NEANSC WORKING PARTY ON INTERNATIONAL EVALUATION COOPERATION

SUBGROUP 12: NUCLEAR MODEL VALIDATION

STATUS REPORT

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May, 16, 1995

Doc.s12.6
Introduction

At the previous Nuclear Model Validation (NMV) subgroup (SG12) meeting, held at the occasion of the Gatlinburg Conference on "Nuclear Data for Science and Technology", in May 1994, 3 steps were indicated for the work of this group:

1. collection of recommended nuclear models
2. indicate the range of applicability of each
3. produce a well tested system of transportable codes

At this time we are proceeding through phase 1-2 and we present here a summary of the material collected up to now from the participants to SG12.

At the occasion of the meeting of the Working Group on Reactions Mechanisms Involving Gamma Rays, held on Nov.10, 1994 in Bologna, in conjunction with the NEA Specialists' Meeting on "Measurements, Calculations and Evaluation of Photon Production Data", a topical session was held of SG12, taking advantage from the presence of several specialists on that subject. Conclusions are here reported.

Here below a short summary is given on basic information, comments and indications about nuclear models and codes commonly used by specialists in nuclear data evaluation.

We closely cooperate with the IAEA group for the development of a data base for nuclear model parameters, which operates within the coordinated research program on "REFERENCE INPUT PARAMETER LIBRARY", (RIPL)

We are including some details on the progress of the different parameter libraries inherent to the different model and codes of interest here. In doing so we follow the schematic representation outlined in the previous report Doc.s12.5 and shown in the table here below.
This approach can be used when transition probabilities are missing only for a few sparse levels out of a large well known level scheme. It is not realistic, but it provides a non-arbitrary criterion for filling missing data. This helps avoiding to cut sizable portions of reliable level schemes.

Codes available are:

BRANCH (G. Reffo, F. Fabbri), not documented, available.

Level density approaches can be used for assignment of missing energy spin and parity characteristics of discrete level schemes, by use of careful statistical analysis of energy, spin and parity distributions of discrete level schemes and of neutron resonance schemes. In this way evaluated level schemes, without missing data holes, can be derived providing with some indication on the cut energy where theoretical level density description becomes more realistic than available discrete level schemes.

Existing codes

AMLETO (G. Reffo, F. Fabbri), Gilbert-Cameron, documented, available

1.2 CONTINUUM EXCITATION ENERGY REGION

A comprehensive review of approaches and theories for the description of total and partial level density is given in ref. 4.

1.2.1. Total level density

At lower energies, rather good description can be obtained using semphenomenological approaches (Gilbert-Cameron approaches including back-shifted versions). More microscopic approaches, based on shell model, BCS theory, etc. are also available (Grimes).

At higher energies (above 10-15MeV), for practical calculations, more reliable results may be obtained using Ignatyuk’s approach. This takes into account the energy dependence of the a-parameter related to shell effects fading with high excitation energy. This approach links nicely to the BCS results below the critical energy, where BCS breaks down. Collective effects can be included by use of enhancement factors. The latter should be dumped with increasing energy in order to account for the coupling of collective states to the single particle component. Ignatyuk approach, at the moment is the most general and relatively accurate description in quite a wide excitation energy range.

Isotopic and energy dependence of the a-parameter can also be inferred from the analysis of the shell-model Hamiltonian spacings. The latter method gives encouraging results for the deformed nuclei but fails to reproduce shell effects in the vicinity of the shell closures. It would be interesting to incorporate this results into the
1. NUCLEAR STRUCTURE

1.1 DISCRETE LEVEL REGION

1.1.a. Experimental data

The collection and filing of experimental data describing discrete levels characteristics is continuing under the responsibility of the ENSDEF network participants.

RIPL group has undertaken an effort to produce a library of discrete level schemes to be derived from ENSDEF. Such a reduced library is meant to include only basic discrete level characteristics (energy, spin, parity, and gamma-decay probabilities) needed for the input preparation of nuclear model codes. A starter file with primary experimental data for some 1500 nuclei has been delivered to IAEA by the Nuclear Data Center of ENEA-Bologna. The ENEA format has been accepted by the RIPL group and a translation code from ENSDEF format is being delivered by ENEA. It is under discussion whether the RIPL group should endorse the effort of producing an evaluated level scheme file. This, however would be, to some extent, model dependent and, therefore, should be taken into consideration after thorough consideration, together with the SG12, on which model to adopt and after the RIPL group has provided all other parameters needed for discrete level scheme analysis.

1.1.b. Theoretical approaches

1.1.b.1. Microscopic approaches

Among the different theoretical approaches available for the prediction of discrete level characteristics, mention has to be made of the Interacting Boson Approximation\(^2\). This appears to be successful in reproducing discrete level spectroscopy as well as electromagnetic transition intensities, for non-magic e-e nuclei in the mass region medium and heavy. Activity is in progress for the treatment of e-o and o-o systems by use of the Interacting Boson Fermion Approximation\(^3\).

Existing codes are:

- **NPBOS, (T. Otsuka)** e-e nuclei, available on request from the author
- **ODDPAR, (R. Bijker)** e-e and o-o nuclei, not available
- **ODDODD, (A. Ventura et al.)** o-o nuclei, not yet documented, not available

1.1.b.2. Semiphenomenological approaches

Missing gamma transition probabilities, very roughly, can be provided using Weisskopf e.m. transition probabilities, under the sharp assumption of either spherical shape with dominance of E1- and M1-transitions, or deformed shape with dominance of E2-transitions.
Ignatyuk model. Still open problem is the degree of damping of the collective effects and the isotopic dependence of the vibrational enhancement factor.

In addition it should also be considered that at very high excitation energies (above approximatively 250-300 MeV) level densities should cease to increase and eventually begin to decline. There are some theoretical consideration regarding this issue but no practical prescription how to treat such a high excitation energy exists.

Rather than codes, there are routines included in cross sections calculations codes (see appendix A).

1.2.1.1. Level density parameter systematics

No approach yet exists providing reliable a-parameters trough the periodic table. Level density parameters are generally derived by normalization of the adopted approach to both discrete level information and continuum region information. Basic information for deriving a-parameters is the mean neutron resonance spacing. Available systematics are obsolete. RIPL activities include the task of providing new systematics, from Ignatyuk model and from re-analysis of more recent neutron resonance schemes (more details here below).

It is clear that a-parameter is model dependent, which implies that its accuracy reflects the uncertainties and ambiguities of the model approximations. It is also phenomenological in nature, affected therefore by experimental information uncertainties as well. Thus, missing basic experimental information, reliability of a-parameters becomes even more questionable. Model dependent systematics, however, have been derived for level density parameters, consistent with the respective approaches used for their determination. Systematics, even if model guided, lump together all uncertainties above mentioned. a-values from systematics should be given uncertainties of 10% or so. These may reflect in a factor of 2 in the uncertainty on total level density at neutron bindings, increasing with excitation energy.

1.2.2. Partial level density

Partial level densities, built on single particle states, have been derived, recently, by Herman and Reffo in the frame of BCS theory, by use of basis of shell model Hamiltonian eigenvalues, as provided by R. Nix and available from IAEA.

There are not many chances for a direct comparison to experimental data possible. Use of these level densities, however, in connection with different pre-equilibrium models seems to confirm the much better quality of cross sections, so calculated. This method seems, at the moment, the only way of reproducing the correct nuclear structure fluctuations and the typical shell model and pairing gaps appearing in the hard tail of particle emission spectra.

For these reasons, use of any Williams approach appears somewhat questionable on the ground of conceptual basis and therefore it cannot ensure an overall reliability of results.

The methods and the results obtained for this type of particle-hole level density calculations offer new tools and new investigation hints in the direction of a unified
treatment of partial and total level densities, provided collective effects are also included.

Parameter systematics have been derived\textsuperscript{7}, that can be better used allowing for the distinction of the two fermion types, as well as of g-values for particles and holes, in order to allow for the important effects of the finite depth of the nuclear potential well.

Codes documented and available are ICAR and TRATES.

2. NUCLEAR REACTIONS

2.1. OPTICAL MODEL

2.1.1. Spherical optical model.

The spherical optical model is a well known tool being used since a few decades and, from the theory viewpoint, does not represent an unknown.

The NEA has organized, in the past, ad hoc code intercomparisons that put in evidence the existence of certain discrepancies. This result should be reconsidered in order to ascertain the necessity of code intercomparisons.

As the model has been used for so long, we have available an enormous amount of optical model parameters sets buried in the literature. Because reactions calculations require optical model parameters for quite a number of nuclei (hundreds at 100 MeV incident energy), it has become vital, for evaluators, having available libraries of optical model parameter sets. This effort has been endorsed by the RIPL group, which is discussing file formats and collecting parameters. Global systematics are also under discussions.

2.1.2. Generalized optical model

Coupled channel approach is also, a few decade years, old and does not represent a novelty. In this case, however, there are not as many codes like for spherical optical model. Among the others, the CIRCE code (Bologna), is available, derived from the earlier version of JUPITOR and ECIS which presents some complexity, not only in the content, but also in the use.

An effort, however, has been undertaken by A. Koning together with the author of the code in the frame of the activities of SG13, which is meant to help users.

ECIS (Equation Couplées en Iterations Séquentielles) is a computer code written by J. Raynal.

ECIS is a coupled-channels code and was primarily used for the description of nuclear reactions to low-lying collective states. However, also simple spherical optical model calculations and DWBA calculations (both in the 1-iteration limit and as "pure" DWBA) can be made. Calculations can be done with either the Dirac equation or the (relativistic or non-relativistic) Schroedinger equation. A variety of nuclear structure
models can be used (vibrational, rotational, etc.). The latest official version is ECIS94. The upgrading from to ECIS94 includes:

- use of the deformation lengths instead of the deformations, when fixed relative deformations lengths are wanted,
- use of "symmetrized" Woods-Saxon form factors,
- two bound states transitions for particle-hole excitations, with the possibility of the particle in the continuum,
- expansion of cross-sections in terms of Legendre polynomials,
- possibility of angular distribution for uncoupled states without giving explicitly all the reduced nuclear matrix elements,
- for Coulomb excitation, use of a magnetic multipole,

Presently, ECIS is being extended with further refinements of compound nucleus calculations (according to Moldauer's width fluctuation method).

The coupled-channels code ECIS, in its recent versions, is able to deal with high efficiency with so many kinds of nuclear reactions induced by particles or by light and heavy ions as well. This capabilities makes ECIS a basic reference for any new theoretical approach dealing with the same processes. As an example of model validation based on ECIS, mention should be made of the Algebraic Scattering Theory for heavy ion induced reactions, proposed by Iachello and Alhassid.

A recent code comparison has revealed that there are large discrepancies in the prediction of reaction cross sections (up to 48% at 160 MeV). Therefore, it has been proposed to organize, within the activities of SG13, a Specialist Meeting on the Optical Model above 20 MeV (with topics ranging from fundamental theory to parametrized sets of optical potentials and global systematics, etc.).

2.2. RESONANCE REGION

2.2.1. Resonance Theory

The theory of nuclear resonance reactions is well in hand. The universally adopted model is R-matrix theory, as formulated by Wigner and Eisenbud (1947) and described in detail by Lane and Thomas (1958). The problem of model validation in the proper sense does not exist, the only questions that arise from time to time are about the adequacy of the approximations available for technical work:

- general R-matrix theory (rigorous to the extent that parity is conserved in nuclear reactions, i.e. for all practical purposes);
- Reich-Moore approximation (best for large numbers of capture channels, i.e. for most nuclides except light and magic ones);
- multi-level Breit-Wigner approximation adequate for nuclides with widely spaced levels, e.g. $^{232}$Th + n, $^{238}$U + n);
- single-level Breit-Wigner approximation (simplest form, for quick and dirty work only).
All this approximations are available in the NJOY program system.

Drastic improvements of most codes computing resonance cross-sections are possible with respect to:

- fast Doppler broadening of multi-level cross-sections (where e.g. NJOY is appallingly slow);
- statistical description of distant levels in terms of strength functions and average partial widths to remove unphysical edge effects and energy dependencies of effective nuclear radii etc.).

The effects of parity non-conservation seem to be negligible in all technological applications of resonance theory.

2.2.2. Resonance analysis

Neutron resonance schemes constitute a most important piece of information useful for nuclear model parameter derivation. In fact from statistical analysis of neutron resonances we derive average spacing needed for level density model testing and for level density parameter determination. Strength functions are needed for optical model parametrizations and for strength function systematics.

Statistical analysis of neutron resonances can be performed only for resonance samples large enough for statistics to apply. These methods are very sensible to the quality of the sample and very frequently, unfortunately, simply do not apply.

A method has been developed by P. Ribon and coded (ESTIMA) at CEA-Cadarache, based on six different statistics. The philosophy is to iterate until convergence is reached (via all statistics) to the same result. Staircase statistics, cumulative reduced neutron width analysis, integrated Porter-Thomas distribution (PTD), segmented PTD, truncated PTD, missing level estimator are all applied.

In the frame of the RIPL activities, The Nuclear Data Centers in Bologna, Obninsk and Beijing have made available preliminary new tables of average resonance parameters. These are being critically discussed, in order to eliminate discrepancies. A recommended file of average resonance parameters will be made available by IAEA pretty soon. This will be useful for the determination of specific optical model parameters and for new level density parameter systematics.

2.3. COMPOUND NUCLEUS THEORY

Hauser-Feshbach (HF) theory is universally used, is a best tested one and does need any further testing, validation or documentation.

It is obvious that energy and parity conservation, and the statistical width fluctuation corrections are essential to perform realistic calculations.

Less popular is the necessity of including isospin conservation, which instead play an important role in the correct determination of the sharing of incoming flux among outgoing channels especially for weak channels. The play of Clebsch-Gordon
coefficients, of isospin-dependent transmission coefficients and isospin-dependent level densities, under certain conditions, may give surprising results.

A relatively large number of codes is available. Most frequently reaction codes include most types of reaction mechanisms, thus, in order to avoid duplications, only one list is given here, with the specifications which have been made available to us.

In the past code intercomparison promoted by the NEA, large discrepancies showed up, even for results from the same code when used from different participants. The SG12 will consider later on the necessity of a new intercomparison.

2.4. PREEQUILIBRIUM MODELS

Preequilibrium models can be divided into two major groups: semiclassical models and quantum mechanical models. These, in turn, may be divided as it follows:

Semiclassical models

- hybrid model
- exciton model
- Harp-Muller-Berne model
- intranuclear cascade model

Quantum mechanical models

- Feshbach-Kerman-Koonin (FKK) model
- Nishioka-Verborsch-Weidenmuller-Yoshida (NVWY model)
- Tamura-Udagawa-Lenske (TUL) model

Both groups are essentially able to provide nucleon spectra and their angular distributions.

2.4.a. Semiclassical models

Exciton and Hybrid models are thoroughly tested, fast, and easy to use. Their results nicely fit experimental data but, in the case of the exciton model, it is on the expense of adjusting the strength parameter $M^2$, a similar situation happens also for the other approaches. All classical preequilibrium models tend to underestimate backward emission at higher exit energies. This fault may be improved using partial level densities when these are renormalized to sum up to the experimentally observed total density of levels. This, to some extent, simulate the mechanism of direct transitions to collective states and, therefore, tends to includes collective effects in the level densities, but the physical meaning of this procedure should be carefully investigated. In view of the later experience with the quantum models, it seems that the problems with the classical formulations are related mostly to the neglect of the separation of the preequilibrium mechanism into Multistep Compound (MSC) and Multistep Direct (MSD) and to the neglect of the collective effects at low excitation energies, both of which can be considered in the quantum mechanical models, while in classical exciton
model it can be approximated only approximatively. Thus quantum models should be preferred over classical ones.

The two remaining classical models (Harp-Muller-Berne model and intranuclear cascade model) follow intranuclear cascade either in the phase space or in the configuration space. At lower incident energies they do not seem to provide substantial advantages over the former classical models, but they are very useful at high incident energies and HI reactions.

2.4.b. Quantum mechanical models

All quantum mechanical models distinguish between Multistep Compound and Multistep Direct mechanisms. The approaches that have been used most extensively, so far are FKK and NVWY in the case of the Multistep Compound and FKK and TUL for Multistep Direct. There are substantial differences in the formulation and practical application of these approaches. Multistep Compound in the formulation of NVWY is more rigorous than FKK and allows for a consistent treatment of the compound part of the reaction within the same model. Recently also microscopic partial level densities (mentioned above) were incorporated in the practical calculations showing strong effects for nuclei in the vicinity of the shell closures. However, low energy part of the spectra, i.e. the part which is dominated by MSC mechanism, is essentially equally well reproduced by NVWY and FKK approaches, provided correct partial level densities are used.

The Multistep Direct formulation by TUL is again more rigorous, but also more involved, than the one by FKK. Surprisingly, practical 2-step calculations, in the frame of the TUL, turn out to be much faster than using FKK formulation, due to the averaged form factor used in the former approach. This situation gets reversed if more steps are required. In fact, there is little hope that TUL calculations can be practically extended to more than 3 steps. A great advantage of the present TUL calculations (codes ORION and TRISTAN) is the use of the RPA (Random Phase Approximation) collective response functions which substitute single particle level densities. This way collective effects are included microscopically in the calculations, which leads, not only to the correct description of the general trend of the measured spectra, but allows also to reproduce and predict energy structures related to both single particles and collective excitations.

The still open problem in the preequilibrium reaction theory is the emission of complex particles. It seems that, so far, this problem has been studied only within classical models and no undoubtful recipe is at hand. In the frame of the quantum mechanical model very little was done with this respect.

2.5. FISSION

Theoretical modeling of prompt fission neutron spectra and average prompt neutron multiplicities have been pursued actively at Los Alamos (D. Madland) and at Dresden (Seeliger, Maerten, both retired).

Ultimately the Hauser-Feshbach approach will be the best way to calculate these two observables. This is because the simultaneous calculation of neutron and gamma-
ray emission in competition, is the best way to account for the dissipation of the total fission-fragment excitation energy.

Status of the code GTLTLT (D. Madland) for the Los Alamos Model:

The code calculates the prompt fission neutron spectrum and average prompt neutron multiplicity using the Los Alamos model of Madland and Nix. The code has been tested against a large number of experiments as well as other theoretical models. It calculates the two observables for both neutron induced and spontaneous fission, for an arbitrary fissioning system. At the present time the code treats first-, second-, and third -chance fission, that is, (n,f), (n,n')f, (n,n''f). Modifications are therefore necessary to calculate the two observables for higher incident energies. A physics modification could also be added. This is the inclusion of anisotropy in the center of mass system as there exists some (weak) evidence that perhaps a 0-10% effect exists. Some work is also necessary to make GTLTLT an exportable code.

Finally, current limitations to calculating the two observables with higher accuracy than is now possible include:

- excitation energy partition in fission
- fission fragment nuclear level densities,
- isospin dependence of global neutron optical potentials,
- fission fragment ground state-masses
- fission fragment mass and charge distribution

Other codes

FINESSE, by Maerten and Seeliger is based upon the Los Alamos model and calculates the same two observables.

2.6. REACTIONS INVOLVING GAMMA RAYS

The first meeting of the VII-th Working Group of SG12 dealing with "Reactions Mechanisms Involving Gamma Rays" has been held on Nov. 11, 1994, in Bologna in conjunction with the NEA Specialists' Meeting on "Measurements, Calculations and Evaluation of Photon Production Data".

The discussion concentrated on the general outline of the existing reaction mechanism leading to photon production and on the relative computer codes. The following mechanisms were found to be the most relevant for nuclear data evaluation:

2.6.1. Direct - Semi-Direct (DSD); this includes transitions to collective level bands. The range of applicability of this mechanism extends up to about 100 MeV and it seems to give an remarkable contribution to the Giant Dipole Resonance (GDR) region.

2.6.2. Statistical Model (HF); a dominant mechanism for the low energy photon emission (say below 10 MeV) independently of the projectile type and energy. Spin and parity conservation is essentia, especially for calculations involving isomeric state transitions, like isomeric ratio calculations.
Multi-Step Compound, currently thought responsible for the minor part of the photon production in the nucleon induced reaction. Its contribution might turn out more significant for the complex projectiles.

2.6.3. Multi-Step Direct; its role is not known at present. It is expected that MSD might contribute in the energy range between HF and DSD.

2.6.4. Exciton model; contributes to the photon energy range between 5 and 40 MeV and may be seen as a classical, numerically convenient, alternative to the quantum mechanical models (DSD, MSD, and MSC). The basic assumptions of the approach and the approximations need reconsideration, at the light of more rigorous models, in order to ascertain the real meaning of the model foundations.

2.6.5. Bremstrahlung; very important, dominant at high photon energies, above 30-40 MeV.

2.6.5. Quasideuteron; applicable at photon energies above 30-40 MeV, has revealed functional similarity to the Bremstrahlung.

2.6.7. Valence Capture; this approach has been invoked on order to explain certain strong correlations observed between incoming neutron channel and widths of neutron resonances. This effect appears to be sizable in the vicinity of shell closures in the KeV region. Neglecting the gamma decay of valence capture excitations may affect up to 50% or more total neutron capture calculations (e.g. Kr and Xe calculations).

The participants have indicated the following codes implementing the above mechanisms:

1. Direct - Semi-Direct

CUPIDO - by F. Dietrich, not documented, not available
HIKARY - by H. Kitazawa
DIRCO - by G. Longo, documented, not available
no name - by Yu. Shubin

2. Statistical Model

ALICE - by M. Blann, documented, available
ALICE F - by T. Fukahori
CATHY - by T. Fukahori
EMPIRE - by M. Herman, not documented, not available
EMPIRE II - by M. Herman, not documented, not available
H.M.S. EMPIRE - by M. Herman, not documented, not available
H.I. EMPIRE - by M. Herman, not documented, not available, heavy ions
MSC EMPIRE - by M. Herman, not documented, not available, MSC
GNASH-FKK - by P.G. Young and M. B. Chadwick, documented, available
FKK-GNASH - by Y. Watanabe
PENELOPE - by G. Reffo and F. Fabbri, not documented, not available, HF + exciton model, 1 gas, 2 gas, microscopic level densities
POLIFEMO - by G. Reffo and F. Fabbri,
STAPRE - by M. Uhl. HF+exciton model-back shifted, documented, available
STAPREH93 - by V. Auvigeanu, HF+hybrid+Fu level density,
TNG - by P. Fu, documented, available, HF+exciton

3. Exciton/hybrid Model

ALICE - by M. Blann, documented, available, Ewing+hybrid, spin parity not included
ALICE F - by T. Fukahori
PEGAS - by E. Betak,
PEQAG - by E. Betak
PENELOPE - by G. Reffo, like above
GNASH - by P.G. Young, HF+exciton model,
TNG - by P. Fu, like above

4. Multi-Step Compound

GNASH-FKK - by P.G. Young and M. B. Chadwick
EMPIRE II - by M. Herman
H.M.S. EMPIRE - by M. Herman

5. Multi-Step Direct

no name - by Dietrich and Chadwick, in progress

6. Brehmsstrahlung

RELAX - by M. Blann
FLUKA - by A. Ferrari

7. Valence capture

EOLO - by A. Mengoni, not documented, not available
VALENCE - by H. Kitazawa

As far as the availability of the codes is concerned, the situation is essentially satisfactory only for the Statistical and Exciton Models groups, in which there are several codes already documented and released. Surprisingly, at present there is no code employing DSD-mechanism available to the evaluator community. As this mechanism is the one responsible for the major part of the photon spectra in the GDR region, filling up of this lack must be given the highest priority. It is hoped that F. Dietrich will make his CUPIDO code public.

Fu has pointed out that for the standard applications of nuclear techniques the most important photon energy range is below 10 MeV, as for higher energies pair production is a major mechanism of the photon energy dissipation. With regard to this, it is essential for the statistical model codes to be well tested. A new code intercomparison, regarding photon spectra, might be helpful.
All participants of the Working-Group VII have been kindly requested to complete the above lists of models and codes with the necessary details and supply their comments.

4. CONCLUSIONS

The experience of the first year showed that most of the specialists are available to help, but there is general suffering from lack of time.

So while it is relatively easier to have references and comments on theoretical arguments, it is relatively more difficult to have people available to be involved on code manuals and documentations etc. Another drawback is the economical difficulty to get specialists together for discussion and conclusions.

At the present stage, however, an overall glance has been given to the different models, theory and approaches, currently available as evaluation tools. Roughly, ideas have been given to start some critical discussion meant to lead to recommendations.

As far as codes are concerned we are still purely on the phase of listing them, this depends on the author availability and will be the longest and heaviest part of SG12 work.

A most appropriate time and place for the presentation of final results of the work of this group, might be at the occasion of the forthcoming conference on "Nuclear Data for Science and Technology", in May 1997.

ACKNOWLEDGMENTS

This report has been written thanks to the participations of all the scientists who kindly agreed to join at the time of the Gatlinburg conference and at the time of the Bologna meeting.

A special thank is due to the monitor of SG12, P. Obloznsky, who followed the work with suggestions and discussions and that patiently pushed hard to get the work done.

In particular my grateful thanks are addressed to the friends who accepted to help with their written contributions: F. Froehner, M. Herman, A. Koning, D. Madland, A. Ventura.
REFERENCES

9. Ribon, E. Fort, Krebs, Tran Quoc Thuong, CEA Report, CEA-N-1832 (1975), and Report EANDC(E)-160 AL
### APPENDIX A. CODES RECOMMENDED FOR CONSIDERATION

A list of codes has been recommended for consideration by the participants to the 1-st NMV meeting of SG12, held in Gatlinburg in May 8, 1994.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>ALICE (BLANN)</td>
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<tr>
<td>GNASH (YOUNG)</td>
<td>Documented*</td>
</tr>
<tr>
<td>GNASH-FKK (YOUNG-CHADWICK)</td>
<td>Documented*</td>
</tr>
<tr>
<td>STAPREH93 (AVRIGEANU)</td>
<td>Documented</td>
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<td>ALICE F (FUKAHORI)</td>
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<td>SINCROS 2 (FUKAHORI-CHIBA)</td>
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<td>CATHY (FUKAHORI)</td>
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<td>TNG (FU)</td>
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<td>RHOTHERM (GRIMES)</td>
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<td>Manual planned</td>
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<td>EXIFON (KALKA)</td>
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<td>In development*</td>
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<td>CAPSIES (KONING)</td>
<td>Fission spectrum, average multiplicity no documentation</td>
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<td>GLTLTLT (MADLAND)</td>
<td>Optical model medium energy, no documentation</td>
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<td>SNOOMP 8 (MADLAND)</td>
<td>Schroedinger eq. optical model including relativistic energies, 2-nd order Dirac, standard optical model as particular case.</td>
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<td>EMPIRE (MARCINKOWSKI)</td>
<td>Hauser-Feshbach + Hybrid, documented</td>
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<td>EMPIRE (MARCINKOWSKI)</td>
<td>MSC-FKK, will be documented.</td>
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<tr>
<td>ANDRE' (MARCINKOWSKI)</td>
<td>FKK-MSD, Will be documented.</td>
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<tr>
<td>MISDO (ROHR)</td>
<td>Level Density Calculations.</td>
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<td>STAPRE (UHL)</td>
<td>HF and exciton model, documented</td>
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<td>FUNF (ZHANG JINGSHANG)</td>
<td>Charged particle induced reactions</td>
</tr>
<tr>
<td>GUNF (ZHANG JINGSHANG)</td>
<td>Gamma induced reactions</td>
</tr>
<tr>
<td>IDA MODULAR SYSTEM (REFFO-FABBRI-HERMAN)</td>
<td>Lev. dens. analysis, documented, available resonance analysis, documented, available reac. list + Q-val.s, documented, available y-branchings, documented available binary x-sections, documented, available cascading emissions, not documented* as above + 2-gas preeq, not documented* generalized opt. model, not documented valence capture, not documented inclusive spectra, not documented. data processing, not documented</td>
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<tr>
<td>AMLETO</td>
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<td>ULYSSES</td>
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<tr>
<td>PEGAS (BETAK-OBLOZINSKY)</td>
<td></td>
</tr>
</tbody>
</table>
33. GAMME (BONETTI-CHADWICK)  
34. MAURINA (UHL)  
35. GRAPE (GRUPPELAAR)  
36. SAMMY (N. LARSON)  
37. SCAT-2 (BERSILLON)  
38. FLUKA (FERRARI et al.)  
39. GROGI  
40. JULIAN  
41. CASCADE  
42. EMPIRE (M. HERMAN)  
   EMPIRE H  
   EMPIRE FKK  
   EMPIRE HI  
   EMPIRE HI2  
   -R-MATRIX  
   -sph. opt. model, available, documented  
   -Documented, 1MeV-1000 GeV  
   - Heavy Ions  
   - Heavy Ions  
   - Heavy Ions  
   -HF+Hybrid  
   -HF+Hybrid+FKK-MSC  
   -HF+Hybrid+FKK-MSC+NVWY-MSC  
   -HF for Heavy Ions, dynamical effects in level density and fission channel  
   -HF+NVWY-MSC for nucleons and Heavy Ions, dynamical effects in level density and fission channel, microscopic partial lev.density  
   -shell model +BCS partial level density  
   -like ICAR+preeq. transition rates for exciton model, one and two gas

In the above list, an asterisk marks codes comprehensive of most important reaction mechanisms and commonly used for rather complete evaluations.

This list contains relatively simple one-step codes and as well as those including multi-particle emission including preequilibrium effects. GROGI, JULIAN, and CASCADE were explicitly set up to treat HI induced reactions. EMPIRE II can do both, nucleon and HI induced reactions, starting from low energies up to several hundreds of MeV. GNASH, PENEOLOPE+POLIFEMO, and TNG are equipped with the possibility of creating files in the ENSDF VI format.
APPENDIX B

List of the participants to the meeting of the VII Working Group on "Reactions Mechanisms Involving Gamma Rays", held on Nov. 11, 1994, in Bologna.

1. A. Likar
2. M. Igashira
3. H. Kitazawa
4. F. S. Dietrich
5. P. Fu
6. P. Oblozinsky
7. E. Betak
8. J. Kopecky
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10. C. Norborg
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Idem
Idem
APPENDIX C

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CODE INFORMATION FORM

CODE
BASIC PHYSICS
RANGE OF APPLICABILITY
DIFFERENCES FROM OTHER SIMILAR CODES
PARAMETER SYSTEMATICS ADOPTED
REFERENCES
CODE AVAILABILITY
MANUAL AVAILABILITY
INTERCOMPARISON NEEDED
PROPOSALS FOR SG12
ANY OTHER INFORMATION
EXAMPLE

AVRIGEANU V.

STAPRE-H93

M. UHL, ref....

HAUSER-FESHBACH-MOLDAUER
SPHER. OPT. MODEL: SCAT2 USED
PREEQ.: GEOM. DEPENDENT HYBRID MDL
+ $\alpha$ (z.p. a335,299 (1990)
+ $I^*$ conservation
+ $a(p,h,E)$ from C. Y. Fu ref.....(1984,1986)
+ $g(E)$ energy dependent single particle level density, ref....
- no multiple preeq. emissions allowed.

0.1 < E < 30 MeV

RANGE OF APPLICABILITY

DIFFERENCES FROM OTHER SIMILAR CODES Geom. Dep. Hybrid including $\alpha$-emissions

PARAMETER SYSTEMATICS ADOPTED

REFERENCES

CODE AVAILIBILTY

MANUAL AVAILABILITY

INTERCOMPARISON NEEDED

PROPOSALS FOR SG12

ANY OTHER INFORMATION


V. Avrigeanu et al. Int. Conf Gatlinburg, poster B12

yes

yes, ref above + STAPRE-H 1988 + ......

YES, BECAUSE ......

..........