclusions will appear in the data-analysis table; however, should the spin value be half integer, such as 7.5, the error analysis will produce nonsense.

- A more dangerous error would be to indicate the level's parity as =1 instead of +1 or -1. In this situation, NUSTART could reject the equals sign and find the parity to be +1, and a reasonable-appearing but incorrect error analysis would be generated if the true parity value happened to be -1.

A final word of caution might be appropriate. It is quite possible for the data-analysis table file to be too large either to write onto a 5-1/4-in., high-density floppy disk or to be opened with a text editor. In our work, we upload this large file onto a main-frame computer to be viewed or to be sent to some output device. There are two ways to reduce the size of the data-analysis table: request a printout for fewer than the actual number of levels, and/or suppress the printing of the branching fraction divided by the transition energy raised to the $(2\ell + 1)$ power. These options will be mentioned again under the Output Print Options menu.

Procedure

Enter input file name

Type in the name of the input file using the following format:

[disk:][path]file_name.ext(Enter)

The disk and path are needed only if the file does not exist on the current disk and is not in the current directory. If the program cannot find the file, it gives a warning message and asks for the name again. Retype the name or press the ESC key to return to the "Select Operating Mode" menu.

NUSTART reads the input file and runs an analysis on the data. If an error is encountered, NUSTART sends an error message to the terminal, writes a more detailed error message to the data-analysis file, and quits processing the input file. NUSTART returns to the main menu; there, you can either edit the input file with the Edit option or terminate NUSTART and use your favorite text editor to correct the data.

When the analysis is complete, two tables are written to the data-analysis file: a table of the input data and branching fractions and a table of the multipole transitions.

Set Output Print Options
f1 = To change INITIAL LEVEL to less than NNN f2 = Suppress printing of reduced BRF - NO f10 = Continue

Once the analysis is complete, you can set the print options for the output.

f1: Changes INITIAL LEVEL to less than NNN

*** NOTE ***

NNN is replaced by the actual number of levels in the file when the form is displayed.

You may now set the number of branching levels that will be printed. As shown when the form comes up (NDISK), the default is to print all of the levels. Press f1 and type in the number of levels to print. If you do not want the data-analysis table written out, use 0 (zero) as the initial level.

When you press f1, the following change occurs in the menu:

Set Output Print Options
f1 = To change INITIAL LEVEL to less than NNN f2 = Suppress printing of reduced BRF - NO f10 = Continue
Enter new maximum level number

Type in the maximum (INITIAL) level (Enter). A level of 0 (zero) will suppress the printing of the data-analysis table.

f2: Suppresses printing of reduced BRF - NO.

f2: Toggles a switch that allows you to control the printing of the branching function (BRF) information. The default is to print everything, except when only one branch occurs.

f10: Continues on with the next step.

The data-analysis file will be written, and you will be returned to the main menu for the next option.

Section 3. Interactive Data File Generation Mode

Select Operating Mode
f1 = Data File Error Analysis f2 = Interactive Data File Generation f3 = Branching Fractions Calculations f4 = Data File Editing ESC = Terminate

Press f2 for the *Interactive Data File Generation* mode.

Introduction

Much of the nuclear-structure information that we receive comes in the form of manually constructed, typed tables rather than as disk files. As an example, we show in Table 3 the structure information for the first 12 levels in ^{191}Ir , taken from Table 1.

Table 3. Nuclear structure information for the first few levels of ^{191}Ir .

E (keV)	$2J^\pi$	Branching fractions/comments [Daughter level energy (% branching)]	
0	3+	Stable	
82	1+	0 (100)	
129	5+	0 (100)	
171	11-	0 (100)	$t_{1/2} = 4.9$ s, isomer
179	3+	0 (24), 82 (76)	
342	7+	0 (59), 129 (41)	
351	5+	0 (49), 129 (2), 179 (49)	
391	7-	171 (100)	
503	9+	129 (59), 342 (41)	
504	7+	129 (48), 179 (31), 351 (21)	
539	3+	0 (45), 82 (11), 129 (25), 179 (19)	
557	13-	171 (100)	

In this example, the level energies are in units of keV, the level spin is given as $2J$ followed by the parity (+ or -), and the multipole branching to lower levels is encoded as the daughter level energy followed by the percent branching in parentheses. Often a comment is appended, such as " $t_{1/2} = 4.9$ s, isomer" for the fourth level. This allows the user to decide if the given half-life of a level is long enough for the level to be considered a long-lived isomer that doesn't decay in the time frame of a given problem. Often we consider levels with half-lives longer than about 10 ns as "stable"!

For our convenience, we require that the level energies be in units of either keV or MeV, that the spins be listed either as J or $2J$, and that there be no more than 30 branches per radiating level. The percent branchings from a given level should sum to 100, although NUSTART will perform this normalization if necessary. The levels should be listed in order of increasing energy, energies should be rounded to the nearest keV, and several levels may have the same energy, although the latter should be avoided by changing one or more level energies by a keV or so. A problem arises with transitions from higher-energy states. In the STAPLUS format, the daughter level is designated by its level number rather than by its energy. Hence, having several levels with the same energy creates no problem, as long as the user is careful in choosing the correct daughter level when it is fed from above. A maximum of 999 levels and their branches may be entered in this mode of NUSTART.

The STAPLUS input file that is being created in this *Interactive* mode is examined for certain errors as each level and its branches are entered. If the level energies are not in

increasing order, or if a transition is indicated to a level whose energy is not among the previous levels, NUSTART issues a warning, and the user is allowed to make a correction. At any time, the user may review the previous input and make changes. We have decided against permitting the easy insertion or deletion of a level card and its branches in the previously constructed input, because NUSTART will not automatically renumber the daughter levels properly in the encoded STAPLUS file. The user should display the last correct input card (NDISK is automatically properly decremented) and recreate the subsequent cards anew.

Procedure

Enter nucleus

Press f10 to continue

Press ESC to go back to previous menu

Type in the name of the nucleus (Enter).

Enter: Acts as a terminator for the input and steps to the next form.

Press f10 to continue.

f10: Steps to the next form without changing any current settings that may exist.

Press ESC to go back to the previous menu.

*** REMINDER ***

When creating a file, you may enter the energy in terms of either keV or MeV and the spin in terms of either J or 2J. When the data are written to the output files, the STAPLUS file is always written in MeV and J, whereas the structure file is written in keV and the selected spin (J or 2J).

Press f1 to toggle

energy is in keV   OFF
energy is in MeV   ON

Press f10 to continue

Press ESC to go back to previous menu

Press f1 key to toggle spin.

f1: Acts as a toggle switch and lets you redefine the energy in units of keV or MeV.

Press f10 to continue.

f10: Steps to the next form.

Press ESC to go back to the previous menu.

Press f1 key to toggle spin

Spin =   J

Press f10 to continue

Press ESC to go back to previous menu

Press f1 to toggle spin.

f1: Acts as a toggle switch and lets you toggle the spin between J and 2J.

Press f10 to continue.

f10: Steps to the next form.

Press ESC to go back to the previous menu.

Enter comment

Press f10 to continue

Press ESC to go back to previous menu

Type in any comment you want put in the output file on card 1. The comment may have a maximum of 45 characters.

Press Enter to terminate the comment entry and to step to the next form.

Press f10 to continue.

f10: Steps to the next form without causing any change in any current setting.

Press ESC to go back to the previous menu.

Nucleus = IR192

Energy = keV

Spin = 2J

Comment:

This is a sample comment

Press f10 to continue

Press ESC to go to previous menus

When all the initial parameters have been set, they are displayed. You can reset any of them by using the ESC key to step back through the forms. Pressing f10 will move you on to the next step.

The filled-in form above is an example of a typical display. The user has set the nucleus to IR192, selected keV for the energy units, set a spin of 2J, and added the comment "This is a sample comment."

Enter Data for Level 1
Number of Branching Fractions = 0

Energy (keV) = 0
Spin 2J = 0.0
Parity = +
Press ENTER to input branching fractions

Press ENTER to edit branching fractions
enter comment

Use UP ARROW and DOWN ARROW to move cursor
f9 to go back one level
f10 for next level

ESC to quit data entry

This is the main form for generating new data files. The first line shows the current level number. The second line shows the current number of branching fractions for the level.

As you fill in the form, the active line is shown by a highlight bar. When you fill in a line, the highlight moves down to the next entry. You can also move up and down through the form by using the UP and DOWN arrow keys to move the highlight bar.

Energy (keV) = 0.

To enter the energy, type in the value (Enter) in keV.

Spin 2J = 0.0.

To set the spin, type in the spin value (Enter).

Parity = +.

The parity is set by using the f1 key as a toggle switch.

Press Enter to input branching fractions as percentages.

To input the branching percentages, press Enter. A new form will pop up to allow you to type in the branching percentage values (see below).

Press Enter to edit branching percentages.

If any of the branches are incorrect, you may edit them by bringing up the editing form. The editing form shows the branches in columns of energy level and percent of decay. Ensure that the branching percentages sum to 100.

Enter comment.

To put a comment in the output file for the current level, type in the comment (Enter). This comment will be written after the branching ratios. The comment may have a maximum of 45 characters.

Press f9 to go back one level.

f9: Moves you down to the previous level. You may change any value in this level.

*** WARNING ***

The code uses the current level as the highest level when the input is ended. Therefore, if you have used the f9 key to move down through the levels, be certain to return to the highest level before ending.

Press f10 for next level.

f10: Moves you to the next highest level.

Press ESC to quit data entry.

When you have filled in the data for all the levels wanted, press the ESC key to quit.

When you select to input branching fractions, the following form is brought up:

Enter Branching Percentages (as blank delimited pairs)
A maximum of 30 branching percentages may be entered

Press f10 to continue

Press ESC to cancel and return

To enter the branching percentages, type them in as blank delimited pairs in the form:

level_energy %_decay level_energy %_decay ...

The level energy is entered in the units (keV or MeV) set at the onset of the editing session. The percent decay may be entered either as integer numbers or as decimal values (e.g., 33, 33.3, .03, etc.). When all the branching percentages are in, press f10 to quit and return. You may, at any time, nullify the data entry and return to the calling form by pressing the ESC key.

*** NOTE ***

The maximum value for the energy is 9999 keV. The percent of decay can have a maximum of four characters (e.g., 33.3, 22.5, etc.); any value greater than 100 percent will be treated as 100.

When you select to edit the branching fractions, the following form is brought up:

Branching percentages for level NNN

EL

%

EL

%

Use the cursor arrows to move cursor to value to be changed
f1 to change value
f10 to return

Use the arrow keys to move the cursor to the value to be changed. You may move through the branching percentages at will, and change them in any order.

*** NOTE ***

NNN is replaced by the actual level number when the form is displayed.

Press f1 to open the value for change.

Type in the new value (Enter).

Press f10 to end the editing and to return to the data entry form.

You may cancel the editing session at any time and nullify all changes made by pressing the ESC key.

```
f1 = save file to disk, STRUCTURE mode
```

```
f2 = save file to disk, STAPLUS mode
```

```
f10 = continue
```

```
ESC = skip save
```

Once you end the data-entry session, you may save the data into disk files in two different forms.

f1: Saves file to disk, STRUCTURE mode.

f2: Saves file to disk, STAPLUS mode.

As you make each selection, the code will ask you to enter a name for the output file. If you do not give an extension to the file name, you will get the default of .lev for the structure file and .stp for the STAPLUS file. The structure file is always written with the energy in keV and either J or 2J for the selected spin. The STAPLUS file is always written with the energy in MeV and the spin in J.

When you select to save a file to disk, the following form is displayed:

```
Enter output file name
```

Type in the output file name (Enter). The name must have eight or fewer characters. The file extension is optional; however, if none is given the default extensions are .lev for the structure file and .stp for the STAPLUS file. If the named file already exist on the disk, it will be overwritten.

Either or both of the output files may be saved. Examples of each are shown in Tables 1 and 3 and in the Appendices.

Section 4. Branching Fractions Calculations Mode

Select Operating Mode
f1 = Data File Error Analysis f2 = Interactive Data File Generation f3 = Branching Fractions Calculations f4 = Data File Editing ESC = Terminate

Press *f3* for the *Branching Fractions Calculations* mode.

Introduction

This mode of operation, termed the *Branching Fractions Calculations mode*, is used to compute estimates of multipole transition probability fractions for the depopulation of specific excited nuclear levels, regardless of the extent to which any gamma ray may be internally converted. For each excited level that decays (the ground state and levels specified as "isomeric" are excluded), the branching fractions sum to unity. Thus, when the branching fractions are used in a nuclear reaction code such as STAPLUS, the computed "gamma-ray spectra" may require modification, depending upon the magnitude of the transition energy and the multipole type. Furthermore, only E1, M1, and E2 transitions are calculated here; in most situations this should cause no problems, except possibly if E0 transitions are of interest. No particular interactions among multipole types are considered, nor is the decline, with increasing energy, of the accuracy of the K-quantum number restrictions for deformed nuclei.

The general scheme followed in this mode is as follows:

- (1) To read in a set of nuclear levels plus their header card, and then
- (2) To calculate the relative strengths of up to 30 of the strongest transitions to lower-energy levels, conserving angular momentum and parity, for dipole and E2 transitions from radiating levels.

We begin with the highest-energy initial level and then search first for transitions to the ground state and then for transitions to the excited final levels as their excitation energy increases and approaches the energy of the initial state. Up to 20 dipole and 10 E2 transitions are located: if an M1 and an E2 transition populate the same final level, their strengths are added. Finally, should more than 10 intense transitions be located, their number is truncated to 10, and the branching fractions are created by normalizing the total strength to unity.

The relative transition strengths are derived from transmission coefficients of the form $CE_1 \cdot E_\gamma^3$, $CM_1 \cdot E_\gamma^3$, and $CE_2 \cdot E_\gamma^5$ where E_γ is the difference between the initial and final level energies. The coefficients CE_1 , CM_1 , and CE_2 are constants, except for CE_1 , which may be either constant or a function of E_γ . These coefficients are equivalent to gamma-ray strength functions; they may be either relative or absolute in magnitude and may be ≥ 0 . Because the branching fractions are normalized, relative values of the coefficients are most often used. These may either be supplied by the user or calculated from the Weisskopf relative values:

$$\begin{aligned} CE_1 &= 1. \\ CM_1 &= 0.31 \cdot A^{2/3} \\ CE_2 &= (7.2 \times 10^{-7}) \cdot A^{2/3} \end{aligned}$$

Here, A is the nuclear mass number.

In Appendix A, we give our preference for these strength-function values and derive the following approximate expression for the energy-dependent coefficients relative value:

$$CE_i(E_\gamma) = k \cdot E_\gamma \cdot [D_1(E_\gamma) + D_2(E_\gamma)] \quad (4-1)$$

The functions D_1 and D_2 reflect the properties of the double- (or single-) peak giant dipole resonance (GDR):

$$D_i(E_\gamma) = \frac{\Gamma_{Ri}}{(E_\gamma - E_{Ri})^2 (E_x + E_{Ri})^2} \quad (4-2)$$

Here, Γ_{Ri} and E_{Ri} are, respectively, the width and the energy of the i^{th} peak of the GDR, and E_x is an adjustable constant that we have fixed⁵ at 11. The units are MeV for all variables.

The normalizing constant, k , forces $CEI(E_\gamma) = CEI$ for E_γ equal to an input of EI in MeV:

$$k = \frac{CEI}{EI} \cdot \left[\frac{1}{D_1 EI + D_2(EI)} \right]. \quad (4-3)$$

Note that the function D_i has a singularity at $E_\gamma = E_{Ri}$; therefore, the highest energy in the discrete level set must be lower than the energy of the first GDR peak. For a single-peak GDR, the values of Γ_{R2} and E_{R2} should be set to zero.

If the code cannot find any dipole or E2 transitions that will depopulate a level, it will term that level to be an "isomer." In addition, the user may specify up to six levels, above the ground state, to be isomers, and the code will skip these levels during the multipole decay analysis. The time frame of the user's problem will dictate which (if any) of these isomers should be retained as such. Any changes in isomer designation or mode of decay must be incorporated by the user. A situation that is *not* handled by NUSTART occurs when a nuclear level may undergo both radiative and nonradiative decay. For example, if a level undergoes beta decay as well as multipole transitions, the correct multipole branching fraction total is less than unity. The user must account for this in some way, such as by declaring the level to be an isomer and editing the results produced by the reaction code that utilizes the output from NUSTART. The same procedure might be followed with $\rightarrow 0^+ \rightarrow 0^+$ transitions, which are not recognized by NUSTART.

Some comparisons of the isomer populations calculated by our nuclear reaction code STAPLUS for reactions on isotopes of bismuth and iridium have been documented⁶ using both experimentally based and NUSTART-calculated multipole branches. So far, the identification of potential isomers and their *calculated* populations have been quite similar using either branching set, for a given discrete level set. How well the populations calculated with either branching set agreed with *experiment* seemed to depend upon the completeness and accuracy of the discrete level set itself.

In Table 4, we show an example taken from Ref. 6, where two sets of multipole branches among the lower levels of ^{208}Bi are compared.

dipole and E2 transitions, respectively. Up to 50 cases where $K \neq J$ may be signaled, and the actual K value for these levels read in. The level numbers in the output file for STAPLUS will not correspond to the true numbers in the complete set from which the bandheads were taken, so provision is made to renumber the levels.

Should the quasi-particle energies in the deformed, Nilsson basis set that create the bandheads be uncertain to a considerable extent, the existence of possible isomeric states and their position with respect to other bandheads may be in doubt. To facilitate sensitivity studies using large sets of calculated levels, we allow a "sensitivity test" option in which all levels of a given parity and with an angular momentum equal to or larger than a specified value of J may be shifted in energy.

One final comment might be made regarding the energy-dependent coefficient option for E1 transitions. For transition nuclei, those between rigid rotors and closed-shell nuclei, the K-quantum number may rapidly lose its validity, and the onset of band mixing may occur. The large intraband M1 and E2 transition probabilities, that is, the energy-reduced $B(M1)$ and $B(E2)$ values, will decrease for the higher-energy levels. It might be possible to simulate this effect by allowing the E1 transition probabilities to increase with energy faster than those for M1 and E2 transitions, since the sum of the branching fractions is normalized to unity.

Procedure

Enter input file name

Type in the input file name (Enter). If the file cannot be found, you will be asked to reenter the file name. Pressing either the ESC key or the f10 key will return you to the calling menu.

f1 = Run Sensitivity Test
f10 = Continue without running Sensitivity Test
ESC = Return to Calling Routine

You can run a sensitivity test on the data by setting the sensitivity parameters. The energy levels that meet the test criteria have an arithmetic operation performed on them. You may either add or subtract some constant from the level energies, or multiply or divide the level energies by some constant. The data are then resorted on the level energies.

Press f1 to bring up the menu for setting the sensitivity parameters.

f1: Runs Sensitivity Test.

Press f10 to continue and to calculate the branching fractions without executing the sensitivity test.

f10: Continues without running Sensitivity Test.

ESC: Returns to Calling Routine. This will take you back to the main menu.

SET SENSITIVITY PARAMETERS

Set Spin Sensitivity greater than 8.0
Set Parity Sensitivity +/-
SUBTRACT constant, in MeV, from energy
constant = 0.280

Press f1 to change setting

Use UP and DOWN ARROW keys to move cursor
f10 = to Continue
ESC = Return to Calling Routine

You can perform the following arithmetic operations on selected level energies:

- (1) Add a constant to the energy.
- (2) Subtract a constant from the energy.
- (3) Multiply the energy by a constant.
- (4) Divide the energy by a constant.

An energy level to be operated on is marked by comparing its spin and parity against the settings made on this form.

To change the settings, use the UP and DOWN arrow keys to move the cursor to the chosen setting. There are five possible settings:

- (1) Set spin sensitivity greater or less than some value N.N. The default setting is greater than N.N. Use the f1 key to toggle between the settings.
- (2) Set the spin parameter by typing in a new value (Enter). The default value is 8.0.
- (3) Set the parity to compare against. Use the f1 key to step through the possible settings. The parity setting may be negative, positive, or both. The default is both.
- (4) Set the chosen arithmetic operation. Use the f1 key to step through the options. Subtraction is the default operation.
- (5) Set the constant to use for arithmetic operations. Type in the new value (Enter). The default constant is 0.28.

When all the settings are correct, press f10 to do the analysis, make any changes, and resort the data.

For example, if you make the following settings:

Set Spin Sensitivity less than 5
Set Parity Sensitivity -
ADD constant, in MeV, to energy
Constant = 0.580

Then, whenever the spin of an energy level is less than 5 and the parity is negative, the level energy will have 0.58 added to it. After all the energy levels have been analyzed, the data are resorted on the level energies.

Only E1, M1 and E2 transition branches
will be considered

Press f10 to continue
Press ESC to go back to previous menu

This is informational only; press f10 to continue.

Press f1 to toggle

Are the Multipole Strength Function
Coefficients (relative or absolute are both OK)
to be supplied by the user? YES
or should the Weisskopf values be used? NO

Press f10 to continue
Press ESC to go back to previous menu

The f1 key acts as a switch to toggle between user-supplied coefficients and the Weisskopf values.

Set Coefficients

CE1 = 0.0000
CM1 = 0.0000
CE2 = 0.0000
Is CE1 energy dependent - YES
Press f1 to toggle setting
Press f10 to continue
Press ESC to return to previous menu

Type in the coefficient values (Enter).

The highlight bar will automatically move to the next setting as you enter the values; alternatively, use the Arrow keys to move the highlight bar.

To toggle the CE1 energy-dependence setting, move the highlight bar to that line and press the f1 key.

Enter Resonance Parameters

EI = 0.0000
ER1 = 0.0000
ER2 = 0.0000
_R1 = 0.0000
_R2 = 0.0000
Press f10 to continue
Press ESC to return to previous menu

Type in the resonance parameters (Enter).

This form is called up when CE1 is chosen to be energy dependent. See the Introduction for the parameter definitions. The highlight bar will automatically move to the next setting as you enter the values; alternatively, use the Arrow keys to move the highlight bar.

Enter MASS Number 000

Press f10 to continue
Press ESC to go back to previous menu

When the Weisskopf values are used, you must give the mass number for the isotope:

MASS (Enter)

Press f1 to toggle

Are the K - Quantum Number Selection Rules
to be considered? NO

Press f10 to continue
Press ESC to go back to previous menu

Use the f1 key to change the setting for the selection rules.

Press f1 to toggle

Are the K - Quantum Number Selection Rules
to be considered? YES

Discrete Level Input will be assumed to be
only Rotational Bandheads

Do any Bandheads have K not equal J? NO

Press f10 to continue

Press ESC to go back to previous menu

When you choose to use the K-Quantum number selection rules, you must tell if any bandheads have K not equal to J. If they do, use the f1 key to toggle your response.

When there are some bandheads with K not equal to J, the following form will appear:

Enter Level Numbers and Positive 'K' Values
(as blank delimited pairs)

A maximum of 50 levels may be entered

Press f10 to continue

Press ESC to cancel and return

Type in the level numbers and the K values as blank delimited pairs in the form:

level K level K level K . . .

The "level" is the level number (1 = ground state, etc).

The K value is to be given as a decimal number.

Press f10 to end the data entry and go on to the next form.

Press ESC to nullify any data entered and return to the calling form.

Press f1 to toggle

Are the BANDHEADS to be renumbered? NO

Press f10 to continue

Press ESC to go back to previous menu

If the f1 key is used to change NO to YES, a subsequent menu will ask for the information required to accomplish the renumbering.

Press f1 to toggle

Are there any ISOMERS present in the data? NO

Press f10 to continue

Press ESC to go back to previous menu

Use the f1 key to toggle your response.

Enter Level Numbers for Isomers (blank delimited)
(a maximum of six levels)

Press f10 to continue

Press ESC to cancel and return

When there are isomers present, you can enter the isomer level numbers. Up to six isomer levels may be entered. Press either the Enter key or the f10 key to terminate input.

Due to the approximate nature of the physics involved, no more than 10 branches will be calculated for each level

Press f10 to continue

Press ESC to go back to previous menu

This is informational only; press f10 to continue and to calculate the branching ratios.

Select Input Mode for Renumbering Levels

f1 = Read New Level Numbers from a Disk File
f2 = Read New Level Numbers from Terminal Input
f3 = Prompt for each New Level Number

ESC = Cancel Renumber and Return to Main Menu

When the option to renumber the bandheads is chosen, the above menu will be displayed. You have three options for passing the renumbering information. These options are described below. Either press the proper function key to select the input mode wanted or press the ESC key to cancel the renumbering of the bandheads, to complete the branching fractions calculations, and to return to the main menu.

Enter input file name

If a disk file is to be used for entering the level values for renumbering, type in the input file name (Enter).

The input file contains a list of the bandhead option (old) level numbers and the true (new) level numbers as blank delimited data pairs. For example,

old level	new level	old level	new level	old level	new level
1	1	2	2	3	4
4	10	5	11	6	13
7	15	etc.			

There are no constraints regarding column placement or the number of pairs on a line. The file must contain NDISK pairs of numbers. Even if the level number is not to be changed, a pair of numbers (the old number repeated) must appear for every level from 1 to NDISK.

Enter NDISK Old and New Level Numbers as Blank Delimited Pairs									
old	new	old	new	old	new	old	new	old	new
level	level	level	level	level	level	level	level	level	level

Use ARROW KEYS to move Cursor
f10 = to continue
ESC = Cancel Data Entry and Return to Main Menu

Enter the bandhead option (old) and the true (new) level numbers through the terminal. Use either the Enter key or the space bar to terminate each number as it is entered. As each number is entered, the cursor will automatically move to accept the next number.

The UP, DOWN, LEFT, and RIGHT arrow keys allow you to move back through the energy numbers for modification. To change a level number, move the cursor to the number to be changed, type in the new number and (Enter) or (Space).

Press f10 to terminate the data entry. NUSTART will then change the level numbers to the new values and will write the revised output to the end of the .STP file.

Press the ESC key to cancel the call to renumber the bandheads and to continue with the normal execution of the program.

Remember—there must be NDISK pairs of numbers.

Enter New Level Number After Prompt									
old	new	old	new	old	new	old	new	old	new
level	level	level	level	level	level	level	level	level	level
1									
Use ARROW KEYS to move Cursor f10 = to continue ESC = Cancel Data Entry and Return to Main Menu									

With this option, the bandhead option (old) level numbers are printed out as a prompt, and you must enter the true (new) level number (Enter). Use the UP, DOWN, LEFT, and RIGHT arrow keys to move around through the new level numbers for editing. To correct the energy number, move the cursor to the value to be changed and type in the new value (Enter).

Press f10 to terminate the data entry. The revised data are written to the end of the .stp file.

Press the ESC key to cancel the bandhead renumbering and to continue with the normal execution of the program.

Set Output Print Options
f1 = To change INITIAL LEVEL to less than NNN f2 = Suppress printing of reduced BRF - NO f10 = Continue

Once the branching fractions have been calculated, NUSTART runs an analysis on the results and writes the calculated branching fractions and the data-analysis table to the data-analysis file.

Once the analysis is complete, you can set the print options for the output.

Press f1 to type in the number of branching levels that will be printed. The default is all of the levels; this is shown when the form comes up (NDISK). If you decide you do not want the data-analysis table written, set the INITIAL LEVEL to 0.

f1: Changes INITIAL LEVEL to less than NNN.

*** NOTE ***

NNN is replaced by the actual number of levels in the file when the form is displayed.

Use the toggle switch f2 to control the printing of the BRF information. The default is to print everything.

f2: Suppresses printing of reduced BRF - NO.

Continue on with the next step. The data-analysis file will be written and you will be returned to the main menu for the next option.

f10: Continues.

These reduction options are particularly useful if the data-analysis file is too large to be written onto a floppy disk.

Section 5. Data File Editing

Select Operating Mode
f1 = Data File Error Analysis
f2 = Interactive Data File Generation
f3 = Branching Fractions Calculations
f4 = Data File Editing
ESC = Terminate

Press f4 to edit any standard STAPLUS data file.

Introduction

You may edit the header card and one or more levels of an input file and change any of the data parameters for that level, including the branching fraction information. No levels may be added or deleted. You may open an input file that contains only the discrete levels and no multipole branches (for the *Branching Fractions Calculations* mode), a file with the discrete levels plus multipole branches (for the *Data File Error Analyses* mode), or the STAPLUS output file from the bandhead option of the third mode with the appended set of renumbered levels for the multipole branches.

First, you must tell NUSTART which file you are going to edit. You then select the level you want to edit. You may then edit any or all of the data parameters for that level. You can step up and down through all the levels in the file, editing any that you want. However, because the editor was not designed to be sophisticated, you are limited to moving through the file one level at a time. Therefore, if you need to edit two widely separated levels, you may want to edit one level, end the editor, and restart it to edit the second level.

Besides allowing you to edit files, the edit mode can be used to create a structure-formatted file from any standard STAPLUS input file. Open any STAPLUS file to any arbitrary level for editing and immediately end the editing mode. When you end the edit mode, you are given the option of writing a structure-format file.

You can also use the edit mode to split up batch files into their component parts by writing each component to a separate file.

In all cases, the editor does not modify your original input file. All modifications are done in memory; the results are written to a new disk file, which you name.

Procedure

```
f1 = open new file to edit  
f2 = edit next file in batch file  
ESC = return to main menu
```

Once you have selected the edit option, you must point to where the file is.

f1: Opens a new disk file and allows you to edit it.

f2: Allows you to edit the next data set in the file when you are working with a batch file.

When a new file is to be opened, the following form is displayed:

```
Enter input file name
```

Type in the input file name (Enter).

Enter nucleus

Press f10 to continue

Press ESC to go back to previous menu

Type in the name of the nucleus (Enter).

Enter: Acts as a terminator for the input and steps to the next form.

Press f10 to continue.

f10: Steps to the next form without changing any current settings.

Press ESC to go back to the previous menu.

Enter comment

Press f10 to continue

Press ESC to go back to previous menu

Type in any comment you want put in the output file on card 1. The comment may have a maximum of 45 characters.

Press the Enter key to terminate the comment entry and to step to the next form.

Press f10 to continue.

f10: Steps to the next form without causing any change in any current setting.

Press ESC to go back to the previous menu.

There are NDISK levels
Enter level number to edit

Press f10 to continue
Press ESC to go back to previous menu

Type in the level number to edit (Enter). You may start at any level; use the f9 and f10 keys to step up or down through the levels (see below for more detail).

Enter Data for Level 1   Number of Branching Fractions = 0   Energy (MeV) = 0   Spin J = 0.0   Parity = +   Press ENTER to input branching fractions   Press ENTER to edit branching fractions   enter comment   Use UP ARROW and DOWN ARROW to move cursor   f9 to go back one level   f10 for next level   ESC to quit data entry

This is the main form for editing the data files. The first line shows the current level number. The second line shows the current number of branching percentages for the level.

As you fill in the form, the active option is shown by a highlight bar. When you fill in a option, the highlight moves down to the next entry. You can also move up and down through the form by using the Up and Down arrows to move the highlight bar.

Energy (MeV) = 0

To enter the energy, type in the value (Enter) in MeV.

Spin J = 0.0

To set the spin, type in the spin value (Enter).

Parity = +

The parity is set by using the f1 key as a toggle switch.

Press Enter to input branching fractions (as percentages).

To input the branching percentages, press Enter. A new form will pop up to allow you to type in the branching percentage values (see below).

Press Enter to edit branching fractions.

If any of the branches are incorrect, you can edit them by bringing up the editing form. The editing form shows the branches in columns of energy level and percent of decay. Ensure that the branching percentages sum to 100.

Use the arrow keys to move the cursor to the value to be changed. You may move through the branching fractions at will, and change them in any order.

Press f1 to open the value for change.

Type in the new value (Enter).

Press f10 to end the editing and to return to the data entry form.

You may cancel the editing session at any time and nullify any changes made by pressing the ESC key.

Enter comment.

To put a comment in the output file for the current level, type in the comment (Enter). This comment will be written after the branching fractions. The comment may have a maximum of 45 characters.

Press f9 to go back one level.

f9: Moves you down to the previous level. You may change any value in this level.

Press f10 for the next level.

f10: Moves you to the next highest level.

When you have filled in the data for all the levels wanted, press the ESC key to quit.

ESC: Quits data entry.

When you select to input branching percentages, the following form is brought up:

Enter Branching Percentages (as blank delimited pairs)
a maximum of 30 branching percentages may be entered

Press f10 to continue

Press ESC to cancel and return

To enter the branching percentages, type them in as blank delimited pairs in the form:

level_energy %_decay level_energy %_decay ...

The level_energy is entered in MeV. The percent decay may be entered as whole numbers or as decimal values (e.g., 33, 33.3, .03, etc.). When all the branching ratios are in, press f10 to quit and return. You may, at any time, nullify the data entry and return to the calling form by pressing the ESC key.

*** NOTE ***

The maximum value for the energy is 9.999 MeV. The percent of decay can have a maximum of four characters (e.g., 33.3, 22.5, etc.) any value greater than 100 percent will be treated as 100.

When you select to edit the branching percentages, the following form is brought up:

Branching percentages for level 14

EL	%	EL	%

Use the cursor arrows to move cursor to value to be changed
f1 to change value
f10 to return

To edit the branching ratios:

- (1) Use the arrow keys to highlight the value to be changed.
- (2) Press the f1 key to toggle the program to accept the change.
- (3) Type in the new value (Enter).

Repeat these steps for each change to be made. When you have made all your changes, press the f10 key to continue.

Press the ESC key to nullify all changes and to cancel the editing option.

```
f1 = save file to disk, STRUCTURE mode  
f2 = save file to disk, STAPLUS mode  
  
f10 = continue  
ESC = skip save
```

Once you end the data-entry session, you may save the data into disk files in two different forms.

f1: Saves file to disk, STRUCTURE mode.

f2: Saves file to disk, STAPLUS mode.

As you make each selection, the code will ask you to enter a name for the output file. If you do not give an extension to the file name, you will get the default of .lev for the structure file and .stp for the STAPLUS file. The structure file is always written with the energy in keV. The STAPLUS file is always written with the energy in MeV. The spin is in J.

Either or both of the output files may be saved; examples of each have been shown in Tables 1 and 3.

```
Enter output file name
```

Type in the output file name (Enter).

The output file name may have a maximum of eight characters plus the .extension. As you make each selection, the code will ask you to enter a name for the output file. If you do not give an extension to the file name, you will get the default of .lev for the structure file and .stp for the STAPLUS file. If the file already exists on the disk, it will be overwritten.

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Appendix A. Energy-Dependent E1 Multipole Strength Function

By invoking the Brink-Axel hypothesis, the classical dipole sum rule, and a functional form, G_R , for the giant dipole resonance (GDR), the E1 strength function may be written as

$$f_{E1}(E_\gamma) = 3.32 \times 10^{-6} \left(\frac{NZ}{A} \right) \frac{F_{SR}}{E_\gamma} \sum_i \frac{G_{Ri}}{\Gamma_{Ri}} \text{ MeV}^{-3} \quad (\text{A-1})$$

Definitions of these terms may be found in Ref. 8; for present purposes, we use the notation in Section 4 of this report, where we defined a relative quantity

$$CE1(E_\gamma) = k \cdot \frac{1}{E_\gamma} \cdot \sum_i \frac{G_{Ri}}{\Gamma_{Ri}} \quad (\text{A-2})$$

Here, k is a normalizing constant, E_γ is the energy of the dipole transition, and G_R is the unit line shape chosen for the GDR. The GDR may have one or two peaks ($i = 1$ or 2), and Γ_{Ri} is the width of the i^{th} peak. For the GDR line shape, we choose the energy-dependent Breit-Wigner form^{8,9}

$$G_R = [1 + 4(E_\gamma - E_R)^2 / \Gamma_R \Gamma(E_\gamma)]^{-1} \quad (\text{A-3})$$

The two new terms are E_R , the GDR peak energy, and $\Gamma(E_\gamma)$, an energy-dependent damping width. For $E_\gamma < E_R$, we have

$$\Gamma(E_\gamma) = \Gamma_R [2E_\gamma / (E_x + E_R)]^2 \quad (\text{A-4})$$

As noted earlier, E_x is a free variable that we have fixed at 11 MeV.⁵ By limiting E_γ to low energies, the first term, 1, in the square brackets of Eq. (A-3) may be disregarded, leading to the previous Eqs. (4-1) and (4-2).

When NUSTART is used to calculate the branching fractions among the discrete levels, values must be assigned to the constants, $CE1$, $CM1$, and $CE2$ [which represent the (usually relative) multipole strength functions] before they are multiplied by the transition energy raised to the appropriate power. If the E1 transitions are based on some representation of the GDR, the additional information previously cited in Section 4 must be supplied. Because we are only beginning to investigate how nuclei in different mass regions and with different deformations should be treated, the user should consider the following merely as a very rough guide.

We rarely use the Weisskopf estimates, preferring to base our choice of strength-function values on those we calculate for the continuum in a given nucleus, modified in some *ad hoc* manner for the collective character in deformed nuclei. Usually, we assume that $CE1 = 1$, at an excitation energy midway among the discrete levels. If $CE1$ is based on the GDR description, additional resonance information must be supplied. Then, we check the literature for existing experimental gamma-ray information for nuclei in the mass region of interest. For medium-weight to heavy nuclei, we often find relative strength-function constants that span a considerable range of values. For example, using $CE1 = 1$, and about 0.5 to 1 MeV of excitation energy, we obtain the values listed in Table A-1.

Table A-1. Typical relative strength-function constants used if CE = 1.

Nuclear type	CM1	CE2
Deformed	3 to 6	1 to 0.01
Intermediate	1 to 5	0.1 to 0.01
Closed shell	0.5 to 5	~0.01

For deformed nuclei, the values in Table A-1 refer to interband transitions; NUSTART should not be used with a complete set of levels from a permanent rotor.

Appendix B. Sample NUSTART Input and Output Files

Example 1

In this example, the input file consisted of the discrete levels of ^{208}Bi and the experimental branching fractions of Set 1 in Table 4. When this file was processed in NUSTART's *Data File Error Analysis* mode, Table B-1 was generated.

Table B-1. Portion of the data-analysis output file for ^{208}Bi .

GAMMA-RAY TRANSITIONS AMONG DISCRETE LEVELS										
Initial Level				Final Level						
N	E	J	P	N	E	J	P	EG	BR F	
28	1.699	4.0	-1							
+				1	0.000	5.0	1	1.699	1.000	
	Possible Multipoles					E1		M2	E3	
27	1.673	7.0	-1							
+				3	0.510	6.0	1	1.163	1.000	
	Possible Multipoles					E1		M2	E3	
26	1.667	4.0	1							
+				1	0.000	5.0	1	1.667	1.000	
	Possible Multipoles					M1		E2	M3	
25	1.664	8.0	-1							
+				7	0.651	7.0	1	1.013	1.000	
	Possible Multipoles					E1		M2	E3	
24	1.637	3.0	1							
+				2	0.063	4.0	1	1.574	0.400	
	Possible Multipoles					M1		E2	M3	
	BR F/EG**(2L+1):					1.03e-001		4.14e-002	1.67e-002	+
1	0.000	5.0	1	1.637	0.600					
	Possible Multipoles					E2		M3		
	BR F/EG**(2L+1):					5.10e-002		1.90e-002		
23	1.629	6.0	-1							
+				1	0.000	5.0	1	1.629	1.000	
	Possible Multipoles					E1		M2	E3	

Table B-1. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
22	1.606	6.0	1						
+				3	0.510	6.0	1	1.096	0.500
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				3.80e-001			3.16e-001	2.63e-001 +
1	0.000	5.0	1	1.606	0.500				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.21e-001			4.68e-002	1.81e-002
21	1.571	10.0	-1					***** ISOMER *****	
20	1.564	4.0	1						
+				2	0.063	4.0	1	1.501	1.000
	Possible Multipoles					M1		E2	M3
19	1.539	2.0	1						
+				6	0.633	3.0	1	0.906	1.000
	Possible Multipoles					M1		E2	M3
18	1.530	3.0	1						
+				2	0.063	4.0	1	1.467	0.800
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				2.53e-001			1.18e-001	5.47e-002 +
1	0.000	5.0	1	1.530	0.200				
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):				2.39e-002			1.02e-002	
17	1.469	5.0	1						
+				2	0.063	4.0	1	1.406	0.400
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.44e-001			7.28e-002	3.68e-002 +
1	0.000	5.0	1	1.469	0.600				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.89e-001			8.77e-002	4.06e-002
16	1.436	3.0	1						
+				10	0.936	3.0	1	0.500	0.400
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				3.20e+000			1.28e+001	5.12e+001 +
4	0.602	4.0	1	0.834	0.600				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.03e+000			1.49e+000	2.14e+000

Table B-1. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
15	1.384	4.0	1						
+				4	0.602	4.0	1	0.782	0.600
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.25e+000			2.05e+000	3.36e+000 +
1	0.000	5.0	1	1.384	0.400				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.51e-001			7.88e-002	4.11e-002
14	1.095	6.0	1						
+				1	0.000	5.0	1	1.095	1.000
	Possible Multipoles					M1		E2	M3
13	1.069	3.0	1						
+				6	0.633	3.0	1	0.436	0.091
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.10e+000			5.78e+000	3.04e+001 +
4	0.602	4.0	1	0.467	0.145				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				1.42e+000			6.53e+000	2.99e+001
+				2	0.063	4.0	1	1.006	0.763
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				7.49e-001			7.41e-001	7.32e-001
12	1.033	4.0	1						
+				2	0.063	4.0	1	0.970	0.400
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				4.38e-001			4.66e-001	4.95e-001 +
1	0.000	5.0	1	1.033	0.600				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				5.44e-001			5.10e-001	4.78e-001
11	0.959	4.0	1						
+				2	0.063	4.0	1	0.896	0.700
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				9.73e-001			1.21e+000	1.51e+000 +
1	0.000	5.0	1	0.959	0.300				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				3.40e-001			3.70e-001	4.02e-001
10	0.936	3.0	1						
+				6	0.633	3.0	1	0.303	0.700
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				2.52e+001			2.74e+002	2.99e+003 +
4	0.602	4.0	1	0.334	0.300				
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				8.05e+000			7.22e+001	6.47e+002

Table B-1. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
9	0.925	2.0	1						
+	Possible Multipoles			6	0.633	3.0	1	0.292	1.000
						M1		E2	M3
8	0.886	5.0	1						
+	Possible Multipoles			2	0.063	4.0	1	0.823	0.500
						M1		E2	M3
	BR F/EG** (2L+1):				8.97e-001			1.32e+000	1.96e+000 +
1	0.000	5.0	1	0.886	0.500				
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):				7.19e-001			9.16e-001	1.17e+000
7	0.651	7.0	1						
+	Possible Multipoles			3	0.510	6.0	1	0.141	0.460
						M1		E2	M3
	BR F/EG** (2L+1):				1.64e+002			8.25e+003	4.15e+005 +
1	0.000	5.0	1	0.651	0.540				
	Possible Multipoles					E2		M3	
	BR F/EG** (2L+1):				4.62e+000			1.09e+001	
6	0.633	3.0	1						
+	Possible Multipoles			2	0.063	4.0	1	0.570	1.000
						M1		E2	M3
5	0.628	5.0	1						
+	Possible Multipoles			2	0.063	4.0	1	0.565	1.000
						M1		E2	M3
4	0.602	4.0							
+	Possible Multipoles			2	0.063	4.0	1	0.539	0.320
						M1		E2	M3
	BR F/EG** (2L+1):				2.04e+000			7.03e+000	2.42e+001
+	Possible Multipoles			1	0.000	5.0	1	0.602	0.680
						M1		E2	M3
	BR F/EG** (2L+1):				3.12e+000			8.60e+000	2.37e+001
3	0.510	6.0	1						
+	Possible Multipoles			1	0.000	5.0	1	0.510	1.000
						M1		E2	M3
2	0.063	4.0	1						
+	Possible Multipoles			1	0.000	5.0	1	0.063	1.000
						M1		E2	M3
1	0.000	5.0	1						

Example 2

In this example, we took 62 bandheads from a set of 291 discrete levels for ^{176}Lu , up to an excitation energy of about 1.5 MeV, among which the multipole branches had been calculated⁵ using only dipole transitions with $\text{CM1}/\text{CE1} = 6$. Then, we used the NUSTART code to recalculate the multipole branches among the band heads. We allowed CE1 to be energy dependent and introduced a significant number of E2 transitions. No levels were designated to be isomers before the start of the new calculation, and NUSTART located level 2 as the only isomer. Finally, the band-head level numbers were changed to their true values in the 291-level set via an input file that listed the pairs of bandhead option (old) and true (new) level numbers. In Tables B-2a through B-2h are shown the pertinent input and output information for this NUSTART calculation.

Table B2a. Set of bandhead levels for ^{176}Lu .

[illegible]

Table B2b. The strength-function parameters that were used for this sample calculation.

there are 62 levels for lu76b2

K - Quantum Number is Conserved

E. Dep. E1 $ce1 = 1.$ $cm1 = 3.2$ $ce2 = 0.32$

$$EI = 1. \quad ER1 = 12.309 \quad ER2 = 15.249 \quad GR1 = 2.491 \quad GR2 = 4.982 \quad \text{const.} = 13993.42$$

The value of the normalizing constant, k , for the energy-dependent E1 transitions was determined by NUSTART to be 13.993.42.

Table B2c. Bandhead levels for which K is not equal to J.

Bandhead levels have been set:

level = 2, K = 0.0

level = 12, K = 0.0

level = 40, K = 0.0

level = 42, K = 0.0

level = 62, K = 0.0

ENERGY (MeV)	SPIN (J)	PARITY	K
0.000	7.0	-1	0
0.123	1.0	-1	
0.198	1.0	+1	
0.343	1.0	+1	
0.372	8.0	+1	0
0.390	1.0	-1	
0.538	8.0	+1	
0.566	6.0	-1	
0.633	9.0	-1	
0.641	1.0	-1	
0.658	4.0	-1	
0.659	1.0	-1	
0.662	3.0	-1	
0.686	4.0	+1	
0.767	3.0	-1	
0.768	7.0	+1	
0.782	4.0	-1	
0.799	3.0	+1	
0.802	6.0	-1	
0.818	4.0	-1	
0.840	2.0	+1	
0.874	0.0	+1	
0.878	5.0	+1	
0.898	7.0	+1	
0.907	5.0	-1	
0.932	3.0	-1	
0.942	4.0	+1	
0.953	2.0	-1	
0.974	4.0	-1	
1.001	2.0	+1	
1.018	4.0	+1	
1.026	5.0	-1	
1.027	3.0	-1	
1.046	7.0	+1	
1.072	5.0	+1	
1.082	4.0	+1	
1.101	5.0	-1	
1.113	3.0	+1	
1.131	2.0	-1	

Table B-2c. (Continued).

ENERGY (MeV)	SPIN (J)	PARITY	K
1.133	1.0	-1	0
1.163	2.0	-1	
1.186	1.0	-1	0
1.210	2.0	-1	
1.211	0.0	+1	
1.214	5.0	+1	
1.218	8.0	-1	
1.231	1.0	-1	
1.273	1.0	-1	
1.292	6.0	+1	
1.307	2.0	+1	
1.324	1.0	-1	
1.339	3.0	+1	
1.342	3.0	-1	
1.367	1.0	+1	
1.379	6.0	+1	
1.397	1.0	+1	
1.410	3.0	-1	
1.412	1.0	-1	
1.432	4.0	-1	
1.440	1.0	+1	
1.468	2.0	-1	
1.489	1.0	-1	0

Table B-2d. Branching fractions before changing the band-head level number.

LEVEL NBR		BRANCHING FRACTIONS									
3	1	2.000									
4	2	2.175	3.825								
5	1	1.000									
6	2	2.981	3.019								
7	2	1.842	5.158								
8	1	1.000									
9	3	1.885	5.113	7.002							
10	4	2.830	3.064	4.013	6.093						
11	1	8.000									
12	4	2.817	3.067	4.014	6.101						
13	1	6.000									
14	2	11.650	13.350								
15	4	6.236	11.401	13.359	14.004						
16	4	1.580	5.349	7.068	8.003						
17	4	8.013	11.514	13.466	14.006						
18	5	3.684	4.172	11.009	13.008	14.126					
19	2	1.976	8.024								
20	6	8.012	11.496	13.460	14.010	15.016	17.006				
21	4	3.666	4.304	6.028	10.001						
22	6	2.167	3.541	4.262	6.028	10.001	12.001				
23	4	8.255	11.062	14.680	17.002						
24	5	1.497	5.372	7.117	8.009	16.005					
25	7	1.505	8.330	11.128	14.005	17.016	19.010	20.006			
26	9	6.084	10.004	11.371	13.354	14.018	15.081	17.060	18.002	20.027	
27	8	11.075	13.071	14.700	15.011	17.007	18.121	20.003	23.011		
28	7	2.093	3.230	4.096	6.434	10.072	13.059	15.015			
29	9	8.013	11.370	13.356	14.022	15.104	17.083	18.003	20.044	25.003	
30	7	3.605	4.326	6.045	10.005	13.004	18.009	21.005			
31	9	11.076	13.073	14.592	15.018	17.014	18.169	20.007	23.044	27.007	
32	9	1.373	8.326	11.166	13.002	14.012	17.048	19.037	20.030	25.006	
33	10	6.066	10.005	11.321	13.311	14.024	15.112	17.093	18.005	20.058	26.005
34	7	1.432	5.367	7.154	8.018	16.025	19.001	24.004			
35	10	8.189	11.084	14.582	16.003	17.020	19.015	20.012	23.073	25.002	27.022
36	10	11.076	13.073	14.517	15.023	17.019	18.187	20.011	23.070	27.023	31.002
37	10	1.317	8.309	11.174	13.003	14.017	17.064	19.053	20.045	25.014	29.004
38	10	3.248	4.105	11.048	13.046	14.306	15.016	17.013	18.121	21.079	27.019
39	10	2.089	3.199	4.099	6.365	10.102	13.090	15.042	18.003	26.007	28.005
40	6	2.527	3.110	4.055	6.201	10.057	12.051				
41	10	2.088	3.195	4.099	6.354	10.106	13.093	15.046	18.004	26.009	28.007
42	7	2.506	3.112	4.058	6.203	10.063	12.057	22.001			
43	10	2.087	3.189	4.100	6.339	10.110	13.098	15.051	18.005	26.012	28.010
44	6	2.190	3.445	4.280	6.059	10.013	12.012				
45	10	8.160	11.086	14.465	17.031	19.025	20.021	23.118	27.062	31.023	35.009
46	7	1.820	5.062	7.025	8.005	9.082	16.005	24.001			
47	10	2.484	3.113	4.060	6.202	10.067	12.061	13.002	21.002	22.001	28.007
48	10	2.468	3.115	4.063	6.202	10.071	12.065	13.002	21.003	22.002	28.009
49	10	1.647	5.047	7.017	8.059	16.105	19.012	23.051	24.044	34.011	35.008
51	10	2.450	3.116	4.066	6.201	10.076	12.070	13.003	21.004	22.003	28.012

Table B-2d. (Continued).

LEVEL	NBR	BRANCHING FRACTIONS									
52	10	3.171	4.086	11.056	13.055	14.256	18.143	21.112	27.056	30.034	31.029
53	10	6.052	11.223	13.219	14.037	15.131	17.121	20.098	26.047	28.040	29.033
54	10	2.171	3.399	4.261	6.062	10.018	12.016	21.033	22.026	28.002	30.011
55	10	1.584	5.050	7.020	8.064	16.115	19.016	23.063	24.055	34.018	35.014
56	10	2.171	3.391	4.258	6.064	10.020	12.018	21.035	22.028	28.002	30.013
57	10	6.052	11.211	13.208	14.039	15.130	17.121	20.101	26.053	28.046	29.039
58	10	2.423	3.119	4.070	6.200	10.082	12.076	13.004	21.005	22.004	28.017
59	10	11.210	13.207	14.040	15.131	17.122	20.103	25.064	26.055	29.041	32.029
60	10	2.170	3.381	4.255	6.066	10.021	12.019	21.039	22.031	28.003	30.015
61	10	2.086	3.166	4.100	6.274	10.118	13.109	15.071	26.031	28.027	33.017
62	10	2.410	3.123	4.075	6.202	10.089	12.083	22.006	40.006	42.004	47.002
end											

Table B-2e. File used to convert bandhead level numbers.

1	1	2	2	3	4	4	10	5	11	6	13	7	22	8	25	9	28	10	29	11	32	12	33	13	34
14	35	15	49	16	50	17	52	18	55	19	56	20	57	21	60	22	67	23	68	24	72				
25	74	26	79	27	83	28	89	29	91	30	95	31	101	32	104	33	105	34	110						
35	118	36	119	37	125	38	128	39	136	40	137	41	146	42	156	43	165	44	166						
45	167	46	169	47	174	48	186	49	195	50	202	51	211	52	215	53	217	54	230						
55	234	56	242	57	247	58	249	59	252	60	259	61	272	62	285										

Table B-2f. Branching fractions with true level numbers.

LEVEL NBR		BRANCHING FRACTIONS									
4	1	2.000									
10	2	2.175	4.825								
11	1	1.000									
13	2	2.981	4.019								
22	2	1.842	11.158								
25	1	1.000									
28	3	1.885	11.113	22.002							
29	4	2.830	4.064	10.013	13.093						
32	1	25.000									
33	4	2.817	4.067	10.014	13.101						
34	1	13.000									
35	2	32.650	34.350								
49	4	13.236	32.401	34.359	35.004						
50	4	1.580	11.349	22.068	25.003						
52	4	25.013	32.514	34.466	35.006						
55	5	4.684	10.172	32.009	34.008	35.126					
56	2	1.976	25.024								
57	6	25.012	32.496	34.460	35.010	49.016	52.006				
60	4	4.666	10.304	13.028	29.001						
67	6	2.167	4.541	10.262	13.028	29.001	33.001				
68	4	25.255	32.062	35.680	52.002						
72	5	1.497	11.372	22.117	25.009	50.005					
74	7	1.505	25.330	32.128	35.005	52.016	56.010	57.006			
79	9	13.084	29.004	32.371	34.354	35.018	49.081	52.060	55.002	57.027	
83	8	32.075	34.071	35.700	49.011	52.007	55.121	57.003	68.011		
89	7	2.093	4.230	10.096	13.434	29.072	34.059	49.015			
91	9	25.013	32.370	34.356	35.022	49.104	52.083	55.003	57.044	74.003	
95	7	4.605	10.326	13.045	29.005	34.004	55.009	60.005			
101	9	32.076	34.073	35.592	49.018	52.014	55.169	57.007	68.044	83.007	
104	9	1.373	25.326	32.166	34.002	35.012	52.048	56.037	57.030	74.006	
105	10	13.066	29.005	32.321	34.311	35.024	49.112	52.093	55.005	57.058	79.005
110	7	1.432	11.367	22.154	25.018	50.025	56.001	72.004			
118	10	25.189	32.084	35.582	50.003	52.020	56.015	57.012	68.073	74.002	83.022
119	10	32.076	34.073	35.517	49.023	52.019	55.187	57.011	68.070	83.023	101.002
125	10	1.317	25.309	32.174	34.003	35.017	52.064	56.053	57.045	74.014	91.004
128	10	4.248	10.105	32.048	34.046	35.306	49.016	52.013	55.121	60.079	83.019
136	10	2.089	4.199	10.099	13.365	29.102	34.090	49.042	55.003	79.007	89.005
137	6	2.527	4.110	10.055	13.201	29.057	33.051				
146	10	2.088	4.195	10.099	13.354	29.106	34.093	49.046	55.004	79.009	89.007
156	7	2.506	4.112	10.058	13.203	29.063	33.057	67.001			
165	10	2.087	4.189	10.100	13.339	29.110	34.098	49.051	55.005	79.012	89.010
166	6	2.190	4.445	10.280	13.059	29.013	33.012				
167	10	25.160	32.086	35.465	52.031	56.025	57.021	68.118	83.062	101.023	118.009
169	7	1.820	11.062	22.025	25.005	28.082	50.005	72.001			
174	10	2.484	4.113	10.060	13.202	29.067	33.061	34.002	60.002	67.001	89.007
186	10	2.468	4.115	10.063	13.202	29.071	33.065	34.002	60.003	67.002	89.009
195	10	1.647	11.047	22.017	25.059	50.105	56.012	68.051	72.044	110.011	118.008
202	10	4.488	10.312	13.069	29.019	34.016	35.003	49.008	55.043	60.033	95.009
211	10	2.450	4.116	10.066	13.201	29.076	33.070	34.003	60.004	67.003	89.012

Table B-2f. (Continued).

LEVEL NBR		BRANCHING FRACTIONS											
215	10	4.171	10.086	32.056	34.055	35.256	55.143	60.112	83.056	95.034	101.029		
217	10	13.052	32.223	34.219	35.037	49.131	52.121	57.098	79.047	89.040	91.033		
230	10	2.171	4.399	10.261	13.062	29.018	33.016	60.033	67.026	89.002	95.011		
234	10	1.584	11.050	22.020	25.064	50.115	56.016	68.063	72.055	110.018	118.014		
242	10	2.171	4.391	10.258	13.064	29.020	33.018	60.035	67.028	89.002	95.013		
247	10	13.052	32.211	34.208	35.039	49.130	52.121	57.101	79.053	89.046	91.039		
249	10	2.423	4.119	10.070	13.200	29.082	33.076	34.004	60.005	67.004	89.017		
252	10	32.210	34.207	35.040	49.131	52.122	57.103	74.064	79.055	91.041	104.029		
259	10	2.170	4.381	10.255	13.066	29.021	33.019	60.039	67.031	89.003	95.015		
272	10	2.086	4.166	10.100	13.274	29.118	34.109	49.071	79.031	89.027	105.017		
285	10	2.410	4.123	10.075	13.202	29.089	33.083	67.006	137.006	156.004	174.002		

Table B-2h is a portion of the data-analysis table for the multipole transitions that shows the lower 26 out of the 62 band-head levels. The numbering of the parent and daughter levels is the original numbering, before the true level numbers were introduced. Note that a restriction to only dipole transitions would force the 4⁻ level at 0.658 MeV to be diagnosed as an isomer, and the 3⁻ level at 0.662 MeV to decay to the above 4⁻ level by an M1 transition rather than by an E2 transition to the 1⁻ level at 0.390 MeV, as shown. Allowing even a small E2 strength can significantly change the relative populations of the ground state and the true isomer at 0.123 MeV.

Table B-2h. Portion of the data-analysis output file for ¹⁷⁶Lu.

GAMMA-RAY TRANSITIONS AMONG DISCRETE LEVELS										
Initial Level				Final Level						
N	E	J	P	N	E	J	P	EG	BR	F
26	0.932	3.0	-1							
+				20	0.818	4.0	-1	0.114	0.027	
	Possible Multipoles					M1		E2	M3	
	BR F/EG**(2L+1):				1.82e+001		1.40e+003		1.08e+005	
+				18	0.799	3.0	1	0.133	0.002	
	Possible Multipoles					E1		M2	E3	
	BR F/EG**(2L+1):				8.50e-001		4.81e+001		2.72e+003	
+				17	0.782	4.0	-1	0.150	0.060	
	Possible Multipoles						M1	E2	M3	
	BR F/EG**(2L+1):					1.78e+001		7.90e+002	3.51e+004	
+				15	0.767	3.0	-1	0.165	0.081	
	Possible Multipoles					M1		E2	M3	
	BR F/EG**(2L+1):				1.80e+001		6.62e+002		2.43e+004	
+				14	0.686	4.0	1	0.246	0.018	
	Possible Multipoles					E1		M2	E3	
	BR F/EG**(2L+1):				1.21e+000		2.00e+001		3.30e+002	
+				13	0.662	3.0	-1	0.270	0.353	
	Possible Multipoles					M1		E2	M3	
	BR F/EG**(2L+1):				1.79e+001		2.46e+002		3.37e+003	
+				11	0.658	4.0	-1	0.274	0.370	
	Possible Multipoles					M1		E2	M3	
	BR F/EG**(2L+1):				1.80e+001		2.40e+002		3.19e+003	
+				10	0.641	1.0	-1	0.291	0.004	
	Possible Multipoles					E2		M3		
	BR F/EG**(2L+1):				1.92e+000		2.26e+001			
+				6	0.390	1.0	-1	0.542	0.084	
	Possible Multipoles					E2		M3		
	BR F/EG**(2L+1):				1.80e+000		6.11e+000			

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
25	0.907	5.0	-1						
+				20	0.818	4.0	-1	0.089	0.006
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					8.51e+000		1.07e+003	1.36e+005
+				19	0.802	6.0	-1	0.105	0.010
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					8.64e+000		7.84e+002	7.11e+004
+				17	0.782	4.0	-1	0.125	0.016
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					8.19e+000		5.24e+002	3.36e+004
+				14	0.686	4.0	1	0.221	0.005
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					4.63e-001		9.48e+000	1.94e+002
+				11	0.658	4.0	-1	0.249	0.128
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					8.29e+000		1.34e+002	2.16e+003
+				8	0.566	6.0	-1	0.341	0.330
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					8.32e+000		7.16e+001	6.16e+002
+				1	0.000	7.0	-1	0.907	0.505
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):					8.23e-001		1.00e+000	
24	0.898	7.0	1						
+				16	0.768	7.0	1	0.130	0.005
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					2.28e+000		1.35e+002	7.97e+003
+				8	0.566	6.0	-1	0.332	0.009
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					2.46e-001		2.23e+000	2.02e+001
+				7	0.538	8.0	1	0.360	0.117
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					2.51e+000		1.93e+001	1.49e+002
+				5	0.372	8.0	1	0.526	0.372
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					2.56e+000		9.24e+000	3.34e+001
+				1	0.000	7.0	-1	0.898	0.497
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					6.86e-001		8.51e-001	1.06e+000

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
23	0.878	5.0	1						
+				17	0.782	4.0	-1	0.096	0.002
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):				2.26e+000			2.45e+002	2.66e+004
+				14	0.686	4.0	1	0.192	0.680
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):				9.61e+001			2.61e+003	7.07e+004
+				11	0.658	4.0	-1	0.220	0.062
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):				5.82e+000			1.20e+002	2.49e+003
+				8	0.566	6.0	-1	0.312	0.255
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):				8.40e+000			8.63e+001	8.86e+002
22	0.874	0.0	1						
+				12	0.659	1.0	-1	0.215	0.001
	Possible Multipoles					E1			
	BR F/EG** (2L+1):				1.01e-001				
+				10	0.641	1.0	-1	0.233	0.001
	Possible Multipoles					E1			
	BR F/EG** (2L+1):				7.91e-002				
+				6	0.390	1.0	-1	0.484	0.028
	Possible Multipoles					E1			
	BR F/EG** (2L+1):				2.47e-001				
+				4	0.343	1.0	1	0.531	0.262
	Possible Multipoles					M1			
	BR F/EG** (2L+1):				1.75e+000				
+				3	0.198	1.0	1	0.676	0.541
	Possible Multipoles					M1			
	BR F/EG** (2L+1):				1.75e+000				
+				2	0.123	1.0	-1	0.751	0.167
	Possible Multipoles					E1			
	BR F/EG** (2L+1):				3.94e-001				

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
21	0.840	2.0	1						
+				10	0.641	1.0	-1	0.199	0.001
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):					1.27e-001		3.20e+000	8.09e+001
+				6	0.390	1.0	-1	0.450	0.028
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):					3.07e-001		1.52e+000	7.49e+000
+				4	0.343	1.0	1	0.497	0.304
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					2.48e+000		1.00e+001	4.06e+001
+				3	0.198	1.0	1	0.642	0.666
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					2.52e+000		6.11e+000	1.48e+001
20	0.818	4.0	-1						
+				17	0.782	4.0	-1	0.036	0.006
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.29e+002		9.92e+004	7.66e+007
+				15	0.767	3.0	-1	0.051	0.016
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.21e+002		4.64e+004	1.78e+007
+				14	0.686	4.0	1	0.132	0.010
	Possible Multipoles					E1		M2	E3
	BR F/EG** (2L+1):					4.35e+000		2.50e+002	1.43e+004
+				13	0.662	3.0	-1	0.156	0.460
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.21e+002		4.98e+003	2.05e+005
+				11	0.658	4.0	-1	0.160	0.496
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.21e+002		4.73e+003	1.85e+005
+				8	0.566	6.0	-1	0.252	0.012
	Possible Multipoles					E2		M3	
	BR F/EG** (2L+1):					1.18e+001		1.86e+002	
19	0.802	6.0	-1						
+				8	0.566	6.0	-1	0.236	0.024
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.83e+000		3.28e+001	5.89e+002
+				1	0.000	7.0	-1	0.802	0.976
	Possible Multipoles					M1		E2	M3
	BR F/EG** (2L+1):					1.89e+000		2.94e+000	4.57e+000

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
18	0.799	3.0	1						
+				14	0.686	4.0	1	0.113	0.126
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				8.73e+001			6.84e+003	5.36e+005
+				13	0.662	3.0	-1	0.137	0.008
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				3.11e+000			1.66e+002	8.83e+003
+				11	0.658	4.0	-1	0.141	0.009
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				3.21e+000			1.61e+002	8.12e+003
+				4	0.343	1.0	1	0.456	0.172
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):				8.72e+000			4.20e+001	
+				3	0.198	1.0	1	0.601	0.684
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):				8.72e+000			2.42e+001	
17	0.782	4.0	-1						
+				14	0.686	4.0	1	0.096	0.006
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				6.78e+000			7.36e+002	7.98e+004
+				13	0.662	3.0	-1	0.120	0.466
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				2.70e+002			1.87e+004	1.30e+006
+				11	0.658	4.0	-1	0.124	0.514
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				2.70e+002			1.75e+004	1.14e+006
+				8	0.566	6.0	-1	0.216	0.013
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):				2.76e+001			5.93e+002	
16	0.768	7.0	1						
+				8	0.566	6.0	-1	0.202	0.003
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				3.64e-001			8.92e+000	2.19e+002
+				7	0.538	8.0	1	0.230	0.068
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				5.59e+000			1.06e+002	2.00e+003
+				5	0.372	8.0	1	0.396	0.349
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				5.62e+000			3.58e+001	2.29e+002
+				1	0.000	7.0	-1	0.768	0.580
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				1.28e+000			2.17e+000	3.68e+000

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
15	0.767	3.0	-1						
+				14	0.686	4.0	1	0.081	0.004
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					7.53e+000		1.15e+003	1.75e+005
+				13	0.662	3.0	-1	0.105	0.359
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					3.10e+002		2.81e+004	2.55e+006
+				11	0.658	4.0	-1	0.109	0.401
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):					3.10e+002		2.61e+004	2.19e+006
+				6	0.390	1.0	-1	0.377	0.236
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):					3.10e+001		2.18e+002	
14	0.686	4.0	1						
+				13	0.662	3.0	-1	0.024	0.350
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					2.53e+004		4.40e+007	7.63e+010
+				11	0.658	4.0	-1	0.028	0.650
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):					2.96e+004		3.78e+007	4.82e+010
13	0.662	3.0	-1						
+				6	0.390	1.0	-1	0.272	1.000
	Possible Multipoles					E2		M3	
12	0.659	1.0	-1						
+				6	0.390	1.0	-1	0.269	0.101
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):					5.19e+000		7.17e+001	
+				4	0.343	1.0	1	0.316	0.014
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):					4.44e-001		4.44e+000	
+				3	0.198	1.0	1	0.461	0.067
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):					6.84e-001		3.22e+000	
+				2	0.123	1.0	-1	0.536	0.817
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):					5.31e+000		1.85e+001	
11	0.658	4.0	-1						
+				8	0.566	6.0	-1	0.092	1.000
	Possible Multipoles					E2		M3	

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
10	0.641	1.0	-1						
+				6	0.390	1.0	-1	0.251	0.093
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):				5.88e+000			9.34e+001	
+				4	0.343	1.0	1	0.298	0.013
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):				4.91e-001			5.53e+000	
+				3	0.198	1.0	1	0.443	0.064
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):				7.36e-001			3.75e+000	
+				2	0.123	1.0	-1	0.518	0.830
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):				5.97e+000			2.23e+001	
9	0.633	9.0	-1						
+				7	0.538	8.0	1	0.095	0.002
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				2.33e+000			2.58e+002	2.86e+004
+				5	0.372	8.0	1	0.261	0.113
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				6.36e+000			9.33e+001	1.37e+003
+				1	0.000	7.0	-1	0.633	0.885
	Possible Multipoles					E2		M3	
	BR F/EG**(2L+1):				8.71e+000			2.17e+001	
8	0.566	6.0	-1						
+				1	0.000	7.0	-1	0.566	1.000
	Possible Multipoles					M1		E2	M3
7	0.538	8.0	1						
+				5	0.372	8.0	1	0.166	0.158
	Possible Multipoles					M1		E2	M3
	BR F/EG**(2L+1):				3.45e+001			1.25e+003	4.55e+004
+				1	0.000	7.0	-1	0.538	0.842
	Possible Multipoles					E1		M2	E3
	BR F/EG**(2L+1):				5.41e+000			1.87e+001	6.45e+001
6	0.390	1.0	-1						
+				3	0.198	1.0	1	0.192	0.019
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):				2.68e+000			7.28e+001	
+				2	0.123	1.0	-1	0.267	0.981
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):				5.15e+001			7.23e+002	

Table B-2h. (Continued).

Initial Level				Final Level					
N	E	J	P	N	E	J	P	EG	BR F
5	0.372	8.0	1						
+				1	0.000	7.0	-1	0.372	1.000
	Possible Multipoles					E1		M2	E3
4	0.343	1.0	1						
+				3	0.198	1.0	1	0.145	0.825
	Possible Multipoles					M1		E2	
	BR F/EG**(2L+1):					2.71e+002		1.29e+004	
+				2	0.123	1.0	-1	0.220	0.175
	Possible Multipoles					E1		M2	
	BR F/EG**(2L+1):					1.64e+001		3.40e+002	
3	0.198	1.0	1						
+				2	0.123	1.0	-1	0.075	1.000
	Possible Multipoles					E1		M2	
2	0.123	1.0	-1						
								***** ISOMER *****	
1	0.000	7.0	-1						

APPENDIX C. Sample NUSTART Structure Output File

Table C-1 is a sample of the structure-formatted output. This particular sample was generated by using the edit mode on the STAPLUS input file (consisting of the levels given in Table B-2a and the branching fractions given in Table B-2d) and asking for structure output.

Table C-1. Sample NUSTART output.

NUSTART vers 0.01.29		
Tue Jan 30 15:04:00 1990		
Results for 1u76b2		
E. Dep. E1 cel = 1. cml = 3.2 ce2 = 0.32		
E (keV)	J	Branching Fractions / Comments [Daughter level energy (% branching)]
0	7.0-	
123	1.0-	
198	1.0+	123(100.0)
343	1.0+	123(17.5) 198(82.5)
372	8.0+	0(100.0)
390	1.0-	123(98.1) 198(1.9)
538	8.0+	0(84.2) 372(15.8)
566	6.0-	0(100.0)
633	9.0-	0(88.5) 372(11.3) 538(0.2)
641	1.0-	123(83.0) 198(6.4) 343(1.3) 390(9.3)
658	4.0-	566(100.0)
659	1.0-	123(81.7) 198(6.7) 343(1.4) 390(10.1)
662	3.0-	390(100.0)

Table C-1 continued.

686	4.0+	658 (65.0) 662 (35.0)
767	3.0-	390 (23.6) 658 (40.1) 662 (35.9) 686 (0.4)
768	7.0+	0 (58.0) 372 (34.9) 538 (6.8) 566 (0.3)
782	4.0-	566 (1.3) 658 (51.4) 662 (46.6) 686 (0.6)
799	3.0+	198 (68.4) 343 (17.2) 658 (0.9) 662 (0.8) 686 (12.6)
802	6.0-	0 (97.6) 566 (2.4)
818	4.0-	566 (1.2) 658 (49.6) 662 (46.0) 686 (1.0) 767 (1.6) 782 (0.6)
840	2.0+	198 (66.6) 343 (30.4) 390 (2.8) 641 (0.1)
874	0.0+	123 (16.7) 198 (54.1) 343 (26.2) 390 (2.8) 641 (0.1) 659 (0.1)
878	5.0+	566 (25.5) 658 (6.2) 686 (68.0) 782 (0.2)
898	7.0+	0 (49.7) 372 (37.2) 538 (11.7) 566 (0.9) 768 (0.5)
907	5.0-	0 (50.5) 566 (33.0) 658 (12.8) 686 (0.5) 782 (1.6) 802 (1.0) 818 (0.6)
932	3.0-	390 (8.4) 641 (0.4) 658 (37.0) 662 (35.3) 686 (1.8) 767 (8.1) 782 (6.0) 799 (0.2) 818 (2.7)
942	4.0+	658 (7.5) 662 (7.1) 686 (70.0) 767 (1.1) 782 (0.7) 799 (12.1) 818 (0.3) 878 (1.1)
953	2.0-	123 (9.3) 198 (23.0) 343 (9.6) 390 (43.4) 641 (7.2) 662 (5.9) 767 (1.5)
974	4.0-	566 (1.3) 658 (37.0) 662 (35.6) 686 (2.2) 767 (10.4) 782 (8.3) 799 (0.3) 818 (4.4) 907 (0.3)
1001	2.0+	198 (60.5) 343 (32.6) 390 (4.5) 641 (0.5) 662 (0.4) 799 (0.9) 840 (0.5)
1018	4.0+	658 (7.6) 662 (7.3) 686 (59.2) 767 (1.8) 782 (1.4) 799 (16.9) 818 (0.7) 878 (4.4) 942 (0.7)
1026	5.0-	0 (37.3) 566 (32.6) 658 (16.6) 662 (0.2) 686 (1.2) 782 (4.8) 802 (3.7) 818 (3.0) 907 (0.6)
1027	3.0-	390 (6.6) 641 (0.5) 658 (32.1) 662 (31.1) 686 (2.4) 767 (11.2) 782 (9.3) 799 (0.5) 818 (5.8) 932 (0.5)

Table C-1 continued.

1046	7.0+	0 (43.1)	372 (36.6)	538 (15.3)	566 (1.8)	768 (2.5)	802 (0.1)	898 (0.4)
1072	5.0+	566 (18.8)	658 (8.3)	686 (58.0)	768 (0.3)	782 (2.0)	802 (1.5)	818 (1.2)
				878 (7.2)	907 (0.2)	942 (2.2)		
1082	4.0+	658 (7.6)	662 (7.3)	686 (51.6)	767 (2.3)	782 (1.9)	799 (18.6)	818 (1.1)
				878 (7.0)	942 (2.3)	1018 (0.2)		
1101	5.0-	0 (31.7)	566 (30.9)	658 (17.4)	662 (0.3)	686 (1.7)	782 (6.4)	802 (5.3)
				818 (4.5)	907 (1.4)	974 (0.4)		
1113	3.0+	198 (24.7)	343 (10.4)	658 (4.8)	662 (4.6)	686 (30.5)	767 (1.6)	782 (1.3)
				799 (12.0)	840 (7.9)	942 (1.9)		
1131	2.0-	123 (8.9)	198 (19.8)	343 (9.9)	390 (36.4)	641 (10.1)	662 (9.0)	767 (4.2)
				799 (0.3)	932 (0.7)	953 (0.5)		
1133	1.0-	123 (52.6)	198 (10.9)	343 (5.5)	390 (20.0)	641 (5.7)	659 (5.1)	
1163	2.0-	123 (8.8)	198 (19.4)	343 (9.9)	390 (35.3)	641 (10.5)	662 (9.3)	767 (4.5)
				799 (0.4)	932 (0.5)	953 (0.7)		
1186	1.0-	123 (50.6)	198 (11.2)	343 (5.8)	390 (20.3)	641 (6.3)	659 (5.7)	874 (0.1)
1210	2.0-	123 (8.7)	198 (18.8)	343 (10.0)	390 (33.8)	641 (10.9)	662 (9.8)	767 (5.1)
				799 (0.5)	932 (1.2)	953 (1.0)		
1211	0.0+	123 (19.0)	198 (44.5)	343 (28.0)	390 (5.9)	641 (1.3)	659 (1.2)	
1214	5.0+	566 (16.0)	658 (8.6)	686 (46.5)	782 (3.1)	802 (2.5)	818 (2.1)	878 (11.8)
				942 (6.2)	1018 (2.3)	1072 (0.9)		
1218	8.0-	0 (82.0)	372 (6.2)	538 (2.5)	566 (0.5)	633 (8.2)	768 (0.5)	898 (0.1)
1231	1.0-	123 (48.4)	198 (11.3)	343 (6.0)	390 (20.2)	641 (6.7)	659 (6.1)	662 (0.2)
				840 (0.2)	874 (0.1)	953 (0.7)		
1273	1.0-	123 (46.8)	198 (11.5)	343 (6.3)	390 (20.2)	641 (7.1)	659 (6.5)	662 (0.2)
				840 (0.3)	874 (0.2)	953 (0.9)		
1292	6.0+	0 (64.6)	372 (4.7)	538 (1.7)	566 (5.9)	768 (10.4)	802 (1.2)	878 (5.1)
				898 (4.4)	1046 (1.1)	1072 (0.8)		
1307	2.0+	198 (48.8)	343 (31.2)	390 (6.9)	641 (1.9)	662 (1.6)	686 (0.3)	767 (0.8)
				799 (4.3)	840 (3.3)	1001 (0.9)		

Table C-1 continued.

1324	1.0-	123(44.9)	198(11.5)	343(6.6)	390(20.0)	641(7.6)	659(7.0)	662(0.3)	840(0.4)	874(0.3)	953(1.2)
1339	3.0+	198(17.1)	343(8.6)	658(5.6)	662(5.5)	686(25.6)	799(14.3)	840(11.2)	942(5.6)	1001(3.4)	1018(2.9)
1342	3.0-	390(5.2)	658(22.2)	662(21.8)	686(3.7)	767(13.0)	782(12.0)	818(9.8)	932(4.7)	953(4.0)	974(3.3)
1367	1.0+	123(17.1)	198(39.9)	343(26.1)	390(6.2)	641(1.8)	659(1.6)	840(3.3)	874(2.6)	953(0.2)	1001(1.1)
1379	6.0+	0(58.4)	372(5.0)	538(2.0)	566(6.4)	768(11.5)	802(1.6)	878(6.3)	898(5.5)	1046(1.8)	1072(1.4)
1397	1.0+	123(17.1)	198(39.1)	343(25.8)	390(6.4)	641(2.0)	659(1.8)	840(3.5)	874(2.8)	953(0.2)	1001(1.3)
1410	3.0-	390(5.2)	658(21.1)	662(20.8)	686(3.9)	767(13.0)	782(12.1)	818(10.1)	932(5.3)	953(4.6)	974(3.9)
1412	1.0-	123(42.3)	198(11.9)	343(7.0)	390(20.0)	641(8.2)	659(7.6)	662(0.4)	840(0.5)	874(0.4)	953(1.7)
1432	4.0-	658(20.9)	662(20.6)	686(4.0)	767(13.0)	782(12.1)	818(10.2)	907(6.3)	932(5.4)	974(4.1)	1026(2.9)
1440	1.0+	123(17.0)	198(38.1)	343(25.5)	390(6.6)	641(2.1)	659(1.9)	840(3.9)	874(3.1)	953(0.3)	1001(1.5)
1468	2.0-	123(8.6)	198(16.6)	343(10.0)	390(27.4)	641(11.8)	662(10.9)	767(7.1)	932(3.1)	953(2.7)	1027(1.7)
1489	1.0-	123(41.0)	198(12.3)	343(7.5)	390(20.2)	641(8.9)	659(8.3)	874(0.6)	1133(0.6)	1186(0.4)	1231(0.2)

Appendix D. Error Messages

When NUSTART encounters an error, the program clears the screen and writes the error message to the screen. It also writes the error message to the data-analysis file. The program pauses until you hit a key to force it to continue. When the error message is only a warning, the program will continue and finish the current process. Fatal errors, however, will cause the program to terminate the current process and return to the main menu.

Table D-1. NUSTART error messages.

Error	Comment
#1 Error on reading levels; possible missing data.	There was a problem reading the STAPLUS format input deck. Check to verify that the level information is correct.
#2 Error on reading levels; too few levels were read.	The first card of the STAPLUS file declared that there were "N" levels in the deck, but NUSTART encountered an END-OF-FILE before "N" levels were read. Correct your input deck.
#3 Level energies are out of sequence.	The level energies must be in numeric order from low to high. The level energies that are out of order are listed in the data-analysis file. Correct your deck.
#4 Unexpected END-OF-LINE in reading branching information. Check data.	This error should never occur. If it does occur, it means that the the code could not read the end_of_line delimiter and there is something wrong with your data.
#5 Attempt to read too many branching fractions. Check the format of the deck.	
#6 Ground state level card was read. Check the format of the deck	
#7 Last branching fraction level number exceeds the number given on card 1 of the input. Check the input deck.	
#8 Number of levels null or equal zero.	The number of levels given on card 1 of the STAPLUS format input deck is a zero or a negative number. Check the input deck.

Table D-1 continued.

#9 Error in branching fraction for level 'N.' The branching fractions may be spurious	This error occurs during the normalization of the input data. Check your input deck.
#10 Error reading branching fractions; EOL not found; check the format of the data.	This error should never occur. If it does occur, it means that the the code could not read the end_of_line delimiter and there is something wrong with your data.
#11 Could not create output file; please retry.	Check to be sure that you have enough disk space to create a file, or that the path you gave in the file name is a valid path.
#12 Could not create DATA ANALYSIS file; terminating.	You probably do not have enough disk space to create another file, or the path you gave for the file name is not valid.
#13 Error on input of branching fractions, you have attempted to branch to an undefined level.	
#14 Error in physics routine. There was an attempt to address a nonexistent array value in the con array (CE1, CE2, CM1).	
#15 Error in physics routine. There was an attempt to divide by zero when calculating a new value for CE1.	
#16 Error in physics routine. There was an attempt to divide by zero when calculating the constant for an energy dependent CE1.	
#17 WARNING: a transition type other than E1, E2, E3, M1, M2, or M3 has been calculated.	
#18 Error in summing branching factors. The sum = 0; terminating.	
#19 Error in reading branching fractions. END card not found, exceeded NDISK levels.	Check your input deck, the END card appears to be missing.

Table D-1 continued.

#20 Unexpected END_OF_FILE while reading branching fractions data. Data will be used without branching fractions.	The header card stated there were more levels than exist in the data set. The program continued so that the rest of the data could be analyzed. Correct your data set.