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## ABSTRACT.

A brief outline of nuclear model codes used by the Nuclear Data Group of the CNEN Computing Centre (Bologna) is provided. Some of the results obtained by using different codes, approximations or computers are sometimes compared.

## 1. INTRODUCTION

The use of nuclear models and electronic computers for the calculation of nuclear data was started at the CNEN Computing Centre (Bologna) since the establishment of the Centre itself (July 1960). This activity was initially undertaken with the limited aim of estimating neutron capture cross-sections in the unresolved resonance region for fission product nuclei of importance for fuel cycle calculations. However, the role of the nuclear models for the evaluation work (especially in connection with the nuclear data requirements for fast reactors) was soon recognized. It was therefore decided to establish a permanent full-time group working on the development and applications of nuclear model codes. During this decennial activity various home-made codes, some of which are now obsolete, have been produced and used. Codes developed elsewhere have been used too, sometimes introducing changes to implement the codes on the computers available at the Centre.

A short account of the codes now in use is given in the following. When not otherwise stated, the programmes are written in FORTRAN IV for the IBM-7094 and/or IBM-360/75 computers.

## 2. STATISTICAL MODEL CODES

a) SAUD [1]. This code was devised in order to calculate  $(n,\gamma)$  cross-sections by statistical model in the framework of the Lane-Lynn formalism [2]. It was originally written for the IBM-650 and its performances are therefore rather limited. Neutron s- and p-waves only are taken into account, and the competition of the inelastic scattering with the capture process is not considered. The Porter-Thomas distribution is assumed for the reduced neutron widths of both angular momenta ( $l=0,1$ ). This implies numerical computations of the error-function, which in the original version (written in BELL) was approximated using a recipe given by Hasting [3]. Such an approximation does not hold whenever very small values of the strength-functions are involved. Recently, the programme has been modified in order to adopt the usual computer subroutine for the error function (IBM-360/75 version). The input parameters required are, among the others, the average radiation width, the average spacing of  $J=0$  compound nucleus levels and the strength-functions  $\bar{S}_0$ ,  $\bar{S}_1$ . The target nucleus spin  $I$  can be 0 or a half-integer up

to 9/2. Typical running times are ~0.25 sec for 20 energy points (IBM-360/75 version).

More recently (1969) a very similar programme was written by Bhat [4]. This programme, named AVERAGE, calculates not only the capture but the compound elastic scattering and fission cross-sections as well. It is written in such a way that the unresolved resonance parameters given in ENDF/B, File 2, can be fed in directly as input data. Results provided by SAUD and AVERAGE were compared at our Centre for a number of cases. It was found that the results for the  $\ell=0$  component were nearly identical, but those for  $\ell=1$  showed very large discrepancies. After inspection of the formulae contained in AVERAGE (version distributed by the ENEA CPL-Ispra), it turned out that the number of accessible reaction channels  $e_{j\ell}^{\downarrow}$  is probably missing in AVERAGE<sup>(1)</sup>. In Table I the results of a sample calculation for  $^{197}\text{Au}$  are shown. The adopted parameters are those of ENDF/B-II.

As one can see by comparing columns A (SAUD) and B (AVERAGE), the two programmes agree quite well for  $\ell=0$ , but they are strongly in disagreement for  $\ell=1$ . Column C shows the results obtained by introducing in AVERAGE the number of accessible reaction channels  $e_{j\ell}^{\downarrow}$ . With such a modification the results given by SAUD and AVERAGE show a much closer agreement, differences being very likely due to the different methods adopted in performing the Porter-Thomas average.

b) FISPRO [5]. This code was written in order to quickly carry out a large amount of neutron radiative cross-section calculations. The availability of a very fast code is of primary importance when the gross behaviour of the capture cross-section for bulk fission product nuclei has to be evaluated. In such a circumstance, in fact, an estimate of several thousand cross-section values is required. The model adopted in FISPRO is essentially the Hauser-Feshbach one as developed by Margolis [6]. In addition, the code allows for a rough estimate of the cross-sections for the following processes:

- i) one-photon "evaporation"
- ii) two-photons "evaporation"
- iii) direct and semi-direct capture.

In the last version (FISPRO-II), two different formulae can be selected for the energy dependence of  $\Gamma_{\gamma}$ , based on the so-called "Weisskopf" and "Axel" estimates respectively. A  $(2J+1)$  law is adopted for the spin dependence of the level density.

As far as the choice of the neutron penetrabilities  $T_{\ell}$  is concerned, there are three options:

- 1) The  $T_{\ell}$  are computed according to the strong interaction model ( $\ell \leq 4$ ).
- 2) The  $T_{\ell}$  are computed by means of the spherical optical model ( $\ell \leq 9$ ).  
The following optical potentials are allowed (without spin-orbit coupling): Saxon-Woods, Buck-Perey, Gauss and square-well.
- 3) The  $T_{\ell}$  are given in input ( $\ell \leq 9$ ).

One of the main deficiencies of the programme is due to the fact that the Porter-Thomas distribution of the reduced neutron widths is not taken into account. In the version for the IBM-7094, typical running times range from 0.5 to 10 sec per energy point, depending on the adopted option.

For some nuclei, Gardner [7] compared the results given by FISPRO with those given by ABACUS-NEARREX. Unfortunately the adopted  $T_{\ell}$  were not

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(1) In the formula for the elastic scattering a summation too seems to be missing.

the same in both cases, so that definite conclusions cannot be drawn concerning the observed differences. Cross-sections for the photon "evaporation" process in  $^{127}\text{I}$  neutron capture were calculated by Sperber [8] and compared with those given by FISPRO. Discrepancies of about a factor three at  $\sim 5$  MeV up to 2-3 order of magnitude at  $\sim 14$  MeV were found, Sperber's values being always larger. These discrepancies were explained mainly in terms of the different level density formulae adopted. The formula used by Sperber, in fact, assumes a more sophisticated spin dependence than the  $(2J+1)$  one. It is not clear, however, whether or not the competition of the  $(n,\gamma n')$  process is taken into account by Sperber<sup>(2)</sup>. It is obvious that if such a competition is ignored, the calculated cross-sections are those for all radiative processes which, at high energies, are in general much larger than those for the capture process only.

c) MARE [9]. This programme was written in order to estimate the cross-sections for reactions induced by particles of several MeV kinetic energy. The theoretical background is provided by the evaporation model and the Blatt-Ewing formula. The programme gives the cross-sections for  $(x;a)$ ,  $(x;a,b)$ ,  $(x;a,b,n)$  processes, where the symbols  $x$ ,  $a$  and  $b$  represent neutrons, protons, alpha or gamma rays indifferently. It is assumed that compound nucleus processes only take place and that no more than three successive particle emissions are energetically allowed. Typical running times are  $\sim 3$  sec for an  $(x;a,b)$  reaction (one energy point) on the IBM-360/75.

d) SASSI [10]. This programme calculates the  $\frac{1}{2}$  spin neutron scattering cross-sections by a spherical potential with a spin-orbit term. The programme outputs are the total and reaction cross-sections, as well as the angular distributions for shape-elastic and compound nucleus processes (elastic and inelastic). The theoretical backgrounds are provided by the spherical optical model and the Hauser-Feshbach statistical model as modified by Goldmann and Lubitz [11] to include spin-orbit effects. Porter-Thomas fluctuations and competition of reactions other than  $(n,n)$  and  $(n,n')$  are not considered. In the IBM-360/75 version, angular momenta up to  $l=50$  are allowed, and the maximum number of excited levels admitted is 100. No option for automatic search for best fit parameters is provided.

SASSI is very similar to the well known ABACUS, whose numerical results have been found to be well in agreement with those given by SASSI. In Table II an example of such an agreement is given. The numerical results are those of SASSI and ABACUS-II (GE-625 version) for the sample problem reported in GEMP-447.

e) ISOSTA [12]. This programme was written to calculate the cross-sections for compound nucleus neutron radiative capture processes leading to isomeric states. The theoretical backgrounds are given by the Hauser-Feshbach and Huizenga-Vandenbosch [13] theories. This programme has not yet been fully tested.

### 3. OPTICAL MODEL CODES

a) SMOG [14]. The mathematical aspects of this programme, whose first version was written several years ago for the IBM-704 computer, are very similar to those of the well known SCAT programme [15]. It was included in SASSI (see above) to carry out the spherical optical model calculations required by

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(2) Our attention on this point was called by D.G. Gardner (private communication).

that programme, so that the reader can refer to SASSI for a short description of its performances.

b) ADAPE [16]. This programme can calculate the total cross-section and the total and differential elastic and direct inelastic scattering cross-sections for 0 or  $\frac{1}{2}$  spin nuclear particles from a rotational permanently deformed nucleus of either even or odd A. The theoretical background is provided by the coupled channel theory in adiabatic approximation. Numerical results were found to be in close agreement with those given by the revised version of JUPITOR (see below). Typical running times are of the order of 5 min on the IBM-7094 and  $\sim$ 1 min on the IBM-360/75 computer.

c) DUMBO [17] and DANGFASI [18]. These programmes, written in FORTRAN II, belong to the series of generalized optical model codes for even-even nuclei, like the 2-PLUS code written by Dunford [19].

DUMBO (1963), calculates the 0 spin neutron scattering from target even-even collective nuclei with a coupled channel method. Only the coupling between the ground state and the first  $2^+$  excited state of the target is taken into account. The  $2^+$  target level can be either of vibrational or of rotational kind. The programme outputs are constituted by the total cross-section, the reaction cross-section, the total and differential shape elastic and direct  $2^+$  inelastic cross-sections, the strength functions and penetrabilities. Typical running times are of the order of 1 min.

DANGFASI is an extension of DUMBO to the case of  $\frac{1}{2}$  spin incident neutrons. In addition, the programme calculates the elastic scattering phase-shifts as well as the polarization of the scattered neutron. Typical running times are of the order of 2 min on the IBM-7094. Numerical results agree very well with those given by 2-PLUS (see Table III-B). It has to be noted that in these two programmes the interaction potential is developed (to the first order) in powers of the deformation parameter. Such a feature must be taken into account whenever comparing numerical results of DUMBO and DANGFASI with those given by other programmes using a Legendre polynomial expansion.

d) "JUPITOR". A version of the JUPITOR code [20] for CDC computers, kindly provided to the CNEN Computing Centre by the author T. Tamura, was checked <sup>(3)</sup> in almost all its parts and implemented <sup>(3)</sup> for the IBM-7094 and IBM-360/75 computers. Several clerical errors were found and some incompatibilities between CDC and IBM FORTRAN languages were removed. As stated above, the numerical results obtained whenever the adiabatic approximation is used are in very good agreement with the results given by ADAPE. An example is given in Table III-A, where results of ADAPE and "JUPITOR" are compared for the case of 7.5 MeV neutrons scattered by  $^{165}\text{Ho}$ .

The following set of parameters was adopted:

$$\left. \begin{array}{l} V = 45.5 \\ W_D = 5.75 \\ V_{SO} = 10 \end{array} \right\} \text{ MeV} \quad \left. \begin{array}{l} a_V = a_{VSO} = 0.58 \\ a_{WD} = 0.35 \\ r_{OV} = r_{OWD} = r_{OVSO} = 1.25 \end{array} \right\} \text{ fm}$$

with  $\beta=0.30$  and  $l_{\text{max}} = 8$ . The adopted level spins and parities were  $7/2^+$ ,  $9/2^+$ ,  $11/2^+$ .

To further test the code, calculations were carried out assuming the

<sup>(3)</sup> By F. Fabbri and P.L. Ottaviani.

deformation parameter  $\beta=0$ . In this way the optical potential is reduced to the spherical one, and it is therefore possible to compare the numerical results obtained with those given by other codes. Table III-B provides an example of such a comparison among the codes SASSI, 2-PLUS and "JUPITOR". The calculated cross-sections are those for 1 MeV neutrons interacting with  $^{184}\text{W}$ . The adopted parameters were:

$$\left. \begin{array}{l} V = 45.05 \\ W_D = 6.68 \\ V_{SO} = 6.20 \end{array} \right\} \text{ MeV} \qquad \left. \begin{array}{l} a_V = a_{VSO} = 0.65 \\ a_{WD} = 0.47 \\ r_{OV} = r_{OWD} = r_{OVSO} = 1.25 \end{array} \right\} \text{ fm}$$

with  $l_{\text{max}} = 5$ .

The adopted level scheme was:  $0, (0^+)$ ;  $0.111(2^+)$ ;  $0.364(4^+)$ ;  $0.750(6^+)$ ;  $0.904(2^+)$ .

In Table III-B a comparison among 2-PLUS, "JUPITOR" and DANGFASI for the same case but with  $\beta=0.24$  is also shown. The rotor model was assumed, with a deformed potential developed in powers of  $\beta$  up to the first order. Obviously, only the coupling  $(0^+, 2^+)$  was considered in "JUPITOR". The small differences among the numerical results are almost entirely due to the fact that "JUPITOR" uses an integration method with variable mesh, whereas in 2-PLUS and DANGFASI a fixed mesh method is adopted.

#### 4. DIRECT INTERACTION CODES

a) DIRCO [21]. This programme calculates the dipole radiative capture of nucleons by nuclei in the framework of the "direct" and "collective" models. In particular, the direct and collective capture cross-sections for individual single-particle bound states are calculated for a given incident nucleon energy. The total cross-section is then given as the sum of the contributions over all possible final states. The incident particle and the target nucleus are assumed to interact through a spherical optical potential including the spin-orbit interaction. The target nucleus is assumed to have zero-spin. The interference between the two capture processes is taken into account in the calculations. The programme has a vast flexibility as to the shape of the interaction that can be used. The programme outputs are the cross-sections and the radial integrals for individual transitions. Optionally, cross-sections (total, direct, collective and interference), wave-functions, and radial integral squares can be plotted vs. the incident nucleon energy.

b) KISS [22]. This code was written to calculate the cross-section for quadrupole direct radiative capture of nucleons by nuclei. Its performances and outputs are very similar to those of DIRCO.

c) PRODE [23]. This code calculates the cross-section for direct (n,p) reactions. The physical background is given by the Brown-Muirhead [24] model, which assumes a Fermi-gas representation of the nucleus. The programme calculates the probability that a proton is knocked-out by the impinging neutron without further collisions. From this probability, the cross-section for the (volume) direct (n,p) reaction is easily obtained. The outputs are the cross-section as well as the energy distribution of the emitted protons. Typical running times are ~0.5 sec for one energy point on the IBM-360/75.

## 5. MICROSCOPIC MODEL CODES

- a) SURF [25]. The output data of this programme are the dipole photoreaction cross-sections of doubly closed shell nuclei in the one particle-one hole continuum approximation. The Schrödinger equation of the system is solved in the coordinate space by means of the coupled-channel method, taking into account the isospin mixing between the  $T=1$  and  $T=0$  states.
- b) MIDI [26]. The programme calculates the dipole radiative capture cross-sections of nucleons by even-even nuclei using a coupled-channel method. The model assumes that the incident nucleon interacts with the target through a Woods-Saxon potential taking into account the target excitations in the giant resonance region. The spectrum of the target can be described by means of a collective model (phonon excitations) or by a microscopic model (1p-1h excitations in Tamm-Dancoff or RPA approximation).
- c) MITOC [27]. The code can calculate the elastic scattering phase-shifts and cross-sections for incident nucleons on even-even nuclei with a microscopic description of target states. The wave-equation is solved in the framework of the coupled-channel theory.
- d) RES [28]. This programme allows to extract the spectroscopic parameters (resonance energy, total and partial widths, configuration mixing coefficients) of a resonant cross-section calculated using a microscopic coupled-channel model.
- e) JUPITOR MICRO [29]. Tamura's JUPITOR code was extended to the case of odd-deformed nuclei to allow for the presence of several rotational bands. A nuclear level of given angular momentum is described as a sum of nuclear levels of equal angular momentum belonging to different bands (band-mixing). The excitation of rotational bands other than the fundamental one is obtained, even in absence of band mixing, by introducing a microscopic nucleon-nucleon interaction allowing the transition of the bound odd nucleon to different orbits. The different intrinsic levels of the various bands are thus generated. Space-exchange effects between the projectile and the odd-target nucleon are ignored.

## 6. MISCELLANEA

Many auxiliary programmes developed at the CNEN Computing Centre are strictly connected with the use and development of nuclear model codes. Among the others, it is worthwhile mentioning the following:

- a) SPEC [30]. It calculates the  $\gamma$ -ray spectra from radiative nucleon capture reactions in the MeV nucleon energy range according to direct and collective mechanisms. To compare calculated and measured spectra, the programme relies on DIRCO to calculate the cross-sections spreading them over an energy interval corresponding to the resolution of the spectrometer.
- b) LILABNER [31]. Calculating the level density parameter  $a$  of the Fermi-gas model. Eight different expressions of the level density formula are considered by the programme.
- c) FGETA [32]. This subroutine calculates the regular and irregular Coulomb functions and their derivatives.
- d) BOSTAW [33]. The programme calculates the normalized eigenfunctions for a nucleon bound in a Woods-Saxon well. If the potential well is known, the programme provides the eigenvalues and viceversa.

e) RAFF [34]. Radial form factors suitable for inelastic scattering calculations can be obtained through this programme. The single-particle wave functions used in the calculations may be eigenstates either of a Woods-Saxon potential well or of an oscillator potential well. Gaussian, Yukawa or Coulomb radial dependence can be used for the two-body interaction.

f) EXODUS [35]. An IBM-360 system code analysing inelastic scattering continuum spectra on the basis of H.F. theory. The code takes advantage of the IBM-2250 Display Unit. By using SASSI, the code calculates:

- the usual quantities of the (spherical) optical model;
- the excitation functions of the various levels in the framework of the conventional H.F. theory;
- a gaussian convolution of groups of inelastic differential cross-sections at a given angle.

The average cross-sections observed are thus simulated. The results of the calculation are plotted on the Display Unit, together with the experimental data. Through a conservative interaction, it is possible to modify:

- i) the optical model parameters;
- ii) the target nucleus level scheme (energies, spins and parities);

until a reasonable fit is achieved for the experimental data. As an example, the figure shows the results of a preliminary analysis of the Perey-Kinney data at 8.56 MeV for  $^{23}\text{Na}$  (ORNL-4518). At this incident neutron energy more than 50 levels can be excited; for most of them, however, the spin and parity assignment is unknown. The experimental data refer to  $90^\circ$  degrees in the Lab. system and are in unit of mb/sr/25 keV. The energy spread is approximately gaussian with  $\sim 160$  keV F.W.H.M. - The excitation energy of the residual nucleus ranges from  $\sim 5.5$  MeV up to  $\sim 7$  MeV.

Picture a) shows the theoretical result (continuous curve) obtained by assuming an arbitrary spin and parity assignment for the unknown levels. Picture b) shows the final result, after the unknown quantities have been selected on the basis of a trial- and error procedure. Both pictures have been obtained directly by taking a photograph of the D.U. screen.

g) NILSSON [36]. This programme calculates the eigenvalues and the eigenfunctions of the hamiltonian of a single  $\frac{1}{2}$  spin particle subject to a Nilsson potential, i.e. an axially deformed harmonic oscillator potential plus  $l.s$  and  $l.l$  contributions. As in Nilsson's work, the representation chosen for the diagonalization of the total hamiltonian is the isotropic-oscillator one where  $l^2$  and  $l_z, s_z$  (the orbital and spin angular momentum components along the axis of symmetry) are diagonal. However, the eigenfunctions are also expressed in the representation where the total angular momentum  $j=l+s$  and its component along the axis of symmetry  $j_z$  are diagonal. Major shell mixing is allowed. For each orbit the intrinsic quadrupole moment, the mean value of the potential and of  $r^2, r^4, r^4 Y_2^0(\theta)$  as well as the orbital density, are calculated. The decoupling parameter is calculated for orbits having the component of  $j_z$  equal to  $\frac{1}{2}$ . The programme can also be used to study the properties of different intrinsic states of a nucleus. For each single combination of occupied levels the total energy, the intrinsic quadrupole moment of the matter distribution, the mean value of  $r^2, r^4, r^4 Y_2^0(\theta)$  are calculated, along with the density, if requested.

Performing the calculation for different values of the potential deformation, the energy minimum and the equilibrium deformation of each intrinsic state can be found.

## 7. CONCLUSIVE REMARKS

The main features of the nuclear model codes in use at the CNEN Computing Centre are summarized in Table IV. In spite of the fact that these codes appear to be useful in the study of a number of problems, it is clear that a substantial effort is still necessary in order to face the various needs of the nuclear data evaluation work. For example, no codes dealing with the fission process have yet been developed or used by the Nuclear Data Group, and no self-consistent, comprehensive nuclear theory calculation system is, as of now, available at the Bologna Centre.

Last, but not least, it should be noted that the nuclear model codes are of little use if they are not supported by good sets of parameters. A large amount of analyses is still necessary in this field to improve the present unsatisfactory situation.

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TABLE I

A comparison between SAUD and AVERAGE for  $^{197}\text{Au}$ 

$E_n$ (keV)	$\sigma(n, \gamma)$ (barn)	$l = 0$		$l = 1$		
		A	B	A	B	C
1	7.849	7.849	7.875	0.148	0.109	0.163
2	4.392	4.392	4.404	0.248	0.151	0.226
3	3.106	3.106	3.113	0.295	0.181	0.271
4	3.422	3.422	3.428	0.331	0.204	0.305
5	1.994	1.994	2.000	0.358	0.222	0.333
6	1.700	1.700	1.703	0.379	0.237	0.354
7	1.483	1.483	1.482	0.396	0.249	0.372
8	1.318	1.318	1.321	0.410	0.259	0.387
9	1.187	1.187	1.190	0.421	0.267	0.399
10	1.081	1.081	1.083	0.429	0.274	0.409

TABLE II

A comparison between SASSI and ABACUS-II (Sample problem)

Quantity (barn)	SASSI (IBM-7094)	ABACUS-II (GE-625)
$\sigma_T$	5.615	5.6149
$\sigma_{s.el.}$	3.221	3.2208
$\sigma_R$	2.394	2.3941
$\sigma_{s.el.} (0^\circ)$	1.5720438	1.5721
$\sigma_{s.el.} (90^\circ)$	0.0780441	0.07843
$\sigma_{s.el.} (180^\circ)$	0.1233591	0.12336
$\sigma_{c.el.} (0^\circ)$	0.0866189	0.0867005
$\sigma_{c.el.} (90^\circ)$	0.0634759	0.0635335

TABLE III-A

A comparison between ADAPE and "JUPITOR" for  $^{165}\text{Ho}$ 

Quantity (barn)	ADAPE		"JUPITOR"	
	IBM-7094	IBM-360/75	IBM-7094	IBM-360/75
$\sigma_T$	4.905742	4.909581	4.90773	4.90756
$\sigma_{s.el.}$	2.452888	2.446848	2.48620	2.48610
$\sigma_{d.in.} (9/2)$	0.274836	0.275864	0.27559	0.27563
$\sigma_{d.in.} (11/2)$	0.120244	0.121650	0.12127	0.12162

TABLE III-B

A comparison among SASSI, 2-PLUS, DANGFASI and "JUPITOR"  
for spherical and non-spherical cases

Quantity (barn)	SASSI	2-PLUS ( $\beta=0$ )	"JUPITOR" ( $\beta=0$ )	2-PLUS ( $\beta=0.24$ )	"JUPITOR" ( $\beta=0.24$ )	DANGFASI ( $\beta=0.24$ )
$\sigma_T$	7.2782	7.2763	7.2947	6.6632	6.6724	6.6645
$\sigma_R$	3.4566	3.4541	3.4673	3.2068	3.1986	3.2055
$\sigma_{se}$	3.8216	3.8222	3.8274	3.4564	3.4738	3.4590
$\sigma_{ce}$	0.7950	0.7947	0.7975	0.7582	0.7695	-
$\sigma_{ci} (1^\circ)$	1.8105	1.8095	1.8172	1.4766	1.4787	-
$\sigma_{ci} (2^\circ)$	0.4154	0.4149	0.4162	0.3783	0.3805	-
$\sigma_{ci} (3^\circ)$	0.0023	0.0023	0.0023	0.0021	0.0021	-
$\sigma_{ci} (4^\circ)$	0.4334	0.4337	0.4341	0.3549	0.3575	-
$\sigma_{ci} (total)$	2.6616	2.6594	2.6699	2.2119	2.2188	-
$\sigma_{dir.incl.}$	-	-	-	0.2367	0.2367	0.2367

TABLE IV

Nuclear model code in use at the CNEN Computing Centre

Name	Comments	CT <sup>(a)</sup>	W.U.? <sup>(b)</sup>	CPL? <sup>(c)</sup>	COMP? <sup>(d)</sup>
	<b>A) STATISTICAL MODEL CODES</b>				
SAUD	$\sigma(n,\gamma)$ by Lane-Lynn method; no competition by $(n,n')$ or other processes; $\ell=0,1$	A;B	yes	yes	yes
FISPRO	$\sigma(n,\gamma)$ by H.F. theory; competition by $(n,n')$ only; no fluctuations; $\ell \leq 9$	A;B	yes	yes	yes
MARE	$\sigma(x;a)$ ; $\sigma(x,a,b)$ , $\sigma(x;a,b,n)$ ; $(x,a,b) \rightarrow (n,p,\alpha,\gamma)$ ; evaporation model	A;B	in press	no	no
SASSI	$\sigma(n,n')$ by H.F. theory; no fluctuations or competition by other processes, $\ell \leq 50$	A;B	yes	yes	yes
ISOSTA	$\sigma(n,\gamma)$ for isomeric states; H.F. + Huizenga-Vandenbosch model	A	no	no	no
	<b>B) OPTICAL MODEL CODES</b>				
SMOG	Spherical o.m.; many types of potential are possible	A;B	yes	yes	yes
ADAPE	Deformed o.m.; adiabatic approximation	A;B	yes	no	yes
DUMBO	$\sigma(n,n), \sigma(n,n')$ for $2^+ \rightarrow 0^+$ transitions in deformed nuclei; no spin orbit coupling	A	yes	yes	yes
DANGFASI	As DUMBO + phase shift analysis; spin-orbit coupling	A	yes	yes	yes
"JUPITOR"	Revised version of JUPITOR1 in use at the CNEN Computing Centre	A;B	no	yes	yes
	<b>C) DIRECT INTERACTION CODES</b>				
DIRCO	Dipole direct-collective $\sigma(n,\gamma)$ , $\sigma(p,\gamma)$ with interference; plotter optional	A;B	in press	no	no
KISS	Quadrupole direct $\sigma(n,\gamma)$ , $\sigma(p,\gamma)$ ; plotter optional	A;B	in press	no	no
PRODE	Direct $\sigma(n,p)$ based on Fermi-gas model; energy spectrum of protons	A;B	no	no	no

(continues)

TABLE IV (continued)

Name	Comments	CT (a)	W.U.?(b)	CPL?(c)	COMP?(d)
	D) <i>MICROSCOPIC MODEL CODES</i>				
SURF	$\sigma_{\gamma}$ for doubly closed-shell nuclei; isospin mixing	A;B	yes	no	no
MIDI	Dipole $\sigma(N,\gamma)$ for e-e nuclei; coupled channel method	A;B	no	no	no
MIMOC	$\sigma(N,N)$ and phase shift for e-e nuclei	A	yes	no	no
RES	Extraction of res. spectroscopic parameters; coupled-channel method	A;B	no	no	no
JUP.MICRO	$\sigma(N,N)$ ; $\sigma(N,N')$ ; nucleon-nucleon interaction + collective potential	A	no	no	no
	E) <i>MISCELLANEA</i>				
SPEC	$\gamma$ -ray spectra from direct and collective capture	A;B	in press	no	no
LILABNER	Level density parameter <u>a</u> of Fermi-gas model; eight options	A	no	no	no
FGETA	Regular and irregular Coulomb functions and derivatives	A;B	yes	no	no
BOSTAW	Eigenvalues or eigenfunctions for a nucleon bound in a W.S. well	A;B	yes	no	no
RAFF	Radial form factors for microscopic model calculations	A	yes	no	no
EXODUS	(n,n') spectra analysis; H.F. theory; up to 100 exct. lvls.; Display Unit required	B	no	no	no
NILSSON	Eigenvalues or eigenfunctions for a nucleon bound in a Nilsson potential	B	no	no	no

a) IBM computers for which the programme has been developed: A = IBM 7094; B = IBM 360/75; b) W.U. = write up available;  
 c) Availability through ENEA Programme Library - Ispra; d) COMP = compared with similar codes.

