INDC(NDS)-423
Distr. G+L

LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT

Summary Report of the Advisory Group Meeting

IAEA Headquarters

Vienna, Austria

28 November – 1 December 2000

Prepared by

D.W. Muir and M. Herman

IAEA Nuclear Data Section
Vienna, Austria

May 2001

Reproduced by the IAEA in Austria
May 2001

INDC(NDS)-423
Distr. G+L

LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT

Summary Report of the Advisory Group Meeting

IAEA Headquarters

Vienna, Austria

28 November – 1 December 2000

Prepared by

D.W. Muir and M. Herman

IAEA Nuclear Data Section
Vienna, Austria

Abstract

The Advisory Group Meeting on Long Term Needs for Nuclear Data Development, was held from 28 November - 1 December 2000 at IAEA Headquarters, Vienna, Austria. The goal of this meeting was to develop a vision of the work needed over the next decades (2000-2020) on the measurement, calculation and evaluation of improved nuclear data for emerging applications. Of particular interest were data improvement activities that could be coordinated by the IAEA. The following areas of nuclear data applications were selected for discussion during the Meeting: Medical Applications; Ion Beam Analysis and Related Techniques; Nuclear Astrophysics; Nuclear Safeguards and Related Applications; Critical Reactors, including Closed Fuel Cycles; Accelerator Driven Subcritical Reactors; ADS Target Design and High-Energy Radiation Shielding.

May 2001

TABLE OF CONTENTS

Summary Report of the

Advisory Group Meeting on

LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT

IAEA Headquarters, Vienna, Austria

28 November – 1 December 2000

Introduction

The Advisory Group Meeting on Long Term Needs for Nuclear Data Development, was held from 28 November - 1 December 2000 at IAEA Headquarters, Vienna, Austria. The goal of this meeting was to develop a vision of the work needed over the next decades (2000-2020) on the measurement, calculation and evaluation of improved nuclear data for emerging applications. Of particular interest were data improvement activities that could be coordinated by the IAEA. The following areas of nuclear data applications were selected for discussion during the Meeting:

1. Medical Applications
2. Ion Beam Analysis and Related Techniques
3. Nuclear Astrophysics
4. Nuclear Safeguards and Related Applications
5. Critical Reactors, including Closed Fuel Cycles
6. Accelerator Driven Subcritical Reactors
7. ADS Target Design and High-Energy Radiation Shielding

Regarding the topical areas emphasized in the meeting, it was assumed that the nuclear data needs for nuclear fusion have already been well covered by a long series of Agency meetings convened in the period from 1978-1999 (the FENDL project), so this topic was not addressed at this meeting. Another application that was not treated is reactor core physics based on conventional fuels. This topic is covered by the NEA Working Party on International Evaluation Cooperation (and in any case can not be considered as an "emerging" application).

In their presentations, participants were asked to keep in mind that the "need for data development" in a given application area depends on the following factors:

- the importance of data in determining the success or failure of the application,
- the extent to which there are important gaps remaining in the data, and
- the feasibility of filling those gaps with a modest research effort.

Clearly, the first two points define the benefits of data research and the third one relates to the cost. Sufficient information was to sought on each of the mentioned items to judge the need for data development work in the area under discussion.

The Meeting was attended by 23 participants and 2 observers from 14 countries. It was opened by the Head of the IAEA Nuclear Data Section D.W. Muir. Welcoming addresses were presented by the Head of the IAEA Department of Nuclear Sciences and Applications W. Burkart and by the Head of the IAEA Department of Nuclear Energy V. Murogov. J. Boldeman (Australia) was elected chairman, with D.W. Muir and M. Herman (IAEA) serving as scientific secretaries. During the course of the meeting, half-day sessions were dedicated to each area of application. The meeting concluded with a round-table discussion.

In the following, the main conclusions and recommendations of each session are summarized. More details, including contributed presentations, will be published in a separate report.

Medical Applications

Speakers: S.M. Qaim, T.W. Burrows, D. Jones

The session chairman (*S.M. Qaim*) opened the session by giving a brief introduction to the importance of nuclear data in medicine. Radioactivity is a unique phenomenon which finds application both in diagnosis and therapy, and hence nuclear data are of great significance in the medical field.

Diagnostic nuclear medicine makes extensive use of radioisotopes, the imaging from outside the body being done by γ-cameras, single photon emission tomographs (SPECT) or positron emission tomographs (PET). The choice of the radioisotope is determined by the nuclear structure and decay data, and its production by the excitation functions of the chosen nuclear processes. The final use of the radioisotope is dependent on the chemical form in which it is attached to a biomolecule prior to administration to a patient. The underlying principle of diagnostic studies is that the radiation dose to the patient should be as low as possible. This calls upon a stringent control of the radioactive impurities.

In radiation therapy the interactions of radiation with matter are of direct relevance. Besides photons, electrons and neutrons, high-energy charged particles like protons, ^{4}He and heavy ions have been finding increasing applications. Evidently, several types of reaction cross section data are relevant.

Besides emphasizing the necessity of accurate data for proper use, the danger of using inaccurate data was also pointed out. In the literature, for example, a report existed which claimed that medium-sized cyclotrons could partly or wholly replace reactors, as far as the production of $^{99}Mo/^{99m}Tc$ is concerned. This claim was based on the exceptionally high $^{98}Mo(p,\gamma)^{99m}Tc$ and $^{100}Mo(p,2n)^{99m}Tc$ reaction cross sections found by the authors of that report. Since this report caused considerable excitement, an IAEA-sponsored study was undertaken at Jülich. Some key measurements were done using highly enriched ^{98}Mo and ^{100}Mo as targets and several cyclotrons. The cross section of the $^{98}Mo(p,\gamma)^{99m}Tc$ reaction was found to be negligibly small (< 0.2 mb) and that of the $^{100}Mo(p,2n)^{99m}Tc$ reaction about 200 mb at the peak position. That study led to the conclusion that ^{99m}Tc can be produced at a cyclotron in small amounts for local use only. The amount of ^{99}Mo produced is small. There is thus no substitute for reactor produced $^{99}Mo/^{99m}Tc$ generators (for details cf. Scholten, Lambrecht, Cogneau, Vera Ruiz and Qaim, Appl. Radiat. Isot. **51**, 69 (1999)).

Over the last 5 years the IAEA has paid considerable attention to the field of nuclear data for medical applications. Several consultants' meetings were held on the topic of nuclear data for medical radioisotope production as well for hadron therapy. Two Co-ordinated Research Projects (CRPs) in these two areas have also been recently completed. The results of therapy related CRP were published a few years ago and those of the isotope related CRP are in preparation as a TECDOC. The latter entitled: "*Charged Particle Cross Section Database for Medical Radioisotope Production*" is a milestone and describes the first evaluation effort on data for cyclotron production of diagnostic radioisotopes. The recommended data for all the commonly used SPECT and PET radioisotopes should prove to be very useful for all Member States, including those establishing new cyclotron facilities, such as Egypt, Syria, Indonesia, Argentina, etc. Therapy related data have also been recently given strong consideration by the International Commission on Radiation Units and Measurements. The published report (ICRU Report 63) entitled: "*Nuclear Data for Neutron and Proton Radiotherapy and for Radiation Protection*" gives comprehensive information on reaction cross sections and kerma coefficients.

Another landmark in the field of nuclear data for medical applications was the organization of an autumn college in 1999 at the Abdus Salam ICTP, Trieste, which was attended by about 50 participants from about 25 countries. Selected lecturers were asked to write special review papers, and a special issue of the international journal *Radiochimica Acta* incorporating those review articles will be published early in 2001.

Thus, for the present, the data needs relevant to the production of diagnostic radioisotopes as well as for radiation therapy appear to be well covered. There are, however, still a few areas which need strong attention. Furthermore, developments in both diagnostic and therapeutic nuclear medicine are occurring very fast, and the data needs will also certainly increase. In subsequent talks some of those areas were discussed.

S.M. Qaim (Jülich) reported on the **production of new diagnostic and therapeutic radionuclides**. The need for new diagnostic radionuclides refers mainly to longer-lived β^+ emitters. The motivations here are to study slow biochemical processes or to quantify biodistribution of SPECT-radiopharmaceuticals using an analogue β^+ emitter and PET. As expected, considerable amounts of nuclear data work is necessary to develop suitable production methods of potentially interesting radionuclides. The production of therapeutic radionuclides is done both at reactors and cyclotrons and the status of the available data calls for careful consideration. In addition, the field of internal radiotherapy using radionuclides has gained considerable importance in recent years. Many of the radionuclides are Auger electron emitters whose decay data may be somewhat uncertain.

There followed a long discussion after Qaim's talk and some of the salient points which emerged are given below:

(a) The therapeutic radionuclides should be given special attention. Many of them are produced in a nuclear reactor via neutron capture, double neutron capture or (n,z) reactions. No evaluation of the relevant data has been done so far. Many other therapeutic radioisotopes are produced at cyclotrons. The available data have not been evaluated; in several cases there are big gaps. The decay data of some therapeutic radionuclides need updating.

(b) In the recently evaluated data file on cyclotron production of diagnostic radionuclides several discrepancies were observed. Attempts should be made to remove those discrepancies. Furthermore, validation of evaluated data should be carried out.

(c) New developments in diagnostic radionuclides should be followed; attempts should be made to remove the discrepancies.

The topic of **internal radiation dosimetry** was treated by *T.W. Burrows* (Brookhaven). The status of available structure and decay data was presented. The role of those data in medical applications was outlined. The methodology used today throughout the world for internal dose calculations is provided by the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine of the USA. The dose calculations help to decide whether the radionuclide under study is suitable for diagnostic or for therapeutic applications. The data used are taken from ENSDF. About 250 radionuclides are of medical interest. Information on the radioactive decay products of those nuclides and on possible contaminants is also required, though with less rigorous requirements.

The data and accuracy needs for internal dosimetry were considered in detail, and the accessibility and documentation of data were discussed. Finally the data sources for prompt radiations from neutron-and ion-induced reactions were mentioned. The latter data are of relevance to dosimetry in hadron therapy.

After the talk of T. Burrows there followed some discussion on the deficiencies in nuclear structure and decay data. Some points of special interest are mentioned below:

(a) Electromagnetic conversion coefficients and electron-capture fractions need to be calculated for all possible atomic electron shells. This will allow detailed information on the Auger electrons. These data are of increasing importance in therapy due to the high Linear Energy Transfer (LET) of the electrons. (See the point above on therapeutic radionuclides). This will also provide more detailed information on the conversion-electron and x-ray spectra, allowing more accuracy in estimating the dose from these irradiations.
Problems: Some well-measured conversion coefficients are "anomalous" when compared to theory or are more accurate than the estimated theoretical uncertainty (˜ 3%). These measured data should be used instead of calculations based on theory.

(b) Continuous spectra from β^+, β^- and internal bremstrahlung need to be more readily available, detailed enough for calculations, and in an easily useable format such as ENDF. This will allow a more precise estimate of the dose associated with these radiations.
Problems: Higher-order (3rd, 4th) forbidden unique transitions seem to be understood but are not implemented in all relevant codes. Higher-order forbidden (2nd, …) non-unique transitions still seem to present problems.

(c) Data should be current
As a minimum requirement, the data should be consistent with "current" knowledge. For diagnostic and other applications, significant changes may require a reevaluation.

(d) Traceability
Most publications and electronic sources since about 1978 have been based on ENSDF. However, some limitations in ENSDF or the age of some of the decay datasets have required revisions to the data. These revisions need to be documented, archived, and made readily available.

Notes: T.W. Burrows is planning an upgrading of RadList to handle (a) and improve it in terms of (b) by the end of 2001. He will communicate these changes to Olivier Bersillon so that these changes may also be made in SDF2NDF, another code derived from RadList.

D.T. Jones discussed the **nuclear data relevant to fast neutron and proton therapy**. He presented a detailed overview of the Report ICRU 63 (mentioned above in the introductory remarks by S.M Qaim). The data were evaluated using a combination of measured data and the GNASH nuclear model code for elements of importance for biological, dosimetric, beam modification and shielding purposes. In the case of hydrogen, both R-matrix and phase-shift scattering theories were used. Neutron cross sections and kerma coefficients were evaluated up to 100 MeV and proton cross sections up to 250 MeV.

Based on the above mentioned report Jones concluded that the current state of knowledge on the most important nuclear data required for calculations pertaining to fast neutron and proton therapy appears to be adequate. Predictions of nuclear models fit the microscopic experimental data reasonably well. Integral neutron experimental measurements are consistent with calculations using evaluations of microscopic data. Monte Carlo calculations using currently available nuclear data evaluations also agree well with various measurements made in therapy beams.

It was pointed out that neutron interactions on C and O are probably the only reactions for which better data may be required to provide more accurate values of the A150/muscle kerma ratio, which is an important parameter in neutron dosimetry. A detailed discussion, however, also revealed that the activation data in both neutron and proton therapy need more attention. This relates both to the activation of beam collimators and human tissue. The formation of short-lived β^+ emitters (^{11}C, ^{13}N, ^{15}O, etc.) and longer-lived products (^{3}H, ^{7}Be, ^{22}Na, etc.) in human tissue needs investigation in more detail.

T. Fukahori (JAERI) made some comments on behalf of the Japanese Nuclear Data Committee (JNDC). Nuclear data for medical applications can be categorized as:

(i) Nuclear data for use of medical equipment for diagnosis and treatment,
(ii) Nuclear data related to radioisotope research of chemical behavior in human body, and
(iii) Nuclear data for radiation interaction in human body.

As far as (i) and (ii) are concerned, the data needs appear to be satisfied. On the other hand, microscopic data evaluating the interactions with the human body, such as absorbed dose, are very poor. The data are needed for radiation interactions at the atomic and molecular levels, for example, electron (< 10 keV) interaction with DNA. From the point of view of radiation protection, decay data (decay mode, branching ratio, half-lives, γ-, α- and β-rays, energies and intensities), cross sections and double differential cross sections for radiation transport, and kerma factor, etc., are necessary. The increase of accuracy is also needed for β- and γ-ray yields of radioisotopes produced through high-energy neutron and proton interactions.

For modern radiation therapy, additional needs exist for photon (from 15 keV to 10 MeV), proton, neutron and high-energy electron induced reactions. Many of the decay data have been reviewed in ICRP Publication 38, which used decay data from ENSDF of 1970s. Due to difficulty in construction of new reactors, low-energy neutron sources using electrons (from (γ,n) reactions) or protons (from (p,n) reactions) at accelerators may be important, especially for Boron Neutron Capture Therapy (BNCT).

A more general discussion also pointed out the possibility of production of new types of medically interesting radionuclides in neutron fields encountered in spallation neutron sources and ADS-type neutron sources. Furthermore, the radioactive beams, presently under development for astrophysics work, may eventually also find application in medical radioisotope production, especially in obtaining exotic short-lived β^+ emitters. All those new activities will demand a considerable amount of nuclear data work.

Recommendations

It is satisfying to note that the field of nuclear data for medical applications has now found a place on the agenda of the IAEA-NDS. For the future it is recommended that it is given long term consideration through data compilation (particularly charged particle data) and development, support of research, training and services. The actions recommended are:

(1) The recently established database for cyclotron production of diagnostic radioisotopes should be updated periodically. Efforts should be undertaken to remove the discrepancies. Data validation should be performed wherever possible and necessary.

(2) Special attention should be paid to therapeutic radioisotopes. This fast developing field of nuclear medicine demands a careful look at the decay properties of the relevant radionuclides as well as at the reaction cross section data used for their production. It appears very timely to evaluate the available data, to attempt to remove the discrepancies and to find out the gaps, both in decay and reaction data.

(3) A few critical cases from the viewpoint of internal dosimetry should be given due attention. In particular the emission of Auger electrons and the shapes of continuous spectra should be better defined. This action is valid both for diagnostic and therapeutic radionuclides.

(4) The neutron and proton therapy related data are generally in good shape. However, the recently established data file should be updated from time to time. Attempts should be made to remove the deficiencies in the data on neutron interactions on C and O. More information on tissue activation with neutrons and protons is needed.

(5) New developments in the three areas, viz., diagnostic radioisotopes, therapeutic radioisotopes and hadron therapy, should be continuously monitored, and the data needs arising therefrom should be reviewed at regular intervals. Appropriate action should be taken wherever necessary.

Ion Beam Analysis and Related Techniques

Speakers: I. Vickridge and A. Gurbich.

Within the field of ion beam analysis (IBA), nuclear reactions are exploited to interrogate the surface region of solids - the first few microns - and are used for determination of light element contents and concentration profiles, which are often difficult to obtain by other means. It is absolutely quantitative for thin films and the isotopic specificity of Nuclear Reaction Analysis is exploited in stable isotopic tracing studies of thin film growth mechanisms.

The nuclear data needs of the IBA community are well defined: the differential cross sections for non-Rutherford elastic scattering of protons and ^{4}He ions and reactions induced by deuteron beams on light elements (carbon, nitrogen, oxygen) are of highest priority. The energy range of interest extends up to 5 MeV.

Many differential nuclear reaction cross sections of interest for IBA were measured in nuclear physics research programs in the fifties and sixties. Most of those data are available from the literature, but mainly as graphs, and in energy and angle intervals outside the range of interest for IBA: although a large amount of cross section data seems to be available, much of it is unsuitable for IBA. Because of this, many IBA research groups started to measure cross sections for their own use whenever an appropriate cross section was not found. The Internet site SigmaBase was developed for the exchange of this and appropriate previously measured data. However, prior to their widespread use, the SigmaBase data need to undergo quality control, and to be evaluated, because

i) analysis of the existing information has revealed numerous serious discrepancies in the reported cross sections values, far beyond quoted experimental errors

ii) the available data are valid only in the case of a scattering geometry very close to the geometry used in the cross sections measurements, because of the cross section dependence on the scattering angle.

For historical reasons charged particles detectors in different laboratories are fixed at different angles in the interval approximately from 130º to 180º. The cross section may depend strongly on the scattering angle, and although in some cases measured data were parameterized using empirical expressions, the parameterization should represent cross sections not only at measured energies and angles but also provide reliable interpolation and extrapolation over the entire range of interest. A theoretical evaluation of the cross sections, firmly based on appropriate physics, seems to be the only reliable way to meet the needs of nuclear data for IBA.

It has been clearly shown in several published works that evaluating cross sections by combining a large number of different data sets in the framework of the theoretical model enables excitation functions for analytical purposes to be calculated for any scattering angle, with reliability exceeding that of any individual measurement. In this respect, low energy nuclear physics may be regarded nowadays as a mature field. Many reaction mechanisms are known and appropriate models have been developed, although some further development of the models is still needed. Even though theory is unable to provide *a priori* prediction of the cross section, a particular cross section can as a rule be reliably represented by adjusting model parameters. In some cases of importance for IBA the reaction mechanisms are known but no code to provide the necessary calculations is available - some work is still needed in this field. A new computer code (SigmaCalc) based on both new and previously published results of data evaluation is under development in order to provide the IBA practitioner with a convenient tool for computing the required excitation functions without needing a high level of nuclear physics expertise. At present SigmaCalc may calculate the excitation functions for non-Rutherford proton scattering from carbon, nitrogen, oxygen, aluminum, silicon, and sulphur and for ^{4}He scattering from carbon and oxygen for any scattering angle in the energy range of interest for IBA.

Continued development and release of the SigmaCalc software would resolve the problem of non-Rutherford proton elastic scattering cross sections for IBA. However this work has been undertaken with little support and therefore makes slow progress. Some kind of cooperation in this project could help to finish it in the near future - especially since coordination is desirable between the theoretical and experimental work so that the most important experiments are performed without unintentional duplication. The problem of deuteron induced reactions is another challenging subject for coordinated efforts, both experimental and theoretical.

The needs of the IBA community in these data are without doubt, and the ways to resolve the problem are clear. The effort required is modest in view of the benefits that will accrue both to the IBA community through the establishment of a solid basis for analytical work and to nuclear physicists through the opportunity to undertake new investigations in an area which remains of interest.

Key points of the summary

- IBA nuclear data needs are well-defined and measurements of the relevant data are currently made in many laboratories in both developed and developing Member States.
- Some raw experimental differential cross sections have been compiled in SigmaBase and NRABASE.
- Work is in progress to include the compiled data in the EXFOR database.
- Serious discrepancies exist amongst available experimental cross sections.
- The feasibility of evaluation of charged particle differential cross sections at low energies has been proven in the framework of existing nuclear physics models.
- Several non-Rutherford elastic scattering cross sections of protons and ^{4}He ions have been evaluated through theoretical work, primarily undertaken in Russia and France.
- Lack of expertise in nuclear physics is significantly hindering the IBA community from making progress in this area.

IBA is a technique which makes substantial use of nuclear data for applications in hundreds of laboratories. Typically, IBA laboratories have many collaborations, and major areas of application include

- studies of crystal structure and its relation to physical properties such as high temperature superconductivity
- mechanisms of epitaxial growth of semiconducting and magnetic thin films
- composition and growth mechanisms of thin films
    - corrosion
    - protection and hard coatings
    - semiconductor components
    - decorative films
- surface and interface engineering
- art and archaeology - partial activity in many labs - two labs are dedicated.
- geology - e.g. dedicated lab in Australia, plus applications in numerous other labs
- environmental studies - mostly Particle-Induced X-ray Emission, but light elements through Particle-Induced Gamma Emission , Nuclear Reaction Analysis and Elastic Recoil Detection
- increasing use in nuclear waste storage.

Technical Recommendations

1. A detailed inventory of all cross sections of interest or potential interest to IBA is needed.
2. Critical evaluation of the available data is needed to reveal its consistency.

3. The information in the IBA databases and new measurements of interest to the IBA community should be incorporated in the EXFOR database.
4. The R33 format should be maintained as the standard computational format so that the IBA community can continue to use this format within their simulation codes.
5. The necessary codes to allow download of cross sections in appropriate computational format need to be developed.
6. The cross section measurements at different IBA laboratories should be co-ordinated.
7. Initial effort should be focussed on non-Rutherford elastic scattering cross-sections of protons and ^{4}He, and deuteron-induced reactions for C, N, and O, with charged particles in the exit channel.
8. A substantial effort should be made to organize the work on IBA data evaluation.
9. The SigmaCalc software, allowing IBA users to calculate excitation functions for cross-sections already evaluated, should be developed for release as soon as possible.
10. Means are needed for incorporation of the interests of the IBA community within the scope of IAEA nuclear data activity.

Organizational Recommendations

1. That the IBA community be invited to propose an IBA Nuclear Data Liaison Officer (non-IAEA funded) to provide a recognized link between the IBA community and the IAEA Nuclear Data Section and the nuclear data centre networks.
2. That the IAEA include IBA needs in nuclear data - based training programmes.
3. That the IAEA establish a CRP on "Compilation, evaluation and measurement of Nuclear Data for IBA (with particular emphasis on applications in materials and environmental sciences)".

Nuclear Astrophysics

Speakers: F. Käppeler, M.S. Smith, S. Goriely

Astrophysics aims at the quantitative understanding of the objects and processes observed in the Universe. Nuclear astrophysics in particular deals with the origin of the chemical elements, their production mechanisms in stars and stellar explosions. It, therefore, constitutes an important source of information with respect to the (chemical) evolution of galaxies and the universe.

The determination of the relevant stellar reaction and decay rates for characterizing nuclear energy production in the Universe and the various nucleosynthetic processes in a quantitative way represents a long-standing activity which will continue to expand as an active field of research in the decades to come. In a natural way, nuclear astrophysics influences and overlaps with many other fields of nuclear science (reactor physics, ADS, fundamental nuclear physics,…).

Due to the nature of stellar and explosive scenarios, nuclear astrophysics requires a twofold effort: while the situation during stellar evolution allows one to collect the relevant nuclear physics data by laboratory experiments, the much more extreme conditions during stellar explosions drives the reaction path to the borders of stability, thus involving theoretical approaches as indispensable tools for determining the respective reaction rates. Though experimental efforts will be restricted to a limited number of reactions relevant for explosive scenarios, measurements are nevertheless important for testing the body of calculated data.

Experiments in nuclear astrophysics have to account for the low projectile energies resulting from the limited temperatures in the stellar interiors. This means that charged particle reactions have to be studied down below the Coulomb barrier where cross sections fall to sub-microbarn values. Neutron induced reactions are difficult because of the high accuracy required for detailed analyses. Accordingly, advanced and innovative experimental techniques have been developed to meet these challenges.

Evaluations are becoming an increasingly important part of this field given the huge number of reactions involved in the various nucleosynthesis processes, collection, evaluation, and dissemination of the input data for astrophysical models. This aspect is not yet organized in a satisfactory way. The existing scattered activities should be expanded and better coordinated and focused on common standards and formats.

Calculations in nuclear astrophysics are invaluable to satisfy the requests coming from explosive nucleosynthesis. Under those conditions (extremely high temperatures and particle fluxes) the reaction paths are shifted away from stability and comprise a huge number of nuclei and reactions. Many of these nuclei are very short-lived and are difficult to produce in the laboratory in sufficient quantities for direct reaction rate measurements. Furthermore, since one is dealing with thousands of nuclei, it is impossible to determine all of the respective reaction rates by experiments. In addition, the specific characteristics of the high-temperature and/or high-density plasma (e.g. thermalization or ionization effects) makes theory an indispensable tool for astrophysical modeling. Accordingly, theory is required to provide this body of data. Since it is necessary to extrapolate to completely unknown nuclei in a high-temperature and/or high-density environment, the theoretical challenge is to use, as far as possible, microscopic physics concepts in fulfilling astrophysics requirements. The state-of-the-art nuclear models must be improved to reach the accuracy of more phenomenological approaches and subsequently be used in practical applications (which could also include reactor physics and ADS).

These fields of research were addressed in the session on Nuclear Astrophysics, the experimental part being covered by *F. Käppeler* (for the case of neutrons) and by *M.S. Smith* (for the charged particle reactions). The aspects related to theoretical calculations were discussed by *S. Goriely* who strongly emphasized the importance of using microscopic approaches for obtaining reliable extrapolations to the mass regions far from stability where nuclear properties are yet unknown.

Recommendations

- To identify overlap of interest with other fields and to coordinate these efforts. Examples are the (n,γ) cross sections of long-lived fission products (with ADS requests, e.g., ^{151}Sm, ^{79}Se), low energy charged particle induced cross sections and energy loss measurements (with ion beam analyses), nuclear modeling.
- To consider nuclear data needs for astrophysics applications in international compilation and dissemination activities, such as
  - (i) encouraging and assisting experimentalists to provide their new results in EXFOR format and inclusion in existing data bases;
  - (ii) encouraging the inclusion of legacy experimental results relevant for astrophysics

(especially charged-particle cross sections) in existing data bases; and

(iii) distributing lists of priority data needs for nuclear astrophysics studies and the formats requested by astrophysical models to the international nuclear data networks.

- To coordinate long-term projects (through CRPs) for the advancement of theoretical reaction models and the corresponding input parameters with emphasis on microscopic approaches, which are fundamental for reliable extrapolation of nuclear physics towards the drip lines. The issues addressed by this project are identical to needs expressed for other nuclear applications (e.g. ADS).
- To open the High Priority Request List to the most important requests from Nuclear Astrophysics ($^{12}C(\alpha,\gamma)$, $^{22}Ne(\alpha,n)$, ..).
- Given the broad appeal and the vigorously growing international efforts in nuclear astrophysics we suggest the Agency to take a leading role in the future coordination of international evaluation activities of nuclear reactions important to astrophysics.
- In view of the innovative potential of experimental and theoretical methods developed in nuclear astrophysics, we feel that a more intense exchange with other fields (ADS, nuclear models, ion beam analyses) might be of immediate mutual benefit. Therefore, we propose that the Agency should consider in the long term including nuclear astrophysics activities in its programme.

Nuclear Safeguards and Other Related Applications

Speakers: J. Boldeman, G. Molnar, D.L. Smith

Nuclear Safeguards

Safeguards measurements can be conveniently divided into two classes of techniques - Destructive Assay Techniques (DAT) and Nondestructive Techniques (NDAT). The former, generally applied at major analytical laboratories to verify field measurements, are normally the most accurate but lack timeliness. Typical techniques include isotope dilution mass spectrometry, x-ray fluorescence, α- and γ-ray counting, neutron resonance absorption and accelerator mass-spectrometry. Nondestructive assay techniques are generally performed in the field by IAEA inspectors to verify data supplied by the operators. All of them are based on nuclear or atomic interactions. Typical techniques include: γ-spectrometry, active neutron interrogation, coincidence counting, measurements of spontaneous fission rates, x-ray fluorescence, and passive neutron assay. Therefore. accurate nuclear data has been a key component of safeguards inspections activities. Safeguard requirements for the present safeguards regime are in general satisfactory; however there are a few selected areas where improvement could contribute to more accurate nondestructive assays.

Nuclear data needs for long term safeguards use depend entirely on the emerging concepts in nuclear power generation. Assuming the current views on the way in which these concepts may develop, and anticipating that future safeguards operation will employ similar principles to those currently in use, a set of data requirements can be derived which would aid present activities and provide support for future inspections:

- Accurate spontaneous fission half lives and associated nubar values and P_ν distributions for the minor actinides will be required for passive and active neutron counting.

- P_ν distributions for neutron fission of ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{235}U as a function of energy require some improvement.
- P_ν distributions for neutron fission of the minor actinides as a function of neutron energy are needed either by some measurements or by extrapolation.
- Improved six-group decay constants and delayed neutron yields for neutron fission of ^{234}U, ^{236}U and Np isotopes would be valuable for current activities. Similar data for the minor actinides may be required for future safeguards applications.

- For future activities (α,n) reactions will become a more significant source of correction in all neutron counting. Better data will be required.
- An analysis of the decay data of all the minor actinides is required to ensure that accurate isotopic concentrations can be made in the future.

In general, the current status of nuclear data is adequate for the present regime of safeguards activities except a limited number of areas where improved data might prove useful. The existing series of handbooks on relevant nuclear data are an excellent resource and should be updated as new information becomes available. New emerging power systems might bring new requirements for safeguards leading in the consequence to requests for additional nuclear data. The nuclear data community should be vigilant to the development of these new technologies so that appropriate evaluations and measurements can be recommended to satisfy any deficiency.

Non-Intrusive Inspection

Various nuclear-based techniques are being explored for use in non-intrusive inspections. Their development is motivated by the need to prevent the proliferation of nuclear weapons, to thwart trafficking in illicit narcotics, to stop the transport of explosives by terrorist organizations, to characterize nuclear waste, and deal with various other societal concerns. The non-intrusive methods are expected to optimize inspection speed, minimize damage to packages, and satisfy environmental requirements while avoiding inconveniencing the innocent. These techniques almost always require the use of highly penetrating radiation and therefore are generally limited to neutrons and γ-rays. The basic concepts related to nuclear inspection techniques were presented by *D.L. Smith.* He has shown that there are extensive needs for nuclear data related to nuclear structure properties and to the decay of radioactive species. For active techniques, such data are also needed along with information on production, scattering, absorption, and nuclear transmutation information for neutrons and gamma rays that are both employed as the interrogating radiation and detected as signals from the inspection process. It is surprising that neutron scattering data for O are not well known and that the most recent ENDF evaluation for Cl (a major constituent of illicit drugs) dates to 1974 and is both uncertain and incomplete. Gamma-ray production data are generally less well known than neutron scattering data. Neutron and γ-ray source data, particularly for thick targets are available only in a very limited number of situations. There would be a clear benefit obtained from comprehensive measurements made of thick-target yields, angular distributions and spectra from (p,n), (d,n), and (p,γ) reactions on all materials up to Fe for incident particle energies from a few keV up to 10 MeV. Finally, there is a need for photo-fission and photo-neutron measurements from threshold up to 10 MeV. The most important requirements are listed below:

- Experimental angular distributions for 4.44 MeV γ ray from C(n,n'γ) as a function of neutron energy in the range 7-10 MeV in 0.5 MeV steps and at E_n ˜ 14 MeV.
- Experimental neutron emission energy spectra and angular distributions for Be(p,n) and Be(d,n) reactions for incident energies from 2 to 10 MeV in 1-MeV steps.
- Experimental neutron yield measurements for (γ,f)+(γ,n) - taken together - for ^{235}U, ^{238}U, ^{239}Pu and ^{240}Pu for E_γ= 6-8 MeV. Photon energy steps of 0.1-0.2 MeV, depending on structure. Prompt neutrons. Total yield.
- Experimental yields and angular distributions for prominent γ-rays from oxygen, nitrogen, and chlorine (n,n'γ) reactions. E_n = 7-10 MeV in 0.5 MeV steps and at E_n ˜ 14 MeV.
- Neutron yield measurements from protons with E_p = 2-4 MeV (in 0.5-MeV steps) on thick (stopping) targets of oxygen, sulfur, carbon, gold, nickel, titanium, iron, and copper. Total yields are desired. Neutron energy spectra from E_n ˜ 0.5 MeV to maximum energy would be desirable also.
- New evaluated neutron data file (ENDF format) for germanium.

Material analysis

G.L. Molnar presented status and nuclear data needs for the emerging nuclear technologies dedicated to material analysis. These methods include well established neutron activation analyses such as delayed gamma (NAA), prompt gamma (PGAA), depth profiling (NDP), and neutron scattering, diffraction and reflectometry. Very recently these techniques were refined by using cold neutron sources and resonance neutron capture in the range between 10 and 100 eV. These techniques appear very promising due to their high selectivity, which makes them perfectly suited for environmental and biological studies. Large amounts of the required nuclear data are actually available (neutron cross sections, decay data, prompt γ energies and intensities for thermal and fast reactor spectra). On the other hand, there is an almost total lack of data for the following quantities:

- prompt γ-ray spectra for cold neutrons
- cross sections of non-1/v nuclides
- cold neutron spectrum characteristics
- γ-ray spectra for resonance capture between 10 and 100 eV
- γ-ray spectra for fast neutron induced reactions used in borehole logging (e.g. ^{35}Cl(n,γ))

Improved recommended cross sections, half-lives, decay γ-rays data, k_0, fission yields and delayed neutron yields as well as spectral compositions are needed for a number of materials. These improvements will require reevaluations often supported by new measurements.

It has been noted that it would be beneficial to users if the relevant data were collected in one place including uncertainties and traceability of the source, and made available as a hard copy, electronic media (Web, CD-ROM) as well as computer readable files (spreadsheet, MCNP inputs, etc.).

It was recommended that future activities focus on:

- Application of cold neutron methods (PGAA, reflectometry) in environment and biology.
- Stimulating new measurements of:

- prompt γ–spectra for cold, epithermal, and fast neutrons
- cold-neutron cross sections for non-1/v nuclides
- fast neutron cross sections (^{16}O, $^{12}C(n,n')$)
- decay half-lives (short and long)
- k_0 (for NAA and PGAA)
- fission yields (short-lived)
- delayed neutrons

- Improved evaluations of thermal cross-sections, neutron resonances, and scattering lengths.

Critical Reactors Including Closed Fuel Cycles

Speakers: N. Rabotnov, N. Kocherov, R. Srivenkatesan

Three reports were presented: "Data Needs for Modeling of Fuel Cycle Concepts for Fast Lead Cooled Reactors" by *N. Kocherov* (RF); "Nuclear Data For Advanced Fast Reactors" by *N. Rabotnov* (RF); "Indian Advanced Heavy Water Reactor for Thorium Utilization and Nuclear Data Requirements and Status" by *R. Srivenkatesan* (India).

The first two reports suggest that fast-reactor concepts are starting to regain importance due to a growing realization of energy supply problems in many regions of the world. This is combined with the fact that fast reactors are based on the only proven technology available that is obviously able to ensure a global energy supply for many centuries.

New trends in fast reactor development shift the needs in improved nuclear data from traditional fissioning isotopes, construction materials, and sodium coolant to minor actinides, as components of recycled fuels to be transmuted in fast neutron spectra; lead-based heavy liquid metal coolants; nuclear data for closed nuclear fuel cycle options, where fuel components retaining high reactivity may be placed in a variety of moderating and reflecting environments, should include low neutron energy data.

Development of the reactors using ^{233}U-Th fuel and of their fuel cycle requires improved data for ^{233}U, ^{232}Th, and crucial isotopes of Pa.

At the same time it was pointed out in the discussions that achievements reflected in existing nuclear data libraries should not be underestimated. They form a solid base for further development in close cooperation with designers and operators of nuclear power plants using various systems of macroscopic nuclear constants.

It was also remarked that accumulation of the heaviest isotopes with relatively short spontaneous fission half-lives increases neutron radiation from spent nuclear fuel so that the corresponding capture cross sections are of special importance. Deterioration of the Pu vector in recycling stresses the need of improving nuclear data for even Pu isotopes.

Recommendations

More accurate and more detailed nuclear data are needed for critical reactor materials:

1. Minor actinides
   - in the fast spectra of breeders and transmuters;
   - in softer, well-moderated spectra corresponding to different off-pile environments of closed nuclear fuel cycles during storage, transportation and reprocessing ("burn-up credit/debit")
2. Light actinides in the Th-cycle (^{232}Th, ^{233}U, Pa isotopes)
3. Natural lead as basic component of promising coolants, high boiling, chemically inert liquid metal.

Methods of reproducible generation of realistic error bands and physically meaningful covariance matrices for nuclear data should be developed, tested and applied.

Accelerator Driven Subcritical Reactors

Speakers: M. Salvatores, A. Ignatyuk, Z.X. Zhao, K. Tsujimoto

M. Salvatores, by way of introduction, reminded the group briefly that ADS concepts have been proposed in the last decade for a variety of applications. However, there is a convergence of interest of several countries and laboratories on the application of ADS to transmutation ("burning"). This applies to plutonium, and/or minor actinides (MA) and long-lived fission products (LLFP). As far as the so-called partitioning and transmutation (P/T) strategies, it was indicated that they can be clarified according to the option taken with respect to Pu and MA, i.e., a) keep Pu and MA together, b) separate Pu from MA. Strategy a) gives rise to transmutation concepts with "homogeneous" recycling of MA in the fuel of "standard" (LWR, Fast Reactors) reactors, or to concepts devoted to Pu+MA burning (i.e., no fertile materials in the fuel), as in the ATW concepts developed in the USA. In this last case the absence of fertile nuclides (e.g., U-238) gives rise to cores with very low β_{eff} and near zero Doppler effect. These features have suggested the use of subcritical core configurations for the burning of pure Pu+MA.

Strategy b) (Pu separated from MA), gives rise to transmutation concepts like "heterogeneous" recycling (e.g. MA targets to be irradiated in "standard" critical reactors), or to the "double strata" concept (originally developed at JAERI-Japan), in which MA are handled in dedicated cores, in a separate stratum of the fuel cycle. These dedicated cores also show low β_{eff} and Doppler coefficients, and these features practically preclude the option of a critical core, and here again ADS find a relevant application.

At present several programs are going on ADS: in Japan in the frame of the Joint Project between KEK and JAERI; in the USA (the Advanced Accelerator Applications, AAA, initiative); in EUROPE, where activities in 9 countries are coordinated by a European Technical Working Group (ETWG), chaired by Carlo Rubbia, and where the European Union is sponsoring and partly funding a dozen of projects (over three years) in different areas of ADS R&D (nuclear data, neutron physics, materials, fuels and preconceptual designs). Finally, several laboratories in Russia are also active in the ADS field. As far as the implications for the definition of nuclear data needs, dedicated subcritical cores should have new type of fuels (Pu+MA in different proportions). Proposals are being worked out. For example, composite (such as ceramic-metallic or ceramic-ceramic) fuels are presently under study. The actinide oxide is dispersed in a metallic matrix (Zr, or W or Mo) or in an oxide matrix (e.g., MgO). In these cases, reliable data are required for the matrix materials. As far as coolants, Pb/Bi, Pb, and gas are considered, besides Na. Hard (or very hard) fast neutron spectrum is required.

As far as realizations, the horizon is 2010-2015 for experimental ADS (power <20 MWth) and 2020-2025 for demonstration experiments at higher power (>100 MWth).

As far as LLFP, transmutation strategies in ADS are proposed. Candidates are ^{129}I, ^{99}Tc, ^{135}Cs, but also ^{79}Se, ^{107}Pd, ^{93}Zr etc. At present, there is no clear option for their transmutation (one needs a high level of thermalized neutrons, support matrixes for target irradiation, isotopic separations, reprocessing techniques, etc.).

Finally, ADS transmutation will give rise to fuel cycles, where very active materials will be present. Cm and higher mass isotopes (up to ^{252}Cf!) will be contributors to dose and neutron source strength. This area will deserve attention in future, in order to define the relevant data needs.

A. Ignatyuk presented a wide review of the status of nuclear data for transmutation in ADS.

A significant point was made, namely that there is evidence, coming from evaluations, microscopic experiments and integral data validation, that nuclear data, not only for major actinides (e.g. Pu isotopes), but also for ^{237}Np, ^{241}Am and ^{243}Am are in acceptable shape. In fact the achieved accuracies are not very far from target accuracies (e.g. ± 5% on fission cross-sections, ± 10% for capture cross-sections, ± 10-20% for inelastic cross sections).

However there is a clear need for better data for Cm isotopes and anomalies in some evaluated data sets where pointed out.

Also the relevance of irradiated sample experiments has been indicated. This is the case for a large series of experiments performed in the BN-350 reactor, for which C/E values where shown. More generally the role of data validation using integral experiments was stressed.

To improve the present situation, and in view of the large effort still needed to reach target accuracy, international cooperation enhancement has been suggested. In particular, the author made a recommendation for an international coordinated effort with the goal to produce a common data file.

Z. Zhao presented an overview of the energy need projections for China up to 2050. He indicated that nuclear should play a growing role and, in that context, an R&D 5-year program on ADS has been approved in order to establish the scientific foundation of the concept and its possible role in the China nuclear energy program.

The author reviewed areas where nuclear data are needed for application of ADS to radioactive elements transmutation, namely:

- Neutron data needed for transmutation of long-lived fission products (LLFP).
- Neutron data needed for transmutation of MA. The requirement for data like fission up to

300 MeV. The relevance of the neutron "tail" above 20 MeV and the impact on the core neutron balance is probably less important that the impact of high energy neutron on shielding assessment.
- Neutron data related to the production of long-lived radioactive wastes <u>inside</u> the ADS (both for thorium or uranium-based ADS).
- Nuclear data related to the fuel cycle (γ- or n-emitters of relevance).

In view of the wide range of needs, the author stressed the role to be played by the IAEA Nuclear Data Section.

K. Tsujimoto illustrated the effect of nuclear data on the characteristics of ADS. The study was related to an ADS design study performed at JAERI (mononitride of Pu and MA as fuel, Pb/Bi coolant). The cases of MA unloaded from a UO_2-PWR and a MOX-PWR were considered. Discrepancies were found when different datasets were used both at the beginning and at the end of the cycle.

A perturbation analysis allows pointing out the nuclear data responsible for such discrepancies (σ_c of ^{237}Np and ^{241}Am for example). Among others, it was indicated that there is a possible problem of the fission cross-section of ^{242}Cm in ENDF/B-VI (unphysically low). Another relevant point is the importance of a good assessment of the branching ratio ^{241}Am(n,γ)^{242g}Am and ^{241}Am(n,γ)^{242m}Am. In the discussion, it was mentioned that an irradiation of an ^{241}Am sample in PHENIX had given a clear indication for the recommendation of the value of such branching ratio (in a fast spectrum). This value was published in Nuclear Science and Engineering. The speaker underlined the need for minor actinides (MA) delayed neutron data, since β_{eff} is used in all reactivity scale measurement techniques and it can change strongly between beginning of cycle and end of cycle. Also, fission neutron and fission spectra are often missing.

The presentation stressed the role of integral data validation, in particular irradiated sample analysis. A series of irradiated samples in PHENIX (the PROFIL experiments documented in the open literature) has been analyzed and preliminary results were shown.

Finally, ^{99}Tc and ^{129}I data were discussed (thermal capture, and resonance integrals).

Recommendations

a) Coordinated work on MA data is still a priority: ^{241}Am, ^{242m}Am, ^{243}Am and Cm isotopes, since the typical target accuracies required (i.e., ˜ 5% for σ_f, ˜ 10% for σ_c, ˜ 15% for σ_{in}) are not yet achieved. In this respect the following recommendations can be made:

   1) Review the consistency of data and eliminate non-physical data (e.g. ^{242}Cm σ_f and ^{243}Cm σ_{in} in ENDF/B-VI).

   2) Perform extensive sensitivity studies for significant parameters of the subcritical core (k_{eff}, reactivity coefficients, peak power, dpa gradients etc.) for systems with different ratios of Pu and MA in the fuel (e.g. Pu/MA=80/20 or = 40/60), for two coolants (e.g., Pb/Bi and gas) and for the initial stage and at end of cycle. This will permit agreement on target accuracies and priorities on a sound basis (to make selected experiments).

   3) Review uncertainties and, more generally, the status of data for the calculation of β_{eff},

decay heat, γ-heating for the systems mentioned in 2), before suggesting new experiments.

b) 1) Review the status of data for materials which are potential new candidates as core support materials (e.g., MgO, Zr, Ti)

2) Same for Pb, Bi, N, ^{15}N (σ_{t}, $\sigma_{n\gamma}$, σ_{el}, σ_{inel}, σ_{np} below 20 MeV).

c) As far as major actinides in the context of transmutation:

1) Review the ^{242}Pu and ^{238}Pu data accuracy, in particular $\sigma_{n,\gamma}$.

2) Assess uncertainty on MA and Pu isotopes σ_f in the region 1-20 MeV (required accuracy: $\pm$ 5%).

ADS Target Design and High-Energy Radiation Shielding

Speakers: A. Koning, T. Fukahori, S. Leray

The nuclear data needs for ADS target design and high-energy radiation shielding concern mainly energy range above 20 MeV, contrary to the data needs for traditional reactors which are limited to energies below 20 MeV. This opens a completely new field, which poses a serious challenge to evaluators. The nuclear data request list is huge, and contains cross sections for many of the components of an ADS, such as shielding, target and window. The approach to satisfy the nuclear data needs is quite clear: the amount of needed nuclear data is so large that experiments alone can never cover all the requests. Therefore nuclear models must be used in combination with a carefully chosen set of experimental results. Many of the nuclear model codes used so far are not applicable in the high energy range, due to internal limitations and omission of nuclear reaction mechanisms which dominate at high energies. A new generation of codes, comprising statistical model, preequilibrium emission and intranuclear cascade model, has to be developed. The formidable increase of the computational power and substantial progress in the nuclear reaction theory allow one to relax many of the approximations used in the past making theoretical predictions more accurate and reliable. Last but not least, the codes must be easy to operate in order to be able to provide the large amount of needed data in a timely manner. Issues related to nuclear reaction modeling were treated in two contributions.

Actual status of available nuclear data in the intermediate energy region and needs for further development were discussed by *A. Koning.* It was noted that LANL evaluations (up 150 MeV) satisfy data needs for the construction materials, while those for actinides are missing. *A. Koning* also presented the current stage of the development of the new code TALYS, which combines statistical model and preequilibrium emission using advanced theoretical formulation. The code is designed for calculations up to 200 MeV and is expected to be released in about 18 months.

Status of the high energy nuclear models was discussed by *S. Leray*. Intranuclear cascade approach followed by evaporation-fission models is applicable at energies above 200 MeV and used for the spallation target design. Required data include double-differential cross sections for neutron production in order to determine neutron multiplicity, optimize target geometry, predict window and structure damage and design shielding. Charged particle (gas) production is needed to estimate embrittlement, swelling and energy deposition. The residual nuclide production is essential for determination of changes in metallurgical properties, induced activity, radiotoxicity, and decay heat. Regarding experimental data a large set is available for neutrons only while there is a clear lack of measurements for charged particles. Comparison with predictions of various intranuclear cascade and evaporation-fission models demonstrates that some of the widely used codes have to be ruled out. New models give encouraging results, but none of them is fully satisfactory. Assessment of the models calls for the coherent analysis of the whole bulk of data and detailed comparison with exclusive measurements. This task would be facilitated by establishment of a reference set of validated experimental data.

ADS activities and related data needs in Japan were presented by *T. Fukahori*. There are at least 14 working or planned high energy accelerators in Japan. This leads to the formulation of an extensive list requirements for specific nuclear data which are briefly summarized at the end of this section.

The recommendations which follow are divided into two energy regions: nuclear data below 200 MeV, which is covered by nuclear data libraries that themselves rely heavily on nuclear model codes, and a region above 200 MeV where intranuclear cascade codes are used to model both data and transport processes.

Recommendations for intermediate energy region (< 200 MeV)

- There is not enough effort on nuclear model development, in comparison with experiment, while nuclear models are the main source for nuclear data above 20 MeV. All existing efforts in the field need to be brought together and coordinated.
- There should be an extension of the current IAEA program on the Reference Input Parameter Library, which does a comparable activity, but now directed towards nuclear model modules, whereby each specialist contributes to the progress in nuclear modeling.
- Special attention should be paid to validation and processing of nuclear data files up to 200 MeV.
- There should be further benchmarks in this energy region besides the 68 MeV JAERI transmission experiment.

Recommendations for high energy region (> 200 MeV)

- Nuclear models need to be tested against the existing experimental data collection and need to be improved. New theoretical methods need to be included. Fission is a particularly serious problem.
- Considerable experimental effort has already been expended over the last few years. Nevertheless, there are still a few gaps, notably neutron-induced reactions (for a few nuclides) and (p,xp…xalpha) reactions (for most nuclides), and residual nuclide production in the A=100 mass range. The new generation of exclusive experiments is important to solve particular problems in modeling nuclear reactions.
- There should be a recommended set of experimental data to be simultaneously compared against high-energy nuclear models. Since in this energy range there is only weak dependence on A, a few complete experimental data sets, representative to each mass region, will be sufficient to validate the models. This should be done for all reaction channels.
- More manpower is needed for model development.

Specific nuclear data needs

Nuclear data for core materials:

U, Th

Nuclear data for target equipment:

Target: Ta, W, Hg, Pb, Bi
Beam Window: V, Mo, W
Beam Window (HT-9): Cr, Mn, Fe, Ni, Mo
Beam Window (ceramics): C, O, Al, Si, Ti, Zn, Ba
Moderator: D
Reflector: Be, Ni, W, Pb
Coolant: H, O, He, Na, Hg, Pb, Bi

Nuclear data for shielding

Structural Material: V, Fe, Ni, Cu, Nb, Mo
Magnet: Na, Ca, Cr, Fe, N, Cu, Nb
Beam Tube: Na, Al, Ca, Cr, Fe, Ni
Beam Dump: C, Fe, Cu
Soil: C, Si
Air: N, O, Ar

In sum, the success in attacking nuclear data problems above 20 MeV mainly depends on nuclear model simulations. Therefore, we recommend an active participation of IAEA-NDS in this area. Nuclear model intercomparisons and development at both intermediate and high-energies is a necessity.

General recommendations

M. Salvatores strongly recommended the association of uncertainties estimates, even preliminary ones, with data (for example in intermediate energy range: residual isotope production, neutron production, charged particle x-sections etc.). This should be encouraged and the resulting uncertainties compiled in a very simple form (e.g. tables) at the beginning, in order to facilitate the dialogue with end users. In fact, that community is interested in information that can help them to define margins in design. The Agency can help to achieve this goal. In addition, he suggested that attention be given to decay data, fission yields and delayed neutron data.

P. Obložinský raised the issue of creating a single worldwide library of nuclear data. He also suggested that the NDS broaden its activities to include more atomic data in addition to those for fusion.

A. Ignatyuk advocated for increase of international coordination and setting clear goals for the activities.

G. Molnar pointed out the necessity of providing users with interfaces specific to particular fields of application. It happens that certain groups of users are reluctant to use available nuclear data just because these are provided in the form which is not convenient to the practitioners.

D. Muir stated that it is important to maintain and expand compilation of experimental data in the EXFOR library. In particular, the compilation of data needed in new applications should be supported.

There was a general consensus that charged particle data constitute a new territory, which is relevant to material analysis, radioisotope production, astrophysics and ADS and should be given more attention.

Many participants stressed that nuclear models are irreplaceable evaluation tools, especially in ADS and astrophysics. Data needs in these areas are too vast to be measured. In the case of astrophysics they are usually inaccessible to experimental investigations. Therefore it is essential that support for nuclear model development and the associated RIPL project be continued. A. Koning emphasized the need to establish an international modular library of model routines.

It was noted that the number of experienced and active evaluators is shrinking to the level that might undermine further activities in the field. To counteract this danger NDS should continue its training program. In particular, courses organized in cooperation with the ICTP at Trieste are considered an efficient mean of preserving the knowledge and attracting young scientists from all over the world. Their scope should be broaden to cover nuclear data for all the fields discussed in the present report.

<u>Appendix 1</u>

International Atomic Energy Agency

Advisory Group Meeting on

LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT

IAEA Headquarters, Vienna

28 November – 1 December 2000

AGENDA

Opening and Agency Perspectives

a. Opening remarks, D.W. Muir
b. Welcoming remarks, W. Burkart, DDG-NA
c. Welcoming remarks, V. Mourogov, DDG-NE
d. International Co-operation in Nuclear Data Research, IAEA Nuclear Data Section

1. Nuclear Data Needs for Medical Applications (1/2 day)

Chair: S. Qaim
Speakers: T.W. Burrows, D. Jones

a. Introduction to data needs in medicine
b. Production of new diagnostic and therapeutic radionuclides
c. Internal radiation dosimetry
d. Fast neutron and proton therapy

2. Nuclear Data Needs for Ion Beam Analysis and Related Techniques (1/2 day)

Chair: I. Vickridge
Speaker: A. Gurbich

a. Ion Beam Analysis
b. Nuclear Reaction Analysis
c. PIGE, RBS, HIRTOFS

3. Nuclear Data Needs for Nuclear Astrophysics (1/2 day)

Chair: F. Kaeppeler
Speakers: M.S. Smith, S. Goriely

a. Neutron induced reactions
b. Charged-particle induced reactions
c. The role of nuclear models in providing nuclear data for astrophysics

4. Nuclear Data Needs for Nuclear Safeguards and Related Applications (1/2 day)

Chair: John Boldeman
Speakers: G. Molnar, D.L. Smith

a. Nuclear Safeguards
b. Material Analysis
c. Neutron interrogation methods

5. **Nuclear Data Needs for Critical Reactors, including Closed Fuel Cycles** (1/2 day)

Chair: N. Rabotnov
Speakers: N. Kocherov, R. Srivenkatesan

a. Burnup credit for fuel storage
b. Advanced fast reactor development, including lead-cooled reactors
c. Advanced thermal reactor development, including molten salt systems

6. **Nuclear Data Needs for Accelerator Driven Subcritical Reactors** (1/2 day)

Chair: M. Salvatores
Speakers: A. Ignatyuk, Z.X. Zhao, K. Tsujimoto

a. Actinide transmutation in subcritical cores
b. Fission-product transmutation in subcritical cores

7. **Nuclear Data Needs for ADS Target Design and High-Energy Radiation Shielding** (1/2 day)

Chair: Arjan Koning
Speakers: T. Fukahori, S. Leray

a. Nuclear Models and their impact on ADS Nuclear Data
b. High energy nuclear data for spallation target design
c. Nuclear Data Needs for Accelerator-Driven System and Shielding

8. **Panel Discussion and Drafting of Summary** (1/2 day)

International Atomic Energy Agency

Advisory Group Meeting on

LONG TERM NEEDS FOR NUCLEAR DATA DEVELOPMENT

IAEA Headquarters, Vienna

28 November – 1 December 2000

LIST OF PARTICIPANTS

AUSTRALIA

John W. Boldeman
Lucas Heights Research Laboratory
Australian Nuclear Science and
Technology Organization
New Illawara Road
Lucas Heights, PMB 1
Menai, NSW 2234
Tel.: +61-2-9717-3206
Fax: +61-2-9717-9265
E-mail: jwb@ansto.gov.au

BELGIUM

Stephane Goriely
Institut d'Astronomie et d'Astrophysique
Université Libre de Bruxelles
CP-226
Campus de la Plaine
Boulevard du Triomphe
B-1050 Brussels
Tel.: +32-2-650-2843
Fax: +32-2-650-4226
E-mail: sgoriely@astro.ulb.ac.be

CHINA

Zhao Zhixiang
China Institute of Atomic Energy
P.O. Box 275 (11)
102413 Beijing
Tel.: +86-10-6935-7261
Fax: +86-10-6935-7008
E-mail: zhaozx@iris.ciae.ac.cn

FRANCE

Sylvie Leray
DAPNIA/SPhN
CEA/Saclay
F-91191 Gif-sur-Yvette
Tel.: +33-1-69-088361
Fax: +33-1-69-087584
E-mail: sleray@cea.fr

Ali Nouri
OECD Nuclear Energy Agency
Le Seine Saint-Germain
12, boulevard des Iles
F-92130 Issy-les-Moulineaux
Tel.: +33-1-45-241084
Fax: +33-1-45-241110
E-mail: nouri@nea.fr

Massimo Salvatores
Direction des Réacteurs Nucléaires
Bâtiment 707
Centre d'Etudes Nucléaires de Cadarache
F-13108 Saint-Paul-lez-Durance
Tel.: +33-4-42-252257
Fax: +33-4-42-254142
E-mail: salvatores@drn.cea.fr

Ian Vickridge
Groupe de Physique des Solides (GPS)
UMR 7588/CNRS
Tour 23
Université Paris 6 et 7, 2 Place Jussieu
F-75251 Paris
Tel.: +33-1-44-274686
Fax: +33-1-43-542878
E-mail: vickridge@gps.jussieu.fr

GERMANY

Franz Kaeppeler
Forschungszentrum Karlsruhe
Technik und Umwelt
Postfach 3640
D-76021 Karlsruhe
Tel.: +49-7247-82-3991
Fax: +49-7247-82-4075
E-mail: keapp@ik3.fzk.de

Syed M. Qaim
Institut für Nuklearchemie
Forschungszentrum Jülich GmbH
Postfach 1913
D-52425 Jülich
Tel.: +49-2461-61-3282
Fax: +49-2461-61-2535
E-mail: s.m.qaim@fz-juelich.de

HUNGARY

Gabor L. Molnar
Department of Nuclear Research
Chemical Research Center
Institute of Isotope and Surface Chemistry
P.O. Box 77
H-1525 Budapest
Tel.: +36-1-3922539
Fax: +36-1-3922584
E-mail: molnar@iki.kfki.hu

INDIA

R. Srivenkatesan
Reactor Design and Development Group
Reactor Physics Design Section
Hall No. 7
Bhabha Atomic Research Centre
Trombay, Mumbai 400 085
Tel.: +91-22-550-5050 Ext. 3571
Fax: +91-22-550-5150
E-mail: rsriven@apsara.barc.ernet.in

JAPAN

Tokio Fukahori
Nuclear Data Center
Department of Nuclear Energy System
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun
Ibaraki-ken 319-1195
Tel.: +81-29-282-5907
Fax: +81-29-282-5766
E-mail: fukahori@ndc.tokai.jaeri.go.jp

Kazufumi Tsujimoto
Research Group for Nuclear Transmutation System
Department of Nuclear Energy System
Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun
Ibaraki-ken 319-1195
Tel.: +81-29-282-6935
Fax: +81-29-282-6438
E-mail: ktsuji@omega.tokai.jaeri.go.jp

NETHERLANDS

Arjan Koning
NRG Nuclear Research and Consultancy Group
Building 34.333
Westerduinweg 3
P.O. Box 25
NL-1755 ZG Petten
Tel.: +31-22456-4051
Fax: +31-22456-3490
E-mail: koning@nrg-nl.com

RUSSIA

Alexander F. Gurbich
SSC RF
Institute for Physics and Power Engineering
Bondarenko Sq. 1
249020 Obninsk, Kaluga Region
Tel: +7-08439-95943
Fax: +7-095-2302326
E-mail: gurbich@ippe.obninsk.ru

RUSSIA (cont.)

Anatoly V. Ignatyuk
Institute of Physics and Power Engineering
Bondarenko Sq. 1
249020 Obninsk, Kaluga Region
Tel.: +7-084-399-8035
Fax: +7-095-230-2326
E-mail: ignatyuk@ippe.obninsk.ru

Nikolai Kocherov
V.G. Khlopin Radium Institute
2nd Murinski Ave. 28
194021 St. Petersburg
Fax: +7-812-247-5781
E-mail: kocherov@atom.nw.ru

N.S. Rabotnov
Ministry of the Russian Federation on Atomic Energy
Staromonetny per. 26
109180 Moscow
Tel.: +7-095-953-5445
Fax: +7-095-230-2420
E-mail: rabotnov@dol.ru

SOUTH AFRICA

Dan T.L. Jones
Medical Radiation Group
National Accelerator Centre
P.O. Box 72
7131 Faure
Tel.: +27-21-843-3820
Fax: +27-21-843-3382
E-mail: jones@nac.ac.za

UNITED STATES OF AMERICA

Thomas W. Burrows
National Nuclear Data Center
Bldg. 197D
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
Tel.: +1-631-344-5084
Fax: +1-631-344-2806
E-mail: burrows@bnl.gov

UNITED STATES OF AMERICA (cont.)

Pavel Obložinský
National Nuclear Data Center
Bldg. 197D
Brookhaven National Laboratory
P.O. Box 5000
Upton, NY 11973-5000
Tel.: +1-631-344-2814
Fax: +1-631-344-2806
E-mail: oblozinsky@bnl.gov

Donald L. Smith
Nuclear Data Program
Technology Development Division
TD 360-L106
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Tel.: +1-630-252-6021
Fax: +1-630-252-4007
E-mail: donald.l.smith@anl.gov

Michael S. Smith
Physics Division
Oak Ridge National Laboratory
Bldg. 6010, MS-6354
P.O. Box 2008
Oak Ridge, TN 37831
Tel.: +1-865-576-5037
Fax: +1-865-576-8746
E-mail: msmith@mail.phy.ornl.gov

IAEA

Douglas W. Muir (Scientific Secretary)
Nuclear Data Section
Wagramer Strasse 5
A-1400 Vienna
Tel.: +43-1-2600-21709
Fax: +43-1-26007
E-mail: d.muir@iaea.org

Michal Herman (Scientific Secretary)
Nuclear Data Section
Wagramer Strasse 5
A-1400 Vienna
Tel.: +43-1-2600-21713
Fax: +43-1-26007
E-mail: herman@ndsalpha.iaea.org

OBSERVERS

RUSSIA

Gennady Nefedov
Ministry of the Russian Federation
on Atomic Energy
Staromonetny per. 26
109180 Moscow
Russian Federation
Fax: +7-095-230-2420

AUSTRALIA

Claudio Tuniz
Permanent Mission of Australia
to the IAEA
Mattiellistrasse 2
A-1040 Vienna
Austria
Tel.: +43-1-512-8580
Fax: +43-1-504-1178
E-mail: tuniz@ansto.gov.au

Nuclear Data Section	e-mail: services@iaeand.iaea.or.at
International Atomic Energy Agency	fax: (+43-1) 26007
P.O. Box 100	cable: INATOM VIENNA
A-1400 Vienna	telex: 1-12645
Austria	telephone: (+43-1) 2600-21710

Online:	TELNET or FTP:	iaeand.iaea.or.at
	username:	IAEANDS for interactive Nuclear Data Information System
	usernames:	ANONYMOUS for FTP file transfer;
		FENDL2 for FTP file transfer of FENDL-2.0;
		RIPL for FTP file transfer of RIPL;
		NDSONL for FTP access to files sent to NDIS "open" area.
	Web:	http://www-nds.iaea.or.at