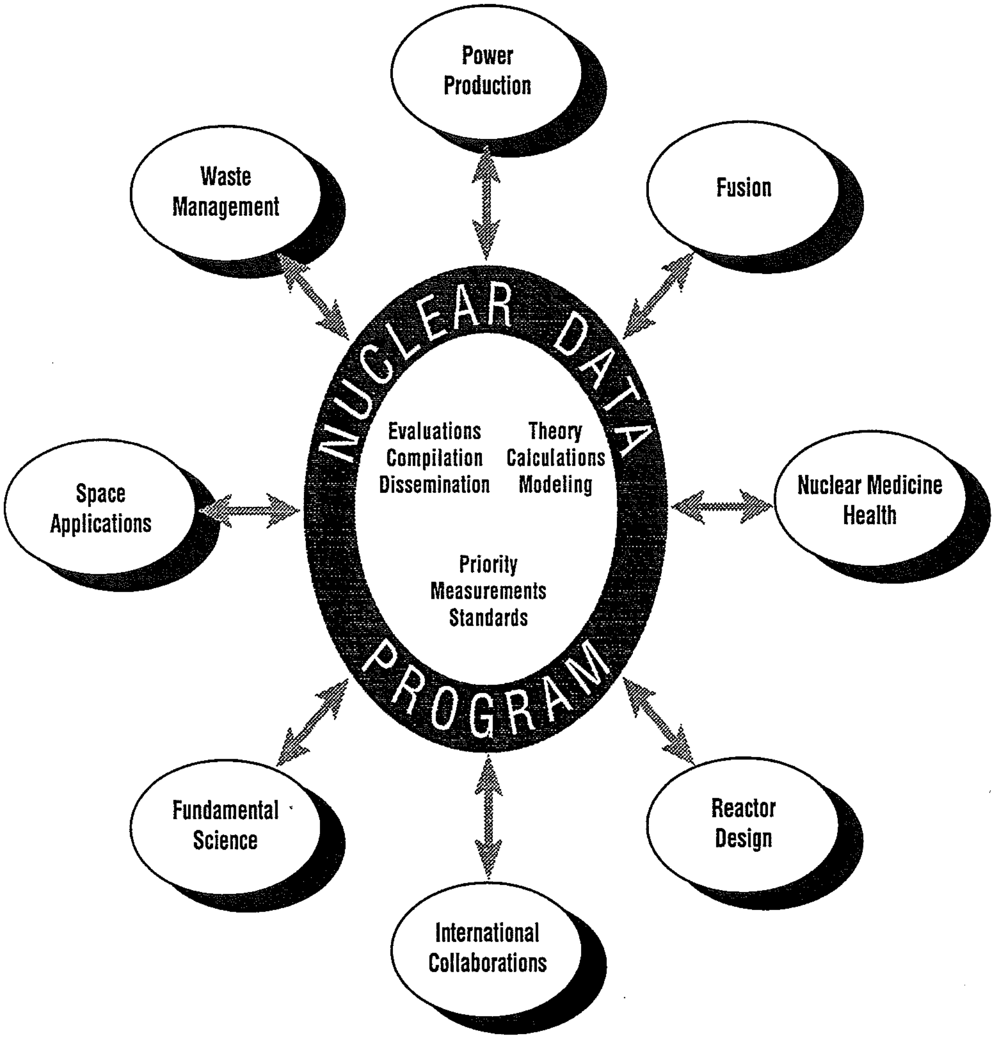
NATIONAL NUCLEAR DATA NEEDS OF THE 1990'S
A REPORT TO THE
NUCLEAR SCIENCE ADVISORY COMMITTEE



BY THE

SUBCOMMITTEE ON NUCLEAR DATA NEEDS

NSAC SUBCOMMITTEE OF NUCLEAR DATA NEEDS IN THE 1990’s

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2. Reactor Design	Dr. William H. Hannum Argonne National Laboratory
3. Nuclear Medicine/Health	Dr. John A. Correia Harvard Medical School Massachusetts General Hospital
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5. Fusion	Prof. Mohamed A. Abdou University of California, Los Angeles
6. Waste Management	Dr. Martin Haas Westinghouse
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Executive Summary

The United States is entering an era of intense international competition in science, technology and business. No nation can maintain a first class economy in this complex age without the ability to maintain a competitive position in international markets. In today's markets quality is the key to survival. This fact is recognized worldwide by business and government leaders and is evidenced by on-going efforts by more than two dozen countries to establish National Quality Awards for business.

Accurate technical data constitute the keystone to quality design and reliability. Those companies or institutions that can assure quality and reduce the cycle time for innovations and quality improvements in their products and services have a distinct advantage in world markets. Thus, rapid access to accurate data is essential to profitability and competitiveness in these fast moving times. These factors were held clearly in mind when the NSAC Subcommittee conducted its study of the Nuclear Data Needs of the 1990's.

The following are the major conclusions of the Subcommittee:

- A strong, viable Nuclear Data Program, operating at the National level, can have a critical impact in the following areas:
  - Industrial competitiveness
  - Health and safety
  - National security
  - Scientific competitiveness

- The Nuclear Data Program can provide overwhelming positive impacts in these areas at a very attractive cost to benefit ratio.

- The national Nuclear Data Program can provide accurate data for priority applications in at least eight important sectors of U.S. technology, including:
  - Power Production
  - Space Applications
  - Nuclear Medicine and Health
  - Fusion Energy R&D
  - National Security
  - Nuclear Waste Management
  - Advanced Reactor Design
  - Fundamental Science

- The Nuclear Data Program supplies major benefits to the nation by:
  - Providing data users with critical data/standards for assuring quality of products and programs
  - Providing a readily accessible source of nationally accepted and validated quality data
  - Providing national and international exchange and intercomparisons for consistency and acceptability
  - Eliminating the need for wasteful duplication of measurements

- The requirements for viability in the Nuclear Data Program are:
  - A critical mass of staff and facilities
  - An integrated core of program elements strongly coupled to the major communities of data users
  - A national mission and scope
  - A confident future based upon stable, long-term support

- The core program elements must include (listed in priority order):

  - Compilation, evaluation, and dissemination. These functions are the most basic components of the nuclear data program, and , without them, a nuclear data program would be of limited usefulness.
  - Priority measurements and standards. These include those measurements that are essential tie points for calculations and modeling, those that demand higher accuracy than available from calculations/models, and those critical data that are benchmarks/standards for large classes of important measurements made by users.
  - Calculations, modeling and theory. Although a smaller program element, the "calculations, modeling and theory" component must be considered a core element. Often, the types of facilities required to obtain key nuclear data may not be available and are too costly to construct and operate. Modeling and calculations, particularly when based upon the latest advances in theory, can offer cost effective alternatives to direct measurements in some very important instances. Model calculations, however, must be referenced to critical (priority) measurements to provide a basis for confidence and limits on accuracy. Thus tightly coupled, calculations and measurements can reinforce each other and have a productivity far beyond that available from either separately.

- Initially, the Nuclear Data Program provided very important benefits to the nation especially in the areas of nuclear power and national security . More recently it has made positive impacts in nuclear medicine and industrial applications. In the future, nuclear waste, space applications, and fusion energy present both challenges and opportunities. To keep pace with the accelerating growth and technological changes in all fields, the needs and capabilities of the nuclear data customers must be integrated even more closely in the planning, execution and support of the program.

Its deliberations led the Subcommittee to the following major recommendations to DoE and NSF:

- To ensure a critical mass of essential core elements, the funding of the Nuclear Data Program should be maintained at least at the 1991/92 level. The clear Subcommittee consensus is that a lower level would seriously jeopardize the program's ability to operate in an effective manner.

- A basic set of manpower and facilities must be maintained to support the core elements.

- DoE and NSF should encourage the formation of an active "User Association" (group) in each of the major data application areas listed above to provide a mechanism for determining user needs, a forum for developing consensus-based priorities reflecting cost benefit considerations, and a basis for arriving at an assessment of likely resources that the users could share with the program and other users to achieve mutual goals.

- A formal Advisory Panel, chaired by a representative from the user community, should be established by the DoE. The panel should include user representatives from each application area, each core element in the program, the Data Program administration, and the general scientific community. The Panel's responsibilities should include:
  - Development of recommended priorities for operating and improving the program,
  - Maintain close liaison with the NAS panel on Basic Nuclear Data Compilations,
  - Explore ways in nuclear data files can be made more accessible and user friendly,
  - Promote closer interactions between modelers and theorists.

NATIONAL NUCLEAR DATA NEEDS OF THE 1990's

Purpose of Review

The DOE/NSF Nuclear Science Advisory Committee was asked by James Decker, DOE, and Marcel Bardon, NSF, to address the national nuclear data needs and related issues and to provide a written report of their findings. The purposes of this review were to (1) determine the national nuclear data needs expected in the 1990's and their appropriate priorities, and (2) address the methods of management and determination of priorities. A copy of the full charge to NSAC is included in Appendix E.

Methodology

The NSAC established a Subcommittee on Nuclear Data Needs for the 1990's and appointed a Chairman who, in consultation with the managers responsible for the existing DOE Nuclear Data Program, identified seven major user communities and selected a representative from each to serve on the Subcommittee. In addition, a representative was chosen to address the international factors and implications, especially for multinational collaboration in data measurement and evaluations. Finally, the Chairman was asked to represent the community that addresses the standards issues related to accurate data measurements.

The DOE managers advised the Subcommittee that funding for these programs would be limited , i.e. that funding in excess of current levels was unlikely. The DOE also counseled the Subcommittee that a simple compilation of data needs would be of limited value.

The representatives of each user community were charged with the responsibility for making contacts with a broad range of experts in their community. The purpose was to seek indications of the needs for data and related activities, such as evaluations and dissemination. The representatives were asked to elicit additional information that indicated the rationale or justification behind specific needs. Some representatives organized workshops or informal seminars. Others used phone calls, letters, questionnaires, electronic mail, notices in technical society newsletters, and personal contacts at meetings. In addition, the Subcommittee invited a few experts from the user areas to make formal presentations to it. The Subcommittee also invited the manager of the National Nuclear Data Center and the Chair of the National Research Council's Panel on Basic Nuclear Data Compilations to present descriptions of their organizations and their activities. Finally, the current DOE manager of the Nuclear Data Program was asked to provide an historic perspective of the existing program. A list of presenters is given in Appendix D.

A preliminary analysis of the collected information was presented orally to the Subcommittee by each member. Subsequent deliberations of the Subcommittee were directed towards the development of a consensus formulation of several general conclusions and a number of specific recommendations.

The findings of the Subcommittee are presented in the form of General Conclusions, Specific Recommendations, and Summaries of Data Needs by User Areas. Needs summaries are included for each of the user areas represented on the Subcommittee membership and for the Space Exploration Initiative. A summary is also provided for the nuclear data standards area.

Appended to the main report are more extensive discussions of the specific examples and justifications for nuclear data needs for most of the user areas (Appendix A). Since those needs are generated by dynamic national efforts, they should be updated routinely throughout the 1990's if they are to remain current.

The last section of the main report is an analysis of nuclear data issues that has been organized as responses to a set of questions that were suggested by the nature of the charge to NSAC by DOE and NSF.

Major Conclusions

The U.S. is now entering an era of intense intenational competition in science, technology, and business. If our country is to maintain a first class economy in this complex age it must be very competitive in international markets. In today's markets quality is the key to survival. Accurate technical data constitute the keystone to quality design and reliability. Those companies or institutions that can assure quality and reduce the cycle time for innovations and quality improvements in their products and services have a distinct advantage in world markets. Thus, rapid access to accurate data is essential to profitability and competitiveness in these fast moving times.

The U.S. Nuclear Data Program has been very successful in providing users in the private and government sectors with data that were critical to the developments in nuclear technology over the past several decades. In the coming decade, a strong, viable Nuclear Data Program can have a critical impact on industrial competitiveness, national security, health and safety, and fundamental science.

The lack of accurate data for technical design and development can lead to inefficiencies, lack of reliability, and safety problems, all of which can be very costly. The applications of nuclear data have become so broad and important that the Nuclear Data Program can continue to provide accurate data to the R&D communities for priority applications in power production, nuclear medicine and health, nuclear waste management, national security space applications, fusion energy, advanced reactor design, and fundamental science. Considering the economic size of these sectors and the impact that accurate, reliable data have, the Nuclear Data Program is an overwhelmingly cost-effective national investment.

The Nuclear Data Program supplies major benefits to the nation in at least four ways. It provides data users with critical reference data and data standards that are essential for assuring quality of products and services. It provides a readily accessible source of data that are thoroughly evaluated, and are nationally accepted. The Program provides essential assistance in international exchanges and intercomparisons that are necessary for consistency and acceptability at this level. The fact that these data are validated and recognized internationally is of growing importance in ensuring the acceptance of U.S. products in foreign markets. Requirements set forth in the ISO 9000 series being adopted by EC-92 is an example. The program, by supplying carefully evaluated data, reduces the need for wasteful duplication of data measurements by different users.

An evolving U.S. Nuclear Data Program is required for the foreseeable future. Current and projected activities in the private and government sectors, which address issues of high priority to the nation, will require the availability of carefully evaluated nuclear data over a much broader range of technical parameters and range of users than in the past. Important nuclear data needed by the major user communities do not exist in many regions of interest or have not been generated with sufficient detail to support an accurate evaluation.

To be viable, the Nuclear Data Program must possess a critical mass of staff and facilities that can support an integrated core of program elements that are strongly coupled to the needs and priorities of the major communities of data users. It must have a national mission and scope. That is, it must make its services available nationally and provide national leadership in planning and developing consensus-based priorities that will promote cooperation and eliminate unnecessary duplication of efforts. Finally, to be viable, the program must offer a confident future based upon stable, long-term support at least at the current level.

The Nuclear Data Program requires three core elements. The first must furnish the competence and support facilities needed for data compilation, evaluation, processing, and dissemination. The program also requires an element capable of producing key (priority) nuclear measurements and standards that are essential tie points for calculations and modeling, for those measurements that demand higher accuracy than available from calculations/modeling, and those critical data that serve as benchmarks or standards for normalizing and ensuring accuracy of large classes of important measurements made by users. The third core element must provide a capability for calculations, modeling, and supporting theory to address the priority needs of the user community that cannot be met due to a lack of adequate measurement facilities or because calculations can provide certain important data in a more cost effective way. Modeling calculations, however, must be referenced to critical measurements to provide a basis for confidence and limits on accuracy. Thus, tightly coupled, calculations and measurements can reinforce each other and have a productivity far beyond that available from either separately.

The availability of facilities to provide critically needed nuclear data in the future is a serious concern. Funding does not appear to be available to support single-purpose data measurement projects. Therefore, future data-measurement efforts will have to utilize available U.S. and international facilities whose main programs might be directed to other purposes. In planning future facilities, DOE should consider design requirements that add the needed capabilities to address projected nuclear data needs.

A long-term commitment from the DOE and NSF is necessary to assure continuity and the needed technical capabilities that are necessary for a viable U.S. Nuclear Data Program. Manpower planning is of critical importance to address the transition that will occur in the 1990's from the current group of well-experienced personnel in the nuclear data field to a new generation of specialists.

Over the years the Nuclear Data Program has broadened its user base from an initial focus on nuclear power and national security to include nuclear medicine and industrial applications. In the future, nuclear waste, space applications, and fusion energy present both challenges and opportunities. To keep pace with the accelerating growth and technological changes in all fields, the needs and capabilities of the nuclear data customers must be integrated even more closely into the planning, execution, and support of the program. Anticipated funding constraints enhance the importance of priority setting and strongly suggest that increased participation of the user community in the Nuclear Data Program is vital to its success. Program priorities should reflect the willingness of the various users to participate in and support many phases of the program, especially the testing of the evaluated data. Feedback from the comparison of evaluated calculations with measurements over parameters of primary interest to the user community is important in directing further work.

Finally, the Subcommittee concludes that a permanent mechanism is needed to provide advice to DOE/NSF regarding the U.S. Nuclear Data Program. A formal Advisory Panel, composed mainly of user representatives, could ensure the development of a consensus of the user community needs and priorities for nuclear data. It also should include representation from the community of data generators and evaluators as well as an at-large representative of the fundamental science community. The panel should monitor relevant developments in the U.S. and international nuclear science and data programs and facility development projects to advise DOE/NSF regarding opportunities for collaboration and resource sharing.

Specific Recommendations

DOE, in association with the NSF, should maintain sufficient support for a core Nuclear Data Program, including facilities and training of experts, to provide long-term stability and continuity if the United States is to respond to critical needs and remain competitive in nuclear applications and technology. Therefore, DOE should fund on a continuing basis a national Nuclear Data Program throughout the 1990's at a level at least comparable with 1991-92 funding.

A basic set of manpower and facilities must be maintained to support the core elements. A less than critical mass in any one of the three core elements would give rise to serious difficulty in the Program's ability to provide the effective data services to the national nuclear data users, to continue to attract and hold new scientists to this important field, and to provide a U.S. base for collaboration and sharing of resources with other industrialized nations in a cost-saving way.

A basic level of compilation, evaluation, processing, and dissemination of data must be maintained. Selected data measurements, including standards, should represent the next highest priority. These measurements should be performed in close collaboration (sharing) with users whenever possible. Data modeling and relevant theory are important components of the nuclear data effort and should be undertaken in close harmony with, and complementary to, measurements. Support for the training of nuclear measurement specialists and theorists/modelers with interests in nuclear data is critical to long-term success of the Nuclear Data Program and should be provided.

A formal, permanent Advisory Panel, chaired by a representative from the user community, should be established by the DOE. The composition should include user community representatives from each of the major data application areas (6 or 7), Data Program technical representatives (2 or 3), Data Program administrators as ex-officio members (1 or 2), and at-large representatives (1 or 2). Among other activities, the Advisory Panel should:

- Develop recommendations regarding priorities and criteria for operating the program and recommending steps to improve its operation. The Advisory Panel should maintain close liaison with the National Research Council's Panel on Basic Nuclear Data Compilations and other relevant advisory committees.

- Explore ways in which nuclear data files can be made more accessible and user-friendly. This activity should be undertaken in cooperation with the technical group that produces the nuclear data files.

- Promote the development of proposals from the research community for viable mechanisms for effecting interactions between theorists and modelers to enhance data prediction capabilities.

DOE and NSF should encourage the formation of an active "User Association" in each of the major data application areas. The purpose of each Association would be to:

- Develop a proactive mechanism for surveying the interests and needs of the users of nuclear data in its area.
- Provide a recognized forum for the discussion of specific nuclear data needs and priorities in its area.
- Develop a proposed plan of action for meeting the highest priority needs for the coming year; this plan would include actions that would be carried out and supported by the users.
- Identify likely resources within the user community for helping to carry out the program activities of mutual interest.

The chief officer from each of the user Associations should be given membership on the Nuclear Data Advisory Panel. Their role on the Advisory Panel would be to work with other members of the Panel to:

- Harmonize the input from the several Associations and to develop a recommended set of national priorities for the Nuclear Data Program.
- Develop recommendations for a consensus-based plan of action for the Nuclear Data Program that would include the high priority actions to be carried out and supported by the users.

The DOE Nuclear Data Program should continue its policy of cost-sharing in its support of academic research and research in other major DOE program areas to gain leverage of its limited funds. Users in the private sector and other government agencies should be encouraged to propose similar cost sharing efforts where mutual benefits can be gained.

To minimize the fiscal burden on the Program, a multiple-use policy in funding new nuclear facilities should be adopted. The need for essential nuclear data measurement capabilities should be considered in the design and construction of such facilities by all nuclear programs in DOE and NSF. The Advisory Panel should seek out multiple-use opportunities and bring these to the attention of the Nuclear Data Program managers.

International collaboration has consistently proven to be beneficial in nuclear data. International involvement provides not only a quantitative multiplier effort, but a peer review process which is the essence of quality assurance for basic science. The existing arrangements have been carefully crafted and effectively managed to address the competing criteria of openness and of provincial self interest. Appropriate policy involvement is needed to assure a reasonable quid-pro-quo, and a very strong technical involvement is also required to assure effective information flow. International collaborations should be emphasized as a means of sharing program costs, especially those of large expensive facilities. A stable U.S. program is essential to a strong negotiating position in such discussions with other nations. More detailed suggestions are listed in Appendix A, Section IX.

Summary of Data Needs by User Area

Nuclear Data Needs for Power Production

Nuclear reactors currently generate 20% of the electricity utilized in the United States. In order to support this important contribution to our current electricity supply and help make it a more important contributor in the future, additional and more precise nuclear data are needed. Nuclear data are utilized by the fuel and reactor vendors in the design of reactors and fuel reloads, utility engineers in managing the operation of reactors, and other organizations that are pursuing new design concepts.

The safe, economical, and reliable operation of nuclear reactors depends upon the use of nuclear data to predict several important characteristics of plant operation. These characteristics include the desired energy production from a reactor core from the time it starts operation to the time it is ready to be refueled, the rate at which heat is being generated in each of the fuel pins, the rate at which neutron bombardment of the pressure vessel leads to embrittlement, the shutdown of the reactor, the effect of shielding to reduce the exposure of equipment and personnel to radiation, and requirements for fuel storage.

The neutron and gamma cross sections that are needed to perform the desired analyses are required for a wide range of materials. The fuel nuclides include, of course, uranium, plutonium, and many of the products of neutron capture leading to higher mass actinides. Structural and coolant materials like zirconium, iron, hydrogen, and oxygen need to be known in considerable detail. Neutron absorbers introduced to control the core, either for shutdown or to gain a longer energy cycle, include materials like hafnium, boron, gadolinium, erbium, silver, and indium.

In the past, deficiencies in detailed nuclear data could be overcome through normalizing calculations to existing reactor measurements or other experiments performed for that purpose. The desire to utilize higher energy fuel, operate existing reactors more economically, and pursue new designs without performing extensive reactor experiments dictates using nuclear data that will support calculations that give dependable results without normalization.

One cross section of concern to the reactor community today is the resonance absorption of ^{238}U. Integral testing suggests that the ^{238}U resonance absorption cross section is still over-predicted by 2-3%. This cross section is central to predicting power coefficients for the reactors. Since the ^{238}U resonances are highly self shielded in fuel rods, the details of how this mismatch of capture cross section occurs can have a much larger effect on the power coefficient than the 2-3% mismatch in the resonance integral. Current literature indicates that the values that are recorded in ENDF/B-V data set yield a ^{238}U delayed neutron fraction that is too low. Experts in the field believe that the uncertainties in this parameter are plus or minus 10%. The knowledge of this important parameter needs to be refined. The cross section data required by the reactor engineer includes neutron cross sections in the range of 0-10 MeV, the energy distribution and magnitude of the fission neutrons, and the production rate, neutron cross sections, and radioactive decay characteristics of the fission products. The production of the gamma rays from the fission process contributes 7% of the total heat generation rate. To determine where that heat deposition occurs, cross sections for these gamma rays up to several MeV are required. The nuclear data developed in the past has supported the development of nuclear power as a vital addition to our energy base. The refinement of these nuclear data and use of new materials will support the introduction of new fuel design that will improve the economics of nuclear reactor operation.

Nuclear Data Needs for Reactor Design

A priority objective for the United States, indeed for the entire industrialized world, is to find efficient and effective means of providing energy to support a decent standard of living for all people, while assuring a safe and healthy environment. This will not be possible without a major contribution from nuclear energy, including the deployment of highly efficient nuclear plants and a responsible closing of the nuclear fuel cycle. Nuclear energy reached a significant plateau in the 1970's with some 20 percent of the U.S. electricity (and also about 20 percent of the world's electricity) being supplied by nuclear power. With reduced pressures for nuclear weapons development, it can be expected that the 1990's will be characterized by increased availability of nuclear resources, facilities, and expertise to advance civilian nuclear power and in closing the back end of the fuel cycle.

Fuel supplied for today's commercial plants must make allowance of about 5% in the expected endurance of the fuel, based on uncertainties in nuclear data for fission products. Advanced designs, with extended burnup, must allow even greater margins.

Modern nuclear designs are utilizing the inherent nuclear and physical properties of reactor materials, rather than engineered systems; fuel element lifetimes are being extended. While modest extrapolations can be competently handled by empirical adjustments to the existing (dramatically successful) nuclear data files, the confidence required to assure safety and efficiency will be maintained only if the data base keeps pace with design evolutions. Allowances for margins in endurance, safety, and performance can easily add a few mils per kilowatt hour of electricity generated; with today's U.S. nuclear power industry, that is many hundreds of millions of dollars per year.

Advanced concepts rely on physical phenomena (thermal and nuclear effects) to assure safety, in place of many of the complex engineered systems in today's plants. Uncertainties in nuclear data can lengthen the time required to bring such systems to economic competitiveness, with the associated restrictions in energy growth and increased pressures on resources and the environment. Key data requirements are decay heat (safety impact) and minor actinide cross sections.

Closing the nuclear fuel cycle will include geologic disposal of scrap and waste and potentially large quantities of spent nuclear fuel. Other strategies involve recycling of residual fuel and potential recovery and reuse of usable fuel from nuclear scrap and wastes. Use of recycled fuel places new demands on nuclear data because of heavier isotopes and extended nuclear interaction chains. Materials declared excess from weapons programs could be deployed as a supplementary resource for fueling power reactors or used in this fashion as a means of denaturing the material. In either instance, improved data will be needed for performance prediction or for confirmation of denaturing. Since these processes are not relevant for present reactors, they have not been carefully studied; in fact any recycle process will have particular and demanding nuclear data requirements (e.g., for criticality and environmental protection assurance). Accurate data are not available to support transmutation programs.

To date, basic neutron data are sufficient over the relevant energy range (0 to 10 MeV) to support reactor design applications. While present data files are sufficient to support responsible technology development programs, efficient deployment will require extensive nuclear data expansions beyond those currently available. The major shortfalls today are in decay data and decay schemes both for extended decay heating and for assay.

A modest continuation of the established program of measurement, evaluation, and compilation should supply the needed data. Accelerators for resonance energies and for fission energies are needed, but existing facilities should be adequate if supported or if equivalent capabilities are made available through sharing of facilities built for other purposes. Benchmark data for reactors are considered generally adequate; confirmatory experiments are likely to be required for reactor concepts which differ substantially from established types. Evaluations based on empirical data fits have achieved a substantial maturity; further work in this area should be coupled to basic nuclear science programs. Basic nuclear science programs should, in turn, be supported to address improving fundamental understandings of the fission and resonance capture processes.

Nuclear Data Needs for Nuclear Medicine and Health

The application of nuclear techniques to medicine represents a major component of the nation's diagnostic and therapeutic armamentarium. Such techniques have had an important impact, for example, on the diagnosis and treatment of cancer, a disease which will afflict thirty percent of Americans in their lifetimes. Also, nuclear diagnostic techniques are routinely applied to diseases of the heart, brain, and other organs as well to cancer. There are currently over 100 million such studies carried out in the United States each year. New diagnostic and therapeutic methods, which are now in the research stages, may potentially result in major improvements in the diagnosis and treatment of disease, but their evaluation and eventual application depends in many instances on nuclear data which is not available today. Thus the Nuclear Data Program is critically important to the advancement of these fields.

Some specific areas in which nuclear data are needed include directed tumor treatment using high-energy beams of neutrons or charged particles, treatment of malignancies using tumor-specific antibodies tagged with radionuclides, and refinements in diagnostic isotope production methods to minimize patient dose. The goal of the therapeutic approaches with either particle beams of tumor specific antibodies is to deliver a maximal radiation dose to tumor tissue while minimizing effects on surrounding tissue. The ability to do this depends directly on knowing particle-interaction cross sections and nuclear-decay schemes, thus nuclear data are central to the development and application of these methods.

Data required during the next decade include neutron interaction cross sections for tissue and related materials in the energy range 20-70 MeV, cross sections for epithermal neutron interactions for tissue and materials used for neutron-capture therapy and isotope production, charged-particle interaction cross sections for high-energy spallation reactions in the range of 100 MeV, as well as reaction cross sections of low abundance isotopes up to 30 MeV, and improved level-scheme data for many radionuclides proposed for use in diagnosis and targeted radiotherapy.

Nuclear data are needed to continue the development of a number of promising diagnostic and therapeutic techniques as exemplified by those discussed above. The emergence of these techniques into clinical use would in all likelihood have a major impact on the detection, management, and treatment of many important health problems facing the United States today.

Nuclear Data Needs for National Security Programs

World events in the past several years have dramatically changed the picture regarding nuclear programs in support of national security objectives. The recent announcements by the United States and the Commonwealth of Independent States (formerly the USSR) are likely to result in major reductions in nuclear weapon stockpiles, in reduced nuclear testing, and revisions in programs for development of new weapons. These developments, coupled with rising environmental concerns, are shifting the emphasis in nuclear weapons towards issues of intrinsic nuclear safety of weapons systems, reduced requirements for special nuclear materials, and more environmentally acceptable weapon materials and manufacturing processes. At the same time, developments in Iraq, North Korea, and elsewhere have heightened sensitivities to the proliferation of nuclear weapon capabilities, including production and diversion of special nuclear materials.

The maturity of U.S. nuclear weapons design resulted in reduced requirements for nuclear data in the past decade, although very specific detailed reaction data remain a shortcoming, particularly for neutron energies from 10 to 30 MeV. The anticipated changes in the nuclear-weapons-related programs will be reflected in the 1990's through continued needs in this energy range with some new requirements for data on materials not utilized before. For example, some traditional materials used in weapons to increase performance can possibly be replaced with different materials that result in more environmentally-benign manufacturing waste. For this to be successful, nuclear data on these new material components will have to be available in sufficient detail to evaluate weapon performance without extensive nuclear testing. Although anticipated nuclear data needs cover a wide range of materials across the periodic table, the trend in requirements for the nuclear weapons program is toward more detailed reaction data in the 10-30 MeV range. Many nuclear data needs for nuclear weapons are similar to nuclear astrophysics needs because they involve reactions on unstable nuclei. In these cases, nuclear modeling, supported by key experimental data, is of great importance in obtaining these data. For example, ^{88}Y is a key nuclide for determining the performance of particualr nuclear designs. Its half-life is short (106 days) thus making direct measurements very difficult. Modeling of key reactions for ^{88}Y coupled with complementary data on nuclei in the same mass region allows one to calculate the required information with increasing confidence as the agreement between measured data and the model improve. There have been recent examples where modeling has lead the way for defining where data needed improvement. For example, reactions on ^{14}N are critical to understand the effects from the Hiroshima explosion. The total cross section for neutrons on ^{14}N in the 100 eV to 100 keV found in the ENDF/B-V evaluation is based on 30-year old measurements. Recent calculations by Hale and Young indicated that the cross section was higher by 10-15% in this region than the ENDF/B-V data. Harvey et al. at ORELA then remeasured this cross section and found agreement with the calculation to 1-2%. The calculations were funded by the Defense Nuclear Agency as part of their rexamination of the Horoshima data. This is an excellent example of how interagency cooperation can provide leverage to the DOE National Nuclear Data Program. It also shows that modern theory and modeling can provide an important stimulus to guide selected measurements.

The nuclear safeguards program is responsible for the monitoring of nuclear materials in countries that have signed the Non-Proliferation Treaty to prevent diversion of such material to nuclear weapons development. The nuclear safeguards program requires nuclear data for developing measurement and assay techniques and standards. Their greatest need exists in the area of neutron emission spectra for both spontaneous and neutron-induced fission in the incident neutron energy range of 0-20 MeV. Specifically, it is important to provide accurate (5%) fission neutron spectra for the uranium and plutonium isotopes if the safeguards program is to develop adequate technology to address the growing proliferation problem. The accuracy requirement is driven by the need to unfold the assay measurements using fission neutron emission spectra with the detector response function to determine amounts of nuclear material with sufficient precision to understand safeguard issues.

Both these communities benefit tremendously from participation in the U.S. National Nuclear Data Program because they are able to obtain much better understanding of their applications with the use of a large set of experimental and/or calculated data that have been carefully evaluated by a broad range of experts. For example, the use of the "best" nuclear data set allows the nuclear weapons designer to investigate physical processes other than nuclear (e.g., atomic processes) that occur in an explosion to study their impact on the design with more confidence than if the nuclear data had great uncertainty. If a National Nuclear Data program did not exist, these communities would be forced to establish their own nuclear data programs to satisfy their needs. Such programs would not benefit as easily from measurements made to support other application areas worldwide, might be subject to classification restrictions, and could have the additional problem of potential biases built into the data to "explain" unknown physical processes.

In summary, although the national security environment is changing rapidly, the need for improved nuclear data to deal with these changes either in weapons design or non-proliferation activities is likely to remain high.

Nuclear Data Needs for Fusion Energy

Demonstrating the potential of fusion as a renewable energy source with attractive safety and environmental features is part of the present National Energy Strategy. A presidential initiative has resulted in an agreement among the USA, USSR, the European Economic Community, and Japan to jointly design the International Thermonuclear Experimental Reactor (ITER) with a decision to construct in 1996. Design of fusion devices such as ITER requires an extensive base of nuclear data for the calculation of the fusion reaction rate in the plasma, prediction of neutron and photon transport in the primary energy conversion system (blanket), calculation of the tritium production rate in the blanket, calculation of nuclear heating, calculation of radioactivity and decay heat, and prediction of gas production rates and atomic displacements as indicators of radiation damage in materials.

Fusion reaction rate calculations require accurate knowledge of fusion reaction cross sections for the D-T, D-D, and D-^{3}He reactions. The data required for predicting nuclear responses includes all neutron-induced reaction cross sections for neutron energy up to 20-MeV, energy and angular distributions of secondary neutrons, gamma-ray production cross sections, energy distributions of emitted charged particles, and decay data for radioactive isotopes.

Priority lists of materials, specific nuclear data needs, and accuracy goals have been generated and refined by the fusion community over the past 20 years. Some of these needs have been met but serious gaps in nuclear data exist.

Fusion research and development crucially depends on having ready access to computerized data files, such as those compiled in the U.S. and also in Japan, Europe, and USSR, as well as a variety of processing codes. Without such a database, it is inconceivable that fusion energy research will continue to progress. Future success in fusion research and development requires maintaining and improving existing data as well as measurements and evaluation of new data. The safety margin in the design can become too large to make fusion devices such as ITER affordable if new data are not available. Quantities such as radioactivity and decay heat, for which the present database is known to be unreliable, must be calculated to new levels of accuracy for approval of construction under current regulations.

Nuclear Data Needs for Waste Management

The waste management area is inclusive of all activities relating to decontamination and decommissioning of facilities as well as the handling, storage, and disposition of radioactive material. Both high-level and low-level radioactive waste forms are included. Consequently, several major national programs are immediately impacted by the quality of nuclear data. These include the High Level Waste Repository, the State Low Level Radioactive Waste Compacts, the Department of Energy Five Year Plan for Environmental Restoration and Waste Management, and the Thirty Year Cleanup commitment of all Federal facilities.

Users of nuclear data in the waste management area include a significant number of federal laboratories and facilities, the State Low-Level Waste repository programs, contractors involved in decontamination and decommissioning activities, plus numerous designers, analysts, and scientists in waste management. Nuclear data quality directly affects calculations relating to evaluations of source terms, of shielding and transportation requirements, and of longevity of different waste forms. Also affected are calculations related to potential designs for the transmutation of nuclear waste to less hazardous forms. These designs include accelerator driven concepts as well as the reactor schemes. Policy makers (and the public) are, in turn, compelled to rely upon these calculations, projections, and technical conclusions as related to decisions concerning radioactive waste management.

The major benefit of accurate nuclear data specifically relates to avoiding unnecessary conservatism in designs related to important issues such as radioactive waste repositories, high-level waste forms, shielding, etc. Equally important is not being conservative enough which may lead to unprecedented environmental problems. In the face of such uncertainty, the only option is to utilize excessive conservatism. This conservatism ultimately translates into additional program costs that may be in the multi-billion dollar range.

The bulk of nuclear data has been generated in response to nuclear reactor design concerns. Emphasis in the past was oriented toward supporting the design and operation of fission reactor design concepts which led to the ENDF/B-VI nuclear data files. Data relating to radioactive waste management issues such as transmutation, actinide burnup, and long-lived fission products have typically been of secondary importance and receive little attention.

In the case of radionuclides important to radioactive waste, such as those identified in Appendix A, Section 6, errors in excess of a factor of ten have been identified which could potentially affect the outcome of both design and policy decisions. The limited examples (see Appendix A, Section 6) are intended to demonstrate those instances where the accuracies of nuclear data are not commensurate with the related uncertainty impacts. Relatively large uncertainties exist relating to some data, some of which have only been estimated. In any event, errors of only 20 percent may represent significant long-term fiscal and/or safety consequences.

New data will also be required in the future in non-traditional neutronic areas such as proton interaction cross-sections in order to support the previously mentioned transmutation concepts for waste management that are being pursued at several of the DOE laboratories. Additionally, the energy ranges of interest for the newer concepts must be extended to the greater than 20 MeV range.

An active nuclear data program will support the current low-level and high-level radioactive waste programs through improved source term predictions, waste form design, and safety. An active program also will directly support potential transmutation programs.

Nuclear Data Needs for Fundamental Science

Studies of basic nuclear processes provide the underpinnings for many applications, and advances in fundamental knowledge frequently extend to related areas. Special needs exist for readily accessible, well-maintained data in the frontier areas of fundamental nuclear science, and access to the most current nuclear data by electronic means is crucial.

Several major experimental projects that will utilize the latest advances in technology for obtaining information about nuclei at high angular momentum will soon be completed. It is important that appropriate technology be utilized to compile, evaluate, and disseminate this large body of nuclear data in a timely and efficient manner. Similarly, effort should be dedicated to providing a nuclear database for intermediate energy nuclear reactions. The establishment of a data file for elastic and inelastic nucleon-nucleus, pion-nucleus, kaon-nucleus, and electron-nucleus data across a broad energy range, up to several GeV, would be desirable.

The data needs of the nuclear astrophysics community are great, and additional demands can be expected to emerge as the decade of gamma-ray observations in space unfolds. Other needs range from neutron emission cross sections for nucleosynthesis to gamma-ray production cross sections for selected elements. Data from nuclei off the valley of stability certainly will be especially important in attempts to understand violent astrophysical events, and radioactive-beam methods will be the only effective way to deal with many of these problems.

Clearly, the testing of nuclear theories relies on the existence and availability of appropriate nuclear data, and exciting new theoretical results have often provided the impetus for experimental investigations. However, it is appropriate to consider how the experimental nuclear database can, in the future, be incorporated into a broader, computer-based nuclear science information system which includes theoretical calculations and computer program libraries.

Many areas of nuclear research which were at the forefront in previous decades and served also as a source of data for various applications are at diminished activity. Basic nuclear science is moving increasingly in the direction of studies with intermediate energy probes and heavy ions, and it seems unlikely that the many applied needs will be met as a by-product of basic scientific investigations (as has occurred frequently in previous generations). Some provision should be made for providing a program of basic measurements, including nuclear decay data, supporting applied research. It should also be noted that, while the databases used by the basic research community have some unique features, they should not be considered as separate entities from other nuclear databases. Indeed, basic nuclear data--e.g., level schemes, level densities, decay properties--are frequently required in many applications to understand fully the implications of measured reaction cross sections.

Nuclear Data Needs for the Space Exploration Initiative

One of the more important considerations of manned spaceflight, outside the Earth's magnetosphere with exploration and habitation of the lunar and Martian surfaces, is the radiation hazard. Specifically, the risk of high levels of radiation due to Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE) during long-duration manned missions of 2-3 years must be quantitatively assessed. Large uncertainties exist in three different scientific areas: (1) the <u>environmental source terms</u>, the GCR and SPE energy, intensity, particle type, and solar cycle modulation must be developed into a predictive solar modulated model, (2) the physics database, transport, and modeling of the radiation field interactions requires a ground-based accelerator program aimed at simulating GCR and SPE interactions with shielding and biological materials, and (3) the radiobiological response of simulated GCR and SPE in ground-based studies of the radiation effects on cells, tissue, and animals or organisms must be developed into an integrated biological model for use in space radiation risk assessment.

The worst case assumptions that incorporate present uncertainties as limits in a calculation, grossly overestimate the shielding requirements by factors of two or more and lead to unacceptable shielding mass requirements for the Space Exploration Initiative. The aim of a comprehensive National Interagency Space Radiation Effects program would be to reduce the uncertainties of all three areas to an overall combined uncertainty of about 15-25%. The Mars mission costs for shielding is about $1B per 10 ton. It is therefore necessary and prudent to define the passive shielding requirements quantitatively with minimum uncertainties in order to reduce the overall vehicle mass. Additionally, the engineering design that utilizes materials, fuels, and cargo for supplemental shielding to a solar storm shelter for solar flares (SPE) will further reduce the vehicle mass and radiation risk.

This National Program goal is an enormous challenge to the technical and scientific community, but is a programmatic one that can be reached with a well-correlated ground- and space-based interdisciplinary research program in the three fields of solar physics, nuclear physics, and radiobiology. At present, only about ten percent of the data base in the nuclear and radiobiological areas have been developed. In addition, the ground-based data must be well correlated and standardized to a high precision in order to achieve the overall goal of a 15-25% total uncertainty and high confidence level. Both nuclear and radiobiological dosimeters and standards must be developed to this specific end. Ultimately, many agencies with their unique capabilities and facilities will be required for this 10-15 year multidisciplined program if the United States goes ahead with its plans to have a permanent base on the moon by 2003-2005 and a Mars base sometime in 2014-2018.

Needs for New Nuclear Data Standards

The user of nuclear cross-section data is generally not directly involved with the fundamental nuclear cross-section standards which form the foundation of the data system. This is because of the intermediate roles of the data evaluator, data measurer, and nuclear model developer. Measurement standards are required to determine incident particle fluence for charged particles, neutrons, and photons. Among numerous requirements, it is experimentally desirable to have a standard that produces the same outgoing particles as those from the reaction under study since this simplifies the measurement process. A number of standards are needed which cover overlapping incident particle energy regions. Improvements in a standard cause all cross sections measured relative to that standard to be improved.

Standard cross sections are sometimes not required for incident charged particles since there may be other means to measure fluence. However, a few charged-particle reference standards need to be established to provide a test for nuclear model and radiation transport codes for users in medical dosimetry, personnel protection, waste transmutation, and materials damage in space applications.

In the past most of the neutron cross-section work has been focused on the neutron energy region below 20 MeV due to applications in fission and fusion systems. There are still important problem areas which need to be addressed for neutron energies in this region. The uncertainties in these standards are estimated to be at the 2-3% level and the requests are for uncertainties of less than 1%. A high priority is the development of new standard cross sections for neutron energies above 20 MeV to support the needs for new applications. Most of the work at these higher energies will be the establishment of improved standards for the (n,p) cross-section for hydrogen and the (n,f) cross section for ^{235}U. Later in the decade, the priority could switch to the selection of new reaction mechanisms for this energy region.

The cross section for the photodisintegration of the deuteron is the main standard used for photonuclear reactions above the energy threshold at 2.2 MeV. The cross section is known to sufficient accuracy for energies below 100 MeV but requires additional effort at higher photon energies.

Only with reliable standards in the energy ranges and for the particles cited above, will it be possible to compare data measurements made in different laboratories, indeed in different countries, and to make reliable estimates of the uncertainties in these data.

Analysis of Issues

In the process of responding to its charter the Subcommittee on Nuclear Data Needs developed a set of questions that, if well answered, would provide the basis for its conclusions and recommendations. Key observations from the information supplied from the various user communities are given below along with the inferences arrived at by the Subcommittee.

Is a national Nuclear Data Program needed?

The consensus among the user communities polled was that a nuclear data program is definitely needed. It was felt that without such a program each user community would be required to establish its own databases, and that the benefits of interactions among user communities would be absent. Furthermore, the very important intercomparisons of measured and calculated results would be difficult if not impossible.

The nuclear data community is in need of national leadership, coordination, and networking in order to assure a sustained, coherent effort in data generation, standards development, evaluation, and dissemination.

The Nuclear Data Program represents an indispensable core resource which provides such leadership. The alternative, reliance on ad hoc efforts to fulfill the national need for nuclear data, would not be efficient, cost effective, or likely to produce data that would be widely accepted nationally or internationally.

There was a strong consensus among the user communities that nuclear data used in many critical areas must be subjected to rigorous quality control in order to meet regulatory standards and good safety practices. It was felt that a continuing, reliable source of evaluated data and standards, i.e. a stable core program, is critical here. The Nuclear Data Program is a logical mechanism for fulfilling this need.

Strong arguments were made by users that a national core program is necessary to stimulate and coordinate the development of new measurement methods, modeling techniques, and theory and to promote the transfer of this technology among user communities.

Users also indicated that without a national program, the U.S. participation in international intercomparisons of data would be difficult since the U.S. would be viewed as making no contribution to the process. Ongoing efforts to build international data libraries and databases are essential to international collaboration on high-cost R&D facilities, e.g., in fusion.

What capabilities should the Program support?

This question addresses several elements in the charge to the Subcommittee, i.e., to identify evolving user communities and their needs, to evaluate the relevance and completeness of the program, and to explore opportunities for the program to provide training and education.

The Subcommittee arrived at a strong consensus that the program should provide capabilities for the compilation and evaluation of data, the processing and dissemination of data, the measurement of priority data and standards, the development of modeling techniques plus calculational methods and supporting theory, and the integration of data with modeling.

A persistent concern among the user communities is the threatened loss of expertise throughout the field of nuclear data. This stems from the "graying" of the personnel originally attracted to the nuclear data program in the growth days of the nuclear field. It also reflects the loss of funds and professional opportunities in recent years. Without this expertise readily available, it will be very difficult to respond to new challenges, to develop and implement new technology in the areas of nuclear data application, and, hence, increasingly difficult to remain competitive as a nation in these application areas. Therefore, training and relevant research are activities that should be supported to attract and hold new staff in this area.

The capability of providing effective feedback from the user testing of data should be provided if the program is to be relevant and responsive to national priorities. A feedback mechanism based on user testing and application should be structured and operated to develop consensus statements by users of their needs and priorities.

A strong, coordinated effort is needed to enhance the national capability for calculating data that cannot be directly measured. Theory and measurement form the backbone of data generation. They build on each other, and progress in the Nuclear Data Program cannot be made unless both are active. Nuclear models form the glue between theory and measurement. More data are needed for unstable nuclei and for critical properties that are very difficult to measure or calculate from theory. Therefore, nuclear models are becoming increasingly important for interpolating and extrapolating. There has been, however, a slow drift of nuclear theorists away from nuclear modeling as the research emphasis has shifted from low-energy to higher-energy physics. There is a strong need to again pull these communities closer together. Caution needs to be exercised, however, so as not to use highly authoritative coordination techniques that might stifle creativity.

The existing centralized service for evaluation, compilation, and dissemination of data has produced the ENDF series of data files that have been highly successful for the design and analysis of light-water and liquid metal-cooled reactors. They have been invaluable for defense programs and have aided the fundamental sciences. They also have provided a useful (but incomplete) service to the fusion community and have been used for gas-cooled and heavy-water reactors. For other applications of special importance in the coming decade, such as the space initiative, safeguards and arms control, waste management technologies, analysis of irradiation effects on structural materials, medical applications, etc., the current files are of distinctly limited value. A broadening or supplementing of these data files would enhance their usefulness to these latter user communities that represent important national priorities.

Facilities, both old and new, may be needed to obtain critical data. A national effort is needed to coordinate the use of these facilities in an efficient and cost effective manner. As a minimum, such data will be required to normalize modeling predictions in order to provide a sound basis for program direction.

How could the program be shaped to better meet user needs?

Planning, collaboration, and implementing new technology are crucial to a successful project. Planning has become more and more informal over the years, despite the decrease in program funding. This trend must be reversed as more users require more types of nuclear data. Planning will also become more crucial as newer technology plays a more important role in the measurement, evaluation, and dissemination of nuclear data.

Given the severe constraints on resources, it is even more important that the program managers have ready access to priority recommendations that reflect the best possible consensus of the users.

The involvement and commitment of users should be maximized. This can be accomplished in part by organizing user groups in each major user community to define data needs and by organizing a permanent advisory body to the program. The users should represent a strong majority of this body. The users could be brought into the planning, design, and priority setting in the nuclear data evaluation, processing, and dissemination work of the program. This should help ensure that the most important data are worked upon and that the format and technology utilized in the dissemination would produce output that could be utilized in the most cost effective manner, i.e. maximize user benefit.

Since a successful Nuclear Data Program requires the strong participation of data users, the Subcommittee suggests that DOE and NSF encourage the development of user groups in each data application area. These user groups should be self-supporting, formal "Associations" that are recognized by the funding agencies as sources of input regarding data needs, priorities, and action plans. The basic strategy is that each Association would develop a consensus of its members regarding their highest priority needs and plans. The Associations would then work with the Nuclear Data Program Advisory Panel to develop recommendations for a combined set of national priorities and plans to fulfill the most urgent nuclear data needs. These interactions would best be served by appointing a representative of each Association to the Nuclear Data Advisory Panel. In addition to defining priority needs and action plans, the Associations should work to produce realistic estimates of the resources available to the Nuclear Data Program directly from the funding agencies. Through the Association/Advisory Panel mechanism, the users can provide valuable input to the managers of the Nuclear Data Program in the long-range planning as well as in the development of annual program plans and budget recommendations. Just as important, this mechanism can provide a forum for user input into defining the nature of the output of the Nuclear Data Program that will be most useful to the users. The lists of user community contacts listed in Appendix C would be an excellent place to start in organizing these "Associations."

To ensure the availability of expertise to measure, model, and evaluate nuclear data, the program should continue its leveraged investment in relevant academic research and partial support of measurement, modeling, and standards work being carried out by other programs at national laboratories. This not only enhances the impact of limited program funds, but also serves to provide a source of graduates with the needed expertise and help provide career opportunities for them after graduation. These efforts could be enhanced further through strong involvement of the user communities.

The critical measurements in the 1990's are expected to cover a much wider scope (in energy and particle type) than in the previous decades. With limited resources, the program must take a flexible approach to obtaining experimental data. This includes using existing facilities currently being used in the program, other facilities that could satisfy special data needs as a secondary mission, and international collaboration.

How should priorities be established; using what criteria?

The overall aim of the nuclear data program is the advancement of user objectives which reflect national priorities. Since the users are at the heart of this system, criteria for establishing priorities should be user-oriented. The following reflect this position.

The setting of priorities should be based on a consensus process implemented through an Advisory Panel made up of representatives from the user communities, Nuclear Data Program, technical staff and administrative representatives, as well as other members of the nuclear science community.

In addition to the Advisory Panel, a working group, that is made up of individuals involved in the day-to-day activities of the Nuclear Data Program, (such as the present CSEWG group) and representatives from the user community should be formed. The purpose of this group would be to address detailed issues related to program operations rather than the broader policy issues addressed by the Advisory Panel.

Priorities should be set through the consistent application of a set of consensus-based criteria. Such criteria should include the impact on user needs that reflect DOE and other national goals, long-term impact on U.S. science and technology, feasibility of completion on a reasonable time scale, and participation of user community and applicability of results to multiple user communities.

How can long-term planning be ensured: using what mechanism?

Long term planning is essential if the program is to be positioned to respond in a timely manner to new sophisticated requirements resulting from the nuclear applications cited in the section on Data Needs and Capabilities.

The Advisory Panel should have long range planning as a goal and should be used to help in long term planning in collaboration with Nuclear Data Program managers, other major DOE/NSF program managers, and leaders of the user communities.

The Advisory Panel should plan and conduct annual workshops at which suggestions for program improvement are solicited from interested and knowledgeable parties.

The Advisory Panel should be involved in annual program reviews and should report at least annually to the sponsoring agencies.

What is the proper funding basis for the National Nuclear Data Program ?

The core program, which includes compilation, evaluation, processing, dissemination, priority measurements, and standards, modeling and theory, should be supported as a DOE base program at a level no less than the current level.

Data validation and special data needs should be funded by the programs demanding these services.

Currently available facilities are adequate for many data needs: new special purpose facilities should be evaluated to see if it would be feasible to incorporate nuclear data measurement capabilities.

International collaborative efforts should be utilized whenever feasible to share program costs, especially those of expensive facilities.

The Advisory Group should supply DOE/NSF with recommendations and priorities as a basis for their budget planning.

Advisory Group recommendations should be used to encourage user involvement and sharing of funding at all levels in the program.

How can the Data Program benefit from international collaborations; what mechanism should be used?

International comparisons of data and standards are essential to competitiveness in the international markets.

A strong, stable U.S. program (with in-depth expertise, effective data processing centers, unique measurement facilities, and widely recognized standards) provides a strong and necessary bargaining position in negotiating international sharing of resources.

International conferences on data techniques, theory, modeling, measurement methods, and standards can greatly assist in ensuring awareness and promoting cooperative attitudes (joint efforts with IAEA, NEA, etc).

The sharing of facilities and program costs can open up broader opportunities in areas with high costs. International planning workshops should be established to explore and define opportunities for multinational collaborations on expensive facilities, measurements,etc.

A U.S. government official should be appointed to the International Nuclear Data Committee (INDC) to complement the technical representatives.

APPENDICES

A. DISCUSSION OF USER COMMUNITY DATA NEEDS AND JUSTIFICATIONS

B. LIST OF USER COMMUNITY CONTACTS

C. LIST OF PRESENTERS

D. DOE/NSF CHARGE TO NSAC

APPENDIX A

DISCUSSION OF USER COMMUNITY DATA NEEDS AND JUSTIFICATIONS

I. POWER PRODUCTION
II. REACTOR DESIGN
III. NUCLEAR MEDICINE AND HEALTH
IV. NATIONAL SECURITY PROGRAMS
V. FUSION ENERGY
VI. WASTE MANAGEMENT
VII. FUNDAMENTAL SCIENCE
VIII. NUCLEAR DATA STANDARDS
IX. INTERNATIONAL COLLABORATION

I. NUCLEAR DATA NEEDS FOR POWER PRODUCTION

Robert. J. Breen

INTRODUCTION

The safe, economical, and reliable operation of nuclear reactors depends on the use of nuclear data to predict several important characteristics of plant operation. A brief description of some of these characteristics follows.

Cycle Energy

The enrichment and burnable poison loadings of a nuclear reactor core are chosen to match a desired energy production from that core from the time it starts operation to the time that it is ready to be refueled. The target cycle energy is chosen to meet requirements of the utility grid. If the design core lasts a shorter time than is required, the utility may not have the power generation available that it desires and it will have to purchase electricity from outside. On the other hand, if the reactor is designed to have more fissionable material than is needed to attain the desired lifetime, undue expense is encountered.

Local Heat Generation Rates

The reactor engineer must be able to predict the rate at which heat is being generated locally, both from neutron fissioning and gamma ray deposition. Both neutron cross sections and gamma-ray cross sections are required for this evaluation. Safety considerations limit the peak heat generation rate that can be tolerated in a particular reactor design. Keeping the peak heat generation rates much lower than those that are allowed, though, will impact operating flexibility and economics.

Reactor Vessel Fluence

Pressurized water reactor vessels can suffer considerable embrittlement from neutron fluence on the vessel. Fairly detailed transport calculations are required to evaluate the amount of fluence that the vessel sees during many cycles of operation. Reactor core designs are modified considerably in some reactors in order to keep the amount of fluence down. Steps taken to do this impact the economies of the reload cycle and can impact strongly the local heat generation rates. Thus, an accurate assessment of pressure vessel fluence is important.

Reactor Shutdown

Analyses must conservatively demonstrate that a reactor can be shut down at any time during its lifetime. While early designs had the minimum shutdown capability at the beginning of a reload cycle, the introduction of burnable poisons has resulted in reactor shutdown having to be addressed very carefully at all points during the reload cycle. Designing the reactor to have overly conservative margins will impact the reactor lifetime, the local heat generation rates, and the total power capability of the reactor itself.

Kinetics Parameters

Many safety limits set for reactor operation are based upon transients that are expected during the lifetime of the reactor and on accidents that are not expected to occur but which, if they do, it must have minimal consequences to the public. The shield transients that are addressed include ones that are initiated by malfunctions of equipment in the plant and those that result from human error. Nuclear cross section data is utilized to compute the parameters that are required for these analyses, and they include the delayed neutron fraction, the temperature coefficient (change of reactivity with moderator temperature), power coefficient (change of reactivity with power level of the core), and neutron lifetime.

Shielding

The impact of power operation of a nuclear reactor, both on equipment in the plant and on personnel working in the plant, must be able to be evaluated. Neutron cross sections, gamma-ray cross sections, and the decay schemes of various nuclides are required for these evaluations.

Fuel Storage

The safe storage of spent fuel depends upon both the knowledge of heat being generated from fission product decay and the ability to assess the criticality of the spent fuel in unusual configurations.

CROSS SECTION DATA REQUIRED FOR USE BY THE REACTOR ENGINEER

In order to perform the analyses outlined in the introductory section, the reactor engineer requires the following cross section types or information.

Neutron Cross Sections

Neutron cross sections (absorption, fission, scattering) in the range 0 to 10 MeV are required for the analyses described above. The scattering cross section has an angular dependence in addition to its energy dependence.

Energy Distribution and Magnitude of the Fission Neutrons

The production of fission neutrons is dependent upon the energy of the neutron creating that fission. In addition, fission neutrons produced also have an energy distribution. Most of the fission neutrons are emitted immediately upon fission. A fraction of them, approximately 1%, result from the decay of the fission products that came from the fission process itself. Both the energy distribution of these delayed neutrons and the radioactive decay constants of the fission products producing them need to be known. The delayed portion of the fission neutron production plays a vital role in the kinetics of nuclear reactors.

Fission Products

The products of the fission process itself absorb neutrons and many of them are radioactive. In order to assess the absorption rate of the fission products, both their cross section and radioactive decay characteristics must be known.

Gamma Cross Sections

The production of the gamma rays from the fission process contributes several percent to the total heat generation rate that is involved. Transport of these gamma rays determines where the heat deposition occurs. Cross sections for these gamma rays up to several MeV is required for these analyses. Gamma-ray detectors are used to determine power levels and radiation levels in power plants. Relating detector response to actual power and radiation conditions requires complex analyses which use gamma-ray cross sections.

Spontaneous Fission

Spontaneous fission rates contribute to the natural neutron source in a reactor. That source combined with the fissions that are induced by alpha particles on low mass nuclides and from gamma-n production leading to neutron-induced fission are important in supplying background fission neutrons.

The neutron and gamma cross sections that are required to perform the analyses outlined in the introduction include a wide range of materials. The fuel nuclides, of course, include uranium, plutonium, and many of the products of neutron capture leading to higher mass actinides. Structural and coolant materials like zirconium, iron, hydrogen, and oxygen need to be known in considerable detail. Neutron absorbers introduced to control the core, either for shutdown or to gain a longer life cycle, include materials like hafnium, boron, gadolinium, erbium, silver, and indium. Also, as mentioned before, the fission products themselves are produced in the core through the fission process. There are several other materials that are present at a lower level which, by themselves, do not have a great deal of impact on the prediction of reactor behavior, but, combined together can be important.

THE APPLICATION OF BASIC DATA TO REACTOR APPLICATIONS

The process for compiling experimental and theoretical data and converting them into a form used by the reactor engineer is outlined in a standard developed by the American Nuclear Society, ANSI/ANS-19.1-1983, Nuclear Data Sets for Reactor Design Calculation. The basic data are generally available as a detailed function of energy. The reactor engineer will perform his calculations with a group structure of neutrons ranging anywhere from two groups up to 100 groups. The choice of group structure is usually a compromise between the energy detail desired and the cost of doing the computing. When the analyses are done in one or even two dimensions, a fairly large number of groups can be handled. When the spatial calculation needs to be done in three dimensions, then the two-group model is more customary. In order to develop these group cross sections, weighting techniques are utilized to convert the continuous data into a group form.

Historically, neither the basic nuclear data nor the approximations that have been introduced in order to keep the spatial calculation tractable have been able to support precise calculations of the parameters of interest. As a consequence, considerable benchmarking has been required of these calculational systems. The benchmarks have included more refined calculational methods, experiments that have been designed to emphasize one or more characteristics of the cross section data and methods that are being employed, and the reactors themselves.

Until a few years ago, it was pretty well taken for granted that the existing differential data would have to be tuned or adjusted to get the desired accuracy when applied to power reactors. It does appear now though, that the ENDF/B/V data set is sufficiently accurate that it can be depended upon for many nuclides without major adjustment or tuning. The reactor industry is beginning to look with more confidence on the use of this data for analyzing geometries and reactor loadings that are a bit beyond those for which we have experimental experience.

The ENDF/B-V data set is being used by some but not all of the reactor industry today. As long as there are approximations built into the methods that are required for describing large power reactors, careful comparison to experimental configurations and reactor operations is essential in validating these methods. Considerable effort has been expended by each utility with earlier cross section sets to find the adjustment needed to achieve the desired validation. Once that effort has been expended, there is a strong inclination to stay with the older set unless there is strong evidence that the older set will lead into difficulty.

In summary, the ENDF/B-V data set appears to be the first set that comes close to giving dependable differential cross section data that can be used directly for reactor analysis. It has been tested considerably and for the most part has responded well to these tests. It is the cross section set of choice when rigorous analytical techniques are being used, particularly for new design configurations. There are areas in this data set, though, that have been found to be lacking. Some of these gaps have been met in the current ENDF/B-VI data set, and others are still to be addressed. These will be described below.

CURRENT AND ANTICIPATED DATA NEEDS

The data needed for current reactor designs can be addressed in three categories:

1. There exist well identified needs for nuclear cross section data today to support current analyses and to resolve existing discrepancies alluded to above.

2. Current fuel designs are leading the industry into fuel enrichments, burnable poison loads, and geometries that are different from those with which we have experience. This puts us into the position of having to extrapolate our knowledge into new areas.

3. As circumstances change, new needs are identified from time to time.

I will describe each of these areas in more detail.

Currently Identified Needs

^{238}U delayed neutron fraction. Current literature indicates that the values that are recorded in ENDF/B-V data set yield a ^{238}U delayed neutron fraction that is too low. Experts in the field believe that the uncertainties in this parameter are plus or minus 10%. The knowledge of this important parameter needs to be refined.

Plutonium Cross Sections. Analysis of critical assemblies fueled by plutonium give overestimates of reactivity up to one percent. It appears that the plutonium cross sections are still sufficiently uncertain to give the desired results.

^{238}U Resonance Absorption. Integral testing suggests that the ^{238}U resonance absorption cross section is still overpredicted by two to three percent. This resonance cross section is central to predicting power coefficients for the reactors. Since the ^{238}U resonances are highly self shielded in fuel rods, the details of how this mismatch of capture cross section occurs can have a much larger effect on the power coefficient than the two to three percent mismatch in the resonance integral.

^{238}U Fission Cross Section. The ratio of ^{238}U fission to ^{235}U fissions continues to be over estimated. It is anticipated that the ^{238}U fission cross section may be too high.

^{235}U Capture-to-Fission Ratio. The ratio seems to be too low to give consistent results in data testing. The energy dependence impacts the moderator temperature coefficient. There seems to some uncertainty as to the shape of this ratio.

Extrapolation of Computing Methods to New Conditions

The reactor industry is designing fuel cycles that have a higher energy content than before. This will allow the industry to extend the time between reloading fuel assemblies into the reactor and, thus, keep the reactor on-line a longer period of time, leading to a decrease in the cost of the power being generated by the reactor.

In order to accomplish this, reload fuel designs are incorporating higher enrichments and higher burnable poison loadings than those with which we have had previous experience. These combinations are taking us out of the range for which the important benchmark activity (integral testing) has been performed in the past years. While additional integral experiments could be performed to test these new parameters, the added complexity of new geometrical arrangements of the fuel rods would make this process even more expensive than before.

An alternative to returning to an extensive experimental benchmarking activity draws on the ability of Monte Carlo simulations of the transport equation to duplicate quite precisely the behavior of neutrons in complicated geometries. It is believed that our ability to perform these analyses is as good as the differential cross section data itself. Thus, we have an opportunity to minimize the cost of integral experiments to validate the methodologies by using sophisticated analytical tools with very accurate cross sections.

Unforeseen Nuclear Data Needs

It can be assumed that, as we progress with current reactor designs and future power reactor designs, the use of new material and inconsistencies between analyses and predictions will demonstrate new needs for nuclear data measurement, evaluation, and refinement. In order to be responsive, it will be necessary that we retain a critical mass of engineers and scientists in the nuclear data field to be able to respond to these requirements. This in itself is an important challenge to the U.S. nuclear data community.

ADDITIONAL CONSIDERATIONS

Our ability to obtain the nuclear data needed to support our reactor power production activities, combined with the needs of other technologies, requires a critical mass of personnel skilled in a wide variety of nuclear data related fields. There are indications that over the last few years we have lost much of our expertise in the area of evaluation and data testing. There is also concern that what we have left will deteriorate rather rapidly. This deterioration will result from experienced people retiring and inadequate funding available to date to train people to take their place.

The power production industry is anticipating and planning for a resurgence of nuclear reactor orders towards the end of this decade. The ability of the United States to participate in that resurgence and have credibility both domestically and internationally is dependent upon our having a reasonably good technology base in place. These comments apply to our nuclear data activities as well as to the other segments of the industry.

I believe that the NSAC Subcommittee on nuclear data needs for the 1990s should address the importance of this strategic consideration and recommend steps to respond to it.

II. NUCLEAR DATA NEEDS FOR REACTOR DESIGN

William. H. Hannum

The current national nuclear data program is based on a program initiated as part of DOE's reactor development effort and is tied to established data compilation programs. The current program has produced a series of Evaluated Nuclear Data Files (ENDF/B) which have become the de facto world standard for design and analysis of current generation nuclear power plants. From its origin, the program has been well focused by its reactor development application. These data files have also been used with minor extensions for a very broad range of nuclear applications (e.g., food irradiation, dosimetry, safeguards, and forensic techniques). While the data files are not exhaustive in their coverage, they fulfill the essential mission for which the program was created. This mission, however, is no longer coincident with DOE's priorities. Therefore, the scope of the national nuclear data program should be broadened to correspond to the current and projected Department priorities.

A nuclear data program can be described in terms of three components:

1. Measurement. Experience has shown that both differential and integral measurements are required, in that they complement each other and thus give a measure of reliability not available from either separately. Differential measurements require a controlled and calibrated source of particles and targets (or for data such as decay schemes, of materials). Integral measurements require a simulation of intended configurations, where all significant interaction influences are reasonably represented. Integral measurement facilities tend to be highly applications dependent; differential data facilities are more adaptable, and are applications dependent only by way of their energy ranges and in terms of feasible targets.

Comment: Except for selected special measurements, the current inventory of differential measurement facilities are capable of addressing the nuclear data needs of all types of civilian fission power reactors. For water and sodium-cooled nuclear power reactor design support, a reasonable complement of integral data facilities is available. For gas-cooled reactor types and for other applications (e.g., space nuclear power), some extension of integral data capability would be highly desirable to reduce design uncertainties.

2. Evaluation/Compilation/Distribution. A centralized service for evaluation, compilation, and distribution is a requirement for applied nuclear data programs and is an essential aid to those for whom nuclear data is a fundamental science. The Evaluated Nuclear Data File (ENDF/B) program and the National Nuclear Data Center (NNDC) have been highly successful programs for nuclear data for

design and analysis of light-water and liquid-metal cooled reactors, have been invaluable for defense programs, and have aided the fundamental sciences programs. They have provided a useful, but incomplete, service to the fusion community, and have been used without validation for gas-cooled and heavy-water reactor designs. For other applications, such as space reactors, deep shielding, waste management technologies, analysis of irradiation effects on structural materials, medical applications, etc., the current files are of distinctly limited value.

Comment. When sponsored as part of the reactor development program, the mission and role were clearly and narrowly defined. In recent years, the role, mission, and clientele have been less clearly defined, resulting in decreased support and productivity.

3. Modeling/Theory. It is impractical and unnecessary to expect to have actual experimental data for all nuclear data. Nuclear systematics are common and useful. In the current ENDF/NNDC nuclear data program, this function has been subsumed within the evaluation effort; for some other programs, (e.g., weapons), it has been contained within the applications program. Coordination and standardization (peer review) are accomplished through normal academic and scientific channels.

Comment. Substantial progress has been made in recent years in extending nuclear systematics to cover many additional observables, but the link to fundamental models remains obscure. Thus, there is a growing confidence in the adequacy of these models for interpolation, but no supportable basis for using these models for extrapolation. There is great hope that a more focused emphasis will be a useful complement to continuing data measurement programs.

This is a great opportunity for good science on nuclear modeling. It must be emphasized, however, that modeling without a continuing stream of data is sophistry.

The Adequacy of Data for Nuclear Designs

The established international data community meets periodically to review the status of data, as well as to advance the art of measurement and evaluation. A recent meeting[1] included a comprehensive assessment of the adequacy of available data. Much of the material which follows is extracted verbatim from a summary of that meeting[2]. (The inserted comments are those of the author of this attachment). The author classed data into three categories; (1) areas where great progress has been made, and where maintenance programs are thought to be all that is required to meet applications needs; (2) areas where great progress is being made, but the data community does not feel that current data is satisfactory; and (3) data needs which are not currently being effectively addressed.

Areas of Great Progress

"Dosimetry cross sections are greatly improved. These energy-dependent reaction cross sections are the flux weighing functions for integral reaction rates measured in nuclear facilities. We are concerned about a two-three percent difference between a ^{238}U fission cross section measured against dosimetry standards and the value from ENDF/B-VI. However, good success in unfolding neutron spectra using dosimetry data will require even more detailed measurements.

"There is continuing improvement in experimental data such as total cross sections and elastic scattering angular distributions, data that are fundamental to comprehension of the neutron cross sections of a nuclide. These improvements have come from more sensitive fast-neutron detectors, improved electronics, and assiduous attention to detail.

"Relatively complete and reliable resonance data are becoming available for more and more nuclides.

"Many good data are now available for gas production in reactions at neutron energies important to fusion energy.

"There have been marked advances in availability of fission product data useful for estimation of delayed neutron effects and after-shutdown decay heat. Nevertheless, decay heat is still not currently represented, leading to significant uncertainties in decay-heat removal and passive removal concepts."

Areas of Good Progress But Great Need

"For ^{235}U the quantity eta(E), the number of fission neutrons emitted per neutron absorbed, has now been shown to decrease for incident neutrons below thermal energies. Integral temperature coefficient data observed for thermal critical systems motivated the differential experiments that demonstrated an increase in the ratio of neutron capture to fission at subthermal energies. The exact magnitude of the effect is still being debated, and must be established because the effect impacts analyses of the temperature coefficient of reactivity for light-water power reactors.

"Resonant neutron capture in ^{238}U, though the correct analysis of resonance absorption in this isotope, has been a central problem in reactor physics. An interim set of resonance parameter results, far more complete than those of the past, are completed. It is not established as to whether this set will meet user needs.

"There are significant uncertainties and inconsistencies in the underlying ^{10}B cross-section data. New experimental results are starting to appear and additional data will become available[3]. In particular, the capture cross section above 100 keV is too high, leading to inaccurate control rod worth calculations."

Problems that Require Greater Effort

"Some types of measurements have proven difficult in that significant, careful efforts have left us with inadequate data. In some cases it is not clear how to obtain the needed experimental results.

"In some fission reactor systems, inelastic scattering in fissile materials is an important mechanism of energy loss that therefore impact the neutron spectrum. Experiments for these nuclides suffer from interference from prompt fission neutrons in addition to all the other difficulties of neutron inelastic scattering work. Uncertainty in neutron spectral shape is also caused by inadequate experimental data on prompt fission neutron spectra for other than ^{252}Cf and perhaps thermal fission in ^{235}U. Model calculations are proving to be very helpful for both inelastic scattering and fission neutron spectrum calculations, but some really clean experiments are needed if they are possible. A particular example is the oxygen scattering cross section, which is poorly represented; applications such as space reactor BeO reflector cannot be effectively designed.

"Strong efforts have been made to measure doubly differential neutron emission spectra for materials important in fusion systems, particularly near 14 MeV. Even in this range where there has been increasing experimental success over the years, the data obtained are marginally adequate for benchmarking the ever-more thorough pre-equilibrium models used to help produce evaluated cross sections and angle-energy distributions. Outside the 14 MeV region, the data are less adequate. Experimental problems include interference from elastically scattered neutrons. There are too many theoretical difficulties for us to expect model calculations to suffice until some precise data can be obtained at least for the most important nuclides.

"Energy-dependent neutron capture in fissile nuclides is very difficult to measure. De-excitation gamma rays are used to identify capture events and the detectors are sensitive to the more-numerous prompt fission gamma rays. Neutron-induced backgrounds tend to be very large in most experiments. Because of a variety of constraints, promising results on ^{235}U obtained a decade ago by Muradyan[4] using a photon multiplicity detector have not yet been extended to the other important fissile nuclides.

"Much has been learned in the last two decades about how to understand and quantitatively express the uncertainties in nuclear data experiments. Nevertheless,

> published experimental results often do not contain all the needed information available to the experimenter. Lacking such information, the user cannot know the value of the data either for direct use or for combination with other information. Comparisons among independent data provide a check, but the information content of such comparisons is often elusive. Overall, the trend toward better documentation of uncertainties and covariances needs to be accelerated. Considerable effort is involved."

The preceding quoted section illustrates both the strength and the weakness of the current arrangement. The availability of clearly stated consensus and the eagerness of the community to respond to applications needs, speak for themselves. However, the current mechanisms can be inefficient in establishing priorities for evolving programs. Appropriate priorities primarily associated with fast reactors (e.g., temperature coefficients), space reactors (e.g., high energy ^{235}U fission cross sections and structural capture cross sections), gas-cooled reactors (e.g., graphite slowing down kernel), heavy-water reactors (deuterium slowing down kernel), have been difficult to establish; feeling no overriding concern, the user communities have, to some extent, left the setting of priorities to the nuclear data community. The user community has also largely abandoned its programs of data testing. These tendencies have led to a degree of stagnation in the perspective of the nuclear data community, which seems unlikely to change until there are substantial real advanced reactor design initiatives.

Recognizing that these needs will reappear, it would be prudent to maintain and use an appropriate spectrum of measurement facilities. The current pause in hard user demands should be used to address the fundamental science aspects of nuclear data.

Thus, reactor design today has few unmet needs. Nuclear energy has become pervasive in the technical community and is certain to continue to play a role in the world's industrial energy supply (central station and specialized application). This will lead to improved designs and applications, which will require concomitant data improvements. The Department of Energy has a role in setting energy policy and in assuring an adequate energy supply. It would be irresponsible for the government to undertake any development program (including military applications, basic science, applied [precompetitive] technology) without providing for appropriate standards, data bases, quality assurance, safety, and environmental evaluations, and providing for appropriate training and personnel development. A proper nuclear data program should address data and standards, provide a basis for quality assurance, safety, and environmental evaluations, and provide a vehicle for training and personnel development.

This will require maintenance of a reasonable stable of integral facilities (which can be maintained in an inactive state until needed), differential data facilities (which need to be used to be maintained), and a maintenance of expertise and training. Expertise and a minimal set of experimental facilities, coupled with a sound theory program, can provide suitable support to reactor design applications programs when needed. This program, even during the current demand hiatus, should not be left to its own self-direction, but should be firmly guided by users; in this case, a blend of theory experts and applications users.

References

1. R. W. Peelle, "Progress and Problems in Energy Related Nuclear Data," Proc. Intl. Conf. on Nuclear Data for Science and Technology, Julich, Germany, to be published. See also Proc. Int. Conf. On Nuclear Data for Science and Technology, May/June 1988, Mito, Japan (Edited by S. Igarasi).

2. Y. Kanda, Y. Kikuchi, Y. Nakajima, M. G. Sowerby, M. C. Moxon, F. H. Frohner, W. P. Poenitz, and L. W. Weston, "A Report on Evaluated ^{238}U(n,Y) Cross Sections," Paper 051 at this conference, includes a discussion of the new evaluated results for the ^{238}U resonance region.

3. A. Carlson, Minutes of the Second Working Group Meeting on the ^{10}B(n,a) Standard, held May 15, 1991, at Julich, Germany, FRG. Private communication, July 1991.

4. G. V. Muradyan, Y. G. Schepkin, Y. V. Adamchuk, M. A. Voskanyan, Proc. of Nuclear Cross Sections for Technology, October 22, 1979, Knoxville, Tennessee, National Bureau of Standards report NBS-594, p. 488 (1980).

III. NUCLEAR DATA NEEDS IN MEDICINE AND HEALTH

John A. Correia

INTRODUCTION

The application of nuclear science and technology to medicine is of major importance to health care today. Techniques involving radionuclides and/or particle beams are central to the diagnosis, treatment, and monitoring of cancer, heart disease, and many other disorders.

Nuclear data needs for medicine during the next decade will be of two types. The first involves the refinement of existing data to better serve ongoing, relatively mature, areas such as diagnostic isotope production. The second involves emerging methodology such as neutron-based or heavy-charged-particle-based radiotherapy, for which either new data or extensions of existing data are required.

The medical world is somewhat unique in that many professional disciplines coexist and carry out various aspects of health care delivery. These include physicians, chemists, physicists, and pharmacists as well as others. The subfields of medicine which utilize nuclear (or related) techniques typically are ones in which these disparate disciplines interact. There may, therefore, be unique problems associated with both the availability of nuclear data across disciplines and the formats in which such data are presented. Because of this, an important aspect of the medical area's needs revolves around the collation and reduction into useful compilations.

The sections below briefly discuss the status of nuclear data needs for several areas of medicine. The information presented here is based on a telephone survey of workers in the subfields listed.

RADIOISOTOPE PRODUCTION

Commercial Production

Until recently, virtually all of the needed medical diagnostic isotopes were provided by commercial companies. There have been a few exceptions to this for research studies (^{127}Xe, for example,[1]) that have been provided from National Laboratories or academic sources. Representatives of the industry feel that it is unlikely that new isotopes will be identified for medical use in the foreseeable future and that much of the data needed exist in the literature. There is, however, a need for improvement in cross-section data and thick target yields, especially for low or moderate abundance isotopes. The main use of such data would be in optimizing irradiations of thick targets so that yield is maximized and radioactive impurities minimized. Examples of this are the accelerator production of ^{201}T1, and ^{123}I, both commonly used diagnostic isotopes.[2] The issue of radioactive impurities is becoming more and more important as the Food and Drug Administration (FDA) and other regulatory agencies respond to heightened concerns about patient radiation dose.

There is an increasing interest in the use of radionuclides for internal radiotherapy and many manufacturers have begun to study the production of nuclides such as ^{90}Y, ^{186,167}Re, and ^{153}Sm for this purpose. The feeling within the industry is that, at this point, sufficient data to develop production of these isotopes exists. However, as mentioned below, potential users of these and other isotopes for therapy feel that there is a need for better level-scheme data to tie down patient absorbed doses.

There is a gap in the commercial production capacity of certain isotopes which has been filled to some degree by the Brookhaven Linear Isotope Production (BLIP) and Los Alamos Meson Proton Facility (LAMPF) programs. There is a feasibility study commissioned by the DOE concerning the establishment of a National Biomedical Tracer Facility which would use high-energy spallation reactions to produce many isotopes not regularly available commercially. Since this is a viable option for the future, the need for production cross-section data for spallations and other reactions at high energies is necessary.

Also for the future, reactor facilities such as Fast Flux Test Facility (FFTF) and EBR2, which provide fast neutron fluxes, may have considerable advantage over reactors which use thermal neutron capture in producing many of the isotopes identified for potential use in internal therapy. Epithermal and fast-neutron cross section data for many of the nuclides of interest are either lacking or ambiguous. Also, cross sections needed for the assessment of impurities in the same energy ranges are needed.[3]

A specific problem existing today is that the supply of ^{99m}Tc, the isotope used in the majority of nuclear medical diagnostic studies, is dependent upon a single supplier (Nordion of Canada) in North America. A shutdown of the reactor providing this supply could jeopardize this important diagnostic service. The search for alternative methods for the production of this isotope is ongoing. One promising method involves the use of fast neutrons from a source such as the FFTF but this development is hindered by a lack of fast neutron cross section data.[4]

Hospital On-Site Isotope Production

The emergence of Positron Emission Tomography (PET) as a physiological imaging method during the past 5 years has led to the proliferation of hospital-based medical cyclotrons with proton beam energies in the rage of 10-30 MeV. An indication of the remarkable growth rate in this area is given by the fact that, 10 years ago there were no more than 5 cyclotrons located in hospital facilities in the United States, while today there are at least fifty either operating or under construction. It is expected that there will be several hundred such facilities within the next decade due to the pending approval of the PET technique for clinical application. Such approval by the FDA and agencies representing Medicare/Medicaid seems almost a certainty within the next 3 years.

The primary purpose of onsite medical cyclotrons is to produce the four short-lived positron-emitting isotopes, ^{11}C, ^{13}N, ^{15}O, and ^{18}F. Cross-section data for most of the reactions which produce these isotopes is available although there are many inconsistencies. Of more importance for the future, is the fact that many other isotopes can potentially be made with the energies and particles available. Perusing the chart of nuclides leads to about 100 realistically possible candidates. Production cross section data, as well as level scheme data for these isotopes, are important for several reasons. The first is that many of these isotopes are potential candidates for diagnostic or therapeutic use, but more immediately, many of them appear as contaminants in the short-lived isotopes listed above. The main process for such contamination is recoil of nuclei from target windows. This type of contamination may become of major importance to the dosimetry of PET imaging.

Another area associated with the production of PET isotopes is the development of low-energy, compact accelerators to replace PET cyclotrons. There are at least four accelerator companies undertaking such development and such machines may well become the norm for hospital-based isotope production. These machines tend to be low energy (2-4 MeV) and high current devices which may use enriched stable isotope targets and proton, deuteron, or helium-3 reactions. Production cross-section and thick-target yield data for many of the reactions of interest are poorly determined or unavailable.

It should be noted that a partial alternative to onsite accelerators is the use of parent-offspring generators such as ^{68}Ge-^{68}Ga as a commercially available source of positron emitting isotopes. The demand for such isotopes may well help to shape the nature of commercial production during the next 10 years.

EXTERNAL BEAM RADIOTHERAPY

Clinical Photon Beam Therapy

For the most part there seems to be a satisfaction with the photon scattering and interaction data currently available. One area where workers in this area cited a lack of data is in the photonuclear reaction data for tissue elements. This is a relatively minor effect and may not be important in the overall scheme of things.

Charged Particle Radiotherapy

The use of high energy proton (and other ion) beams has been pursued by several research centers for over 10 years. The techniques have become highly refined and there is interest on the part of the National Institutes of Health (NIH) in establishing several regional centers to further test the feasibility of the technique. There is a need for better characterization of high-energy interactions, particularly spallation, in tissue and their effects on dosimetry. Similarly, beam fragmentation data for heavier ions is lacking.

A more esoteric area, but one which may prove to be of importance in charged-particle radiotherapy, is the production and use of radioactive beams of selected e/m for tuned radiotherapy. The main advantage of such beams is that the energy deposition at the Bragg Peak region is a sensitive function of e/m and thus highly customized therapy beams could be produced. Cross sections for the production of such beams from primary accelerated beam are lacking and are needed to pursue this work.

Neutron Beam Radiotherapy

Studies of the effectiveness of neutron beams for radiotherapy have been ongoing for a number of years with limited success. There is interest in the community in using higher energy neutrons as well as making better determinations of dose distributions at lower energies. While there is some room for improvement in existing tissue interaction data below 20 MeV, the main area where cross section data is lacking is in the 20-70 MeV energy range. Preliminary work with neutron beams at these energies has shown considerable promise but is hampered by a lack of reliable interaction cross section data in tissue.

Neutron Capture Therapy

Another area of research which has been ongoing for more than 20 years is "capture therapy" which involves the loading of tissue with a compound containing a nuclide which has a significant cross section for charge particle production via a neutron induced reaction. Originally, thermal neutrons were used with ^{10}B reaction as well as similar data for other potentially useful reactions. If refined, these data could contribute to finally bringing this technique to clinical use.

Related data, needed for capture therapy, involves the detailed modeling of charge particle (alphas in particular) LET near the end of their tracks. This is similar to the information needed for charged particle beam therapy as mentioned above.

DOSIMETRY AND SHIELDING

Dosimetry of Internal Emitters

A major emerging area in the treatment of cancer involves the use of tumor-specific antibodies tagged with radionuclides in order to deliver very high radiation doses locally to tumor cells while sparing healthy tissue. Such targeted radiotherapy may have a major impact on cancer treatment in the immediate future. Accurate determination of tissue absorbed dose is critical to the evaluation and eventual application of this therapy. Examples of isotopes currently under study include ^{90}Y, ^{166,167}Sm.

There is some level-scheme data available for most radioisotopes in use or suggested for future use. The problem most often identified by workers in both diagnostic and therapeutic nuclear medicine is the fact that there are large uncertainties in much of the data with different results being widely disparate. With the increasing concern about radiation dose in general, improvement of these data, especially for widely used radionuclides are important.

A second problem area identified is related to the forms in which level scheme data are available. It is often the case that such data are used by individuals with little sophistication in nuclear physics and what is desired, therefore, are compilations which give particle and photon yields rather than transition probabilities, conversion coefficients, etc. There are several excellent compilations of this nature for common radionuclides already but they need to be expanded.

Shielding

There seems to be an overall satisfaction with shielding data available for neutrons and photons. One area where data are lacking is in the thick target distributions of neutrons and photons from accelerator induced nuclear reactions. The availability of such data might allow for the refinement (and possible reduction in size) of shielding designed for medical accelerators. This will be of importance in hospitals where space is at a premium.

Selected Bibliography

1. Proceedings of the First International Symposium on Neutron Capture Therapy, R. Fairchild and G. Brownell, eds., BNL Report 51730 (1984).

2. Proceedings of the Second International Symposium on Neutron Capture Therapy, , eds., (1991).

3. Proceedings of the Workshop on Cf-252 Brachytherapy and Fast Neutron Bean Therapy, Y. Marumama, J. Beech and J. Feola, eds., in Nuclear Science Applications B, Vol. 2, No. 3 (1986).

4. Proceedings of the Second International Charged Particle Therapy Workshop, M. Goitein ed, in International J. Radiation Oncology (1988).

5. Clinical Neutron Dosimetry Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons, ICRU Report 45 (1989).

6. Evaluation of Treatment Planning for Particle Beam Radiotherapy, S. Zink, ed, NCI Report (1987).

7. Bhargava, K. and Acharya, A., "Labeling of Monoclonal Antibodies with Radionuclides," Seminars in Nuclear Medicine 3:187-219 (1989).

8. Order S., "Presidential Address: Systemic Radiotherapy - The New Frontier," Int. J. Radiation Oncology Biol. Phys., 18:981 (1990).

9. Hendee, W., "The Impact of Future Technology on Oncologic Diagnosis," Int. J. Radiation Oncology Biol. Phys., 9:1851-1855 (1983).

10. National Biomedical Tracer Facility Planning and Feasibility Study, R. Holmes, Society of Nuclear Medicine, Inc., New York (1991).

11. Proceedings of the IAEA Consultant's Meeting on Data Requirements for Medical Isotope Production, K. Okamoto, ed., Report INDC(NDS)-195/GZ, International Atomic Energy Agency, Vienna (1988).

12. Status on the Compilation of Nuclear Data for Medical Radioisotopes Produced by Accelerators, D. Gandarias-Cruz and K. Okamoto, eds., Report INDC(NDS)-209/GZ, International Atomic Energy Agency, Vienna (1988).

13. Status Report on Cross Sections for Monitor Reactions for Radioisotope Production, O. Schwerer and K. Okamoto, eds., Report INDC(NDS)-218/GZ, International Atomic Energy Agency, Vienna (1989).

14. Schenter, R. and Myjak, M., "Isotope Production at the FFTF by Neutron Transmutation," in Proc. Int. Conf. on Nuclear Data for Science and Technology (1989).

15. Schenter, R., "Comparison of Medical Isotope Production in Fast and Thermal Reactor Systems," Publication WHC-SA-0956-FP, Westinghouse Hanford Co. (1990).

16. "Nordion's Main Medical Reactor Shuts Down," Newsline, J. Nuclear Medicine 32:30N (1991).

IV. NUCLEAR DATA NEEDS FOR NUCLEAR WEAPONS/NUCLEAR SAFEGUARDS

John C. Browne

The nuclear weapons community that utilizes nuclear data in a major way is centered at Los Alamos National Laboratory and Lawrence Livermore National Laboratory. Their nuclear data needs fall into several categories. First, nuclear data are needed in the design of a nuclear weapon to predict its performance and output in great detail. Small uncertainties in certain cross sections can produce major effects in the nuclear performance. Neutron and charged particle reactions are of great interest to the nuclear designer over a wide range of energies from the kev range to 30 MeV. More detailed reaction data are becoming of interest and importance in the nuclear design process. Second, nuclear data are needed in the nuclear testing area to support the design of prompt and radiochemical diagnostics. In this regard, more detailed reaction data are critical to the interpretation of the nuclear tests. Third, nuclear data are needed in the nuclear effects arena since the output of a nuclear weapon is critically dependent on a variety of nuclear reactions/interactions during the nuclear explosion process as well as the transport of radiation through material.

The goals of the current nuclear weapons program have changed significantly in the past few years. Issues such as the environment, safety and health of the nuclear weapon production complex, tritium supply, nuclear pit reuse, intrinsic safety of the nuclear design, and others vie with the traditional requirements to develop nuclear weapons that meet military requirements. These new directions could mean replacement of certain hazardous materials currently used in nuclear design by other more environmentally benign materials. Such changes require that the nuclear designers have improved cross section and reaction data on materials which have not traditionally been incorporated into the nuclear data files for weapons design with the level of information required. Because the nuclear explosion involves very short time scales and very high neutron and gamma fluences, the types of nuclei and reactions for which information is required resemble those of interest to the astrophysics community more than any other application area. For this reason, nuclear theory and modeling is of great importance to calculate nuclear information that cannot necessarily be measured directly. Such nuclear models require benchmarking either with nuclear data obtained on related nuclei or with theoretical calculations that elicit the underlying physical processes.

There are a sizeable number of high priority nuclear information needs in the nuclear weapons community. A few representative examples include the following:
Accurate (five percent) fission neutron spectra for uranium and plutonium isotopes and for the incident neutron energy region up to 20 MeV.

Gamma-ray production cross sections and spectral data for Plutonium isotopes and for a variety of stable/unstable nuclei in the incident neutron energy range up to 20 MeV and gamma spectral region up to 25 MeV.

The nuclear safeguards community is represented by institutions from around the world. Their primary technological mission is to develop the techniques to help the international control of fissionable material thereby slowing the proliferation of nuclear weapons technology into countries that might desire to have nuclear weapons and thereby threaten the stability of the nuclear deterrent. Nuclear measurements techniques have been used successfully to assay material that has been identified as accountable under the Non-Proliferation Treaty. The main United States safeguard technology activities that require nuclear data are centered at Los Alamos National Laboratories. In Europe, similar but smaller activities exist at ISPRA in Italy and EURATOM in Belgium. The International Atomic Energy Agency (IAEA) is the main international body that implements the safeguards program in the countries that are signatories of the Non-Proliferation Treaty. The nuclear measurements performed by the IAEA inspection teams utilize measurement techniques developed in the safeguards program. These non-intrusive techniques can provide quantitative determinations of the amounts and types of nuclear material present in a facility.

To improve the accuracy of the safeguards measurements, the experimentalists require accurate nuclear information in several areas. One particularly useful type of data involves the fission neutron multiplicity distributions for neutron-induced fission of ^{239,240,241}Pu and ^{235,238}U as a function of incident neutron energy. The fission neutron multiplicity distribution for spontaneous fission of ^{238,240,242}Pu and ^{238}U is also of great importance. A source of background neutrons in these types of measurements comes from the (alpha,n) reactions for samples of plutonium mixed with fluorine, sodium, magnesium, and chlorine. The intensities and spectra of the emitted neutrons is crucial to the interpretation of these data. Six group decay constants and delayed neutron yields for ^{234,236}U and neptunium isotopes are also critical in the safeguards measurement business.

The main benefit of a national nuclear data program is the existence of comprehensive data sets from which the technology developers can quickly evaluate current and new techniques for assaying nuclear material. The nuclear data community can also respond to the critical nuclear data needs of this community since the types of required measurements are very similar to those needed for other nuclear programs. Since it might not be possible to measure certain intermediate reactions required to interpret safeguards data, this community would certainly benefit from the access to the various reaction and fission codes that can model the desired information on a much faster time scale than if the safeguards people had to develop and maintain their own codes. A similar statement can be made about experimental information because, although the safeguards community does make special measurements for their purposes, they do not have to create an entire nuclear measurements capability to feed into their program.

Without such access, they would have to increase the priority on their own nuclear data needs relative to other issues in the program. In the short term, they would be able to do a credible job. In the long term, one would be concerned about the growth of "personal" data sets to fit measurements with the possibility of propagating error for many years if there are not the checks and balances provided by a truly national program for nuclear information.

V. NUCLEAR DATA NEEDS FOR FUSION

Mohamed A. Abdou

Demonstrating the potential of fusion as a renewable energy source with attractive safety and environmental features is part of the present National Energy Strategy. A presidential initiative has resulted in an agreement among the USA, USSR, the European Economic Community, and Japan to jointly design the International Thermonuclear Experimental Reactor (ITER) with a decision to construct in 1996. Design of fusion devices such as ITER requires an extensive base of nuclear data for the calculation of the fusion reaction rate in the plasma, prediction of neutron and photon transport in the primary energy conversion system (blanket), calculation of the tritium production rate in the blanket, calculation of nuclear heating, calculation of radioactivity and decay heat, and prediction of gas production rates and atomic displacements as indicators of radiation damage in materials.

Fusion reaction rate calculations require accurate knowledge of fusion reaction cross sections for the D-T, D-D, and D-^{3}He reactions. The data required for predicting nuclear responses includes all neutron-induced reaction cross sections for neutron energy up to 20-MeV, energy and angular distributions of secondary neutrons, gamma-ray production cross sections, energy distributions of emitted charged particles, and decay data for radioactive isotopes.

Priority lists of materials, specific nuclear data needs, and accuracy goals have been generated and refined by the fusion community over the past 20 years. Some of these needs have been met but serious gaps in nuclear data exist.

Fusion research and development crucially depends on having ready access to computerized data files, such as those compiled in the U.S. and also in Japan, Europe, and USSR, as well as a variety of processing codes. Without such a database, it is inconceivable that fusion energy research will continue to progress. Future success in fusion research and development requires maintaining and improving existing data as well as measurements and evaluation of new data. The safety margin in the design can become too large to make fusion devices such as ITER affordable if new data are not available. Quantities such as radioactivity and decay heat, for which the present database is known to be unreliable, must be calculated to new levels of accuracy for approval of construction under current regulations.

VI. NUCLEAR DATA NEEDS IN WASTE MANAGEMENT

Martin Haas

Uncertainty errors in nuclear data are not uncommon, especially as related to elements or isotopes that have not been important in the fission or fusion reactor designs. In the field of nuclear waste management, uncertainties of 50% are not uncommon. This in turn leads to instances where the accuracy of nuclear data are not commensurate with the uncertainty impact.

An example of the potential cost impact of nuclear data uncertainty in the waste management area relates to the burnup of actinides in the Integral Fast Reactor (IFR) design currently under consideration by Argonne National Laboratory (ANL). The scenario for burnup entails the data uncertainties in turn result in uncertainties relative to decay heat, doppler control, and safety margins. Consequently, a more conservative design is required to accommodate these issues. The resultant economic impact could amount to an additional $200 million per IFR plant.

A second example of the nuclear data uncertainty impact is in the area of routine spent fuel shipping. Improved burnup calculations through better nuclear data could result in increased fuel loadings by as much as 10 to 15%. This could result in corresponding savings in shipping costs with savings of $100,000 to 150,000 per shipment.

A limited but not exhaustive list of examples of such instances are presented below:

Item	Discussion
^{129}I, ^{99}Te	Relatively large uncertainties are associated with the transmutation of both isotopes. Both are limiting isotopes in the designs of both high and low level radioactive waste storage facilities such that large uncertainties may significantly affect the economics of transmutation concepts.
^{90}Sr	This isotope is an important source term for both shielding and transport considerations. The commonly assumed neutron cross-section is 1 barn. However, recent data indicate that the true value may be as high as 10 barns, a factor of 10 higher.
^{126}Sn, ^{79}Se	Both isotopes are important in high-level waste management, however the destruction cross-sections are wholly inadequate at this time for meaningful calculations.
Fe, Ni, Nb	The cross section data bases continue to be expressed in terms of the element, not each individual isotope. While this may be

	adequate for reactor physics, it is not sufficient for waste management where prediction of the products of neutron absorption is required.
long-lived fission products	The neutron capture cross-section of this fission products important class of isotopes is only poorly known. Nonetheless, these isotopes are of direct importance in repository design, in waste form integrity as well as in transmutation concepts.
higher actinides	The delayed neutron yields of this class of isotopes are only poorly known. However, they are significant in that their values could significantly affect the integrity of high-level waste forms over the contemplated lifetime of 10,000 years.

Photoneutron and Alpha-n Reactions

Both processes are significant in the production of neutrons, particularly with the light elements in waste forms (e.g. B, N). These could potentially be significant as they may affect the integrity of high-level waste forms over extended times (10,000 Yrs).

VII. NUCLEAR DATA NEEDS IN FUNDAMENTAL SCIENCE

Steven W. Yates

Background

Nuclear data compilation efforts in fundamental science have been primarily in such areas as mass-chain evaluations, as published in Nuclear Data Sheets, the Evaluated Nuclear Structure Data File (ENSDF), which contains structural data from a variety of nuclear reactions and from radioactive decay, and the evaluated file of nuclear cross sections (ENDF/B). These resources are viewed as critically important for investigations in fundamental science and provide the foundation for many areas of applied research. The groups providing these data nd evaluations are providing vital services to the entire nuclear science community, as well as to many other users.

Significant changes are occurring in the fundamental science area of the nuclear data program. For example, the pace at which new radioactive decay data are becoming available has significantly slowed in recent years, while a data explosion brought about by the implementation of large detector arrays may be on the horizon. Moreover, many new directions of basic study have emerged, and the forefront areas of fundamental nuclear science are continuously changing. A modern nuclear data program should be able to effectively serve these developing areas, as well as provide convenient access to the vast quantity of structural and reaction data accumulated in the past decades. In addition, every effort must be made to make available data in all areas as current as possible and easily accessible.

The Panel on Basic Nuclear Data Compilations of the National Research Council reviews annually the status of these compilations and, in their most recent report[1], has offered a number of recommendations. Many of these suggestions are related to the production of mass-chain evaluations on a timely basis; the concept of "continuous review"--i.e., an annual updating of every mass chain and incorporation of these data into the database--also seems quite attractive. Since its inception in the mid-80s, online access to nuclear databases has grown considerably and is expected to continue to increase. The Panel also describes the development of electronic publication of the Nuclear Data Sheets as an area of high priority and mentions such projects as the 8th edition of the Table of Isotopes, also in electronic format, and a PC version of the Table.

General Comments

Fundamental investigations are generally regarded as being at the forefront of nuclear science. For these studies to be performed in a timely manner, access to the most current nuclear data is at a premium.

For researchers involved in any form of fundamental science, convenient electronic access is crucial. Moreover, it should be possible to transfer the needed data over the data network with a minimum of complications. The system should be user friendly, preferably with an entire menu of utilities for making searches on the database, with interactive and instructive graphics. Such an up-to-date environment would greatly enhance the utility of the nuclear data compilations to the broad nuclear science community. It is also important that the data be as current as possible and that duly-labeled "unevaluated" data be included in the database.

Many of the methods of nuclear research which were at the forefront in previous decades are at diminished activity, with work often reserved for special problems brought forward to answer specific questions. The vast evaluated data pools from decades of work need a constant level of attention to remain useful in the form desired for current applications. Since few of the laboratories using these methods will remain, it is vital that a well-maintained source of their results is available; it is unrealistic to expect users to go back to the original archival publications of measurements. An online, user-friendly set of compilations is the best way to retain the usefulness of these carefully measured results and to quickly pinpoint gaps and inconsistencies in existing data sets. Many of the large nuclear research centers have files of fully developed, but as yet unpublished, data. With some level of assistance for evaluation and compilation, distributed to at least a few of these large nuclear centers, a considerable body of valuable data could be extracted and made available.

It should also be noted that, while the nuclear databases used by the basic research community have some unique features, they should not be considered as separate entities from other nuclear databases which might be considered "applied." Indeed, basic nuclear data--e.g., level schemes, level densities, decay properties--are frequently needed in many applications to understand fully the implications of measured reaction cross sections. For this reason, it should be emphasized that bifurcation of nuclear data into "basic" and "applied" areas seems unwise. Only by maintaining common formats and easy access to all of the nuclear databases will the nuclear science community be best served.

Basic nuclear science is moving increasingly in the direction of studies with intermediate energy probes--e.g., pions and kaons--and heavy ions, and these studies will undoubtedly lead to improved understanding of the nucleus. It seems unlikely, therefore, that the many applied needs will be met as a by-product of basic scientific investigations (as has occurred frequently in previous generations), and some provision should be made for providing a program of basic measurements, including nuclear decay data, supporting applied research. Continuing research capabilities in areas related to nuclear energy, nuclear medicine, nuclear techniques in analysis, and national security are important. Precise measurements of nuclear reaction cross sections and decay properties are far from trivial, and support for projects developing these capabilities is necessary to prevent a loss of expertise.

Fundamental science has special needs for readily accessible wee-maintained data in the active areas at the frontier of the field. While the identity of the "frontier areas" may be arguable and in a constant state of change, nuclear data needs in some of these areas are noted below.

High-Spin Physics

In the near future, several major experimental projects will be completed--e.g., Eurogam (1992) and Gammasphere (1993)--that will utilize the latest advances in technology for obtaining information about nuclei at high angular momentum. It is crucial that appropriate technology be utilized to compile, evaluate, and disseminate this large body of nuclear data in a rapid and efficient manner. Much information can be realized by direct manipulation of such data; a number of examples, such as the determination of chaos versus order in the nuclear quantum system, exist in the literature. These analyses can be accomplished in a timely manner only if the spectroscopic data are collected, "evaluated," and disseminated in a format that can be readily manipulated. Such data compilation efforts are in progress at several institutions; unfortunately, much of this work is being performed outside and well-established nuclear data community and suffers from lack of central coordination.

Intermediate Energy Physics

Some attention has been directed toward providing a nuclear database for intermediate energy nuclear reactions. but considerably more effort is needed. Pearlstein[2] has provided an example of how such reference data libraries can be produced and has demonstrated how modeling can be incorporated into this endeavor, and a proposal for establishing a medium-energy nuclear data library[3] was made several years ago. While no funding has been received for this project, an appreciable amount of work has been done a LAMPF on a library containing data for pion-induced reactions. The creation of similar data files for elastic and inelastic nucleon-nucleon, kaon-nucleus, electron-nucleus and other reaction data across a broad energy range, up to several GeV, would be desirable. Such data are required for the testing of reaction theories and, as accelerators are phased out, these data are at risk. Such data are also useful in a number of applications--e.g., biomedical and space radiation studies.

Nuclear Astrophysics

The data needs of the nuclear astrophysics community are great, and the extent of some of those needs is just emerging. The needs range from neutron emission cross sections for nucleosynthesis, transition rates for the s- and p-processes in stars, and gamma-ray production cross sections for selected elements. Many of the gamma-ray needs can be expected to become clearer as the decade of gamma-ray observations in space unfolds. Lifetime observations for nuclei off the valley of stability certainly will be especially important in attempts to understand the violent events being examined with ever greater detail; radioactive beam methods will be the only effective way to deal with most of these problems. Many of the astrophysically related quantities are dependent on nuclear models, and there continues to be a need for refinement of such models as the dispersive optical model and the statistical mode. The continued development of these models requires total and scattering cross section data from near the neutron binding energies into the 100 MeV region.

Nuclear Theory

The testing of nuclear theories relies on the existence and availability of appropriate nuclear data, and exciting new theoretical results have often provided the impetus for experimental investigations. However, it is appropriate to consider how the experimental nuclear database can, in the future, be fit into a broader computer-based nuclear science information system. This system could contain tabulated results of theoretical calculations and computer program libraries with programs for both experimental and theoretical applications, as well as programs for data handling and data display related to the use of the large databases.

BIBLIOGRAPHY

1. Assessment of the Current Status of Basic Nuclear Data Compilations, Report of the Panel on Basic Nuclear Data Compilations, National Academy Press, 1991.

2. S. Pearlstein, The Astrophysical Journal **346**, 1049-1060 (1989).

3. E. R. Siciliano, E. D. Arthur, Medium-Energy Nuclear Data Library (MENDLIB) Phase I, LA-11085-MS, 1987.

VIII. NEW DIRECTIONS FOR NUCLEAR DATA STANDARDS

Wayne A. Cassatt

Introduction

The user of nuclear data cross sections is generally not directly involved with the fundamental nuclear cross section standards which form the foundation of the data system. This is because of the intermediate roles of the data evaluator, data measurer, and nuclear model developer. Measurement standards are required to determine incident particle fluence for neutrons and photons. It is also experimentally desirable to have a standard that produces the same outgoing particles as those from the reaction under study since this simplifies the measurement process. Thus a number of standards are needed. Since no single cross section satisfies the conditions for a standard for the entire energy range, it is necessary to have standards which cover overlapping incident particle energy regions.

However, such standard reactions are usually not required for incident charged particles since there are other means to measure fluence. Also the number of possible charged-particle reactions is much larger. Therefore, a few charged-particle reference standards need to be established to provide a test for nuclear model and radiation transport codes for users in medical dosimetry, personnel protection, waste transmutation, and materials damage in space applications.

Neutron Reactions

Most neutron cross sections are measured relative to neutron cross section standards in order to eliminate the direct measurement of the neutron fluence which is the most difficult part of the measurement. Improvements in a standard cause all cross sections measured relative to that standard to be improved. The need is for accurate standards which are easy to use in cross-section measurements. Most of the cross-section work in the past has been focused on the neutron energy region below 20 MeV due to applications in fission and fusion systems. There are still important measurement improvements required in this region, even at thermal energies, for the standards. However a high priority is the development of new standards for neutron energies above 20 MeV to support the need for new cross-section data for new applications. Most of the work on these higher energy standards has been done on the H(n,p) and ^{235}U(n,f) cross sections. Later in the decade, the priority could switch to the selection of new reaction mechanisms for this energy region. This work, including monitor reactions for radiation dosimetry, and additional proposed high energy neutron standards were the topics of discussion of a recent international specialists meeting held in Uppsala, Sweden in May 1991. Though this higher energy field is in its infancy and the accuracies needed are not well defined, initial estimates are that the standards should be determined to about three percent. There are energy regions where the present uncertainties in the best known standard,

H(n,n), are approximately ten percent. There are still important problem areas which need to be addressed for neutron energies below 20 MeV neutron energy. The uncertainties in the standards are estimated to be at the two to three percent level and the requests are for uncertainties of less than one percent. Work is now being done to improve the H(n,n) cross section where a discrepancy of about two percent near 14 MeV has caused considerable concern. The problems with the database for the ^{10}B(n,alpha) cross-section standard caused considerable concern during the ENDF/B-VI standards evaluation process. An international working group was formed to improve this database. The work on these cross sections is needed to provide a smooth transition from the lowest to the highest energies with the minimum number of cross-section standards.

Neutron Spectra

In addition to standards for cross section measurements, several other nuclear data standards are important for use where absolute measurements are very difficult to make. For measurements of fission neutron spectra and source strength, the ^{252}Cf spontaneous fission and ^{235}U thermal neutron-induced fission spectra are often used as neutron standards. There are presently discrepancies in measurements of the ^{252}Cf neutron spectrum at both the low and high energy ends of the spectrum which need to be resolved.

Photon Reactions

The cross section for the photo disintegration of the deuteron is the main standard used for photonuclear reactions above the energy threshold at 2.2 MeV. The cross section is known to sufficient accuracy for energies below 100 MeV, but requires additional effort at higher photon energies. The additional cross-section standards for activation produced from ^{12}C and ^{63}Cu targets require improvements for photon energies above 25 MeV.

Charged-Particle Reactions with Light- and Heavy-Ion Beams

The increased importance of proton and heavy-ion beams for radiation therapy as well as the calculation of the effects of cosmic rays on humans and materials during long space missions requires the selection of a few optimized experiments (benchmarks) to serve as standards. For these experiments the selected beams, target materials, and geometry must provide simulations useful to the ultimate user. These selected measurements need to cover the incident energy interval, energy and angular distribution of secondary radiation with sufficient accuracy to test the adequacy of nuclear reaction models and radiation transport codes.

For example, a standard for medical therapy might include the measurement the interactions of 200 MeV protons on a thick carbon target. A standard for personnel dosimetry and radiation damage for space applications could include the reactions from 200 MeV Fe ions on Al.

International Cooperation in Data Measurement, Compilation, and Evaluation

Due to limited resources and the need for international acceptance, it is important that the determination of these radiation standards become an international program. This will require increased coordination among the measurers, compilers, and evaluators. The neutron program can serve as a model on which to construct the more extensive data effort.

IX. INTERNATIONAL COLLABORATION

Current nuclear data programs have operated under a carefully managed and highly effective international exchange arrangement. Scientific measurement techniques and data collection in the traditional open academic forum. Universities play a major role in measurement programs and are generally open to foreign nationals. Non-U.S. scientists participate regularly in U.S. programs and U.S. scientists participate openly and fully in European nuclear science programs. The exchanges have tended to be somewhat more limited with the Commonwealth of Independent States (formerly the USSR) due to security considerations, with Japan due to language problems, and with the developing countries. This pattern has been extended to U.S. laboratories in both in-house and user facility programs.

Evaluated nuclear data exchanges have been more rigorously controlled, due to economic and occasionally national security considerations. The U.S. data center (NNDC) operates as part of a formal four-center exchange with the NEA Data Bank representing western Europe and Japan, the Nuclear Data Center in Obninsk, Russia representing the former Soviet block group, and the IAEA Nuclear Data Section representing the remaining countries.

Within the restrictions set by governmental authorities, data and evaluations are exchanged, joint evaluations are prepared, and various forms of data validation performed. In addition to the actual data obtained, this exchange arrangement has been effective in encouraging reciprocity in that each center has demanded a reasonable participation from the other participants as a condition for data exchange.

The four-center exchange is currently in a slack period at this time because of the low output of the current U.S. program and restrictions being placed on the U.S. Evaluated Nuclear Data File (ENDF-B) version 5. ENDF-B4 had been the world standard as a melding of the best world data available at the time. For the recently issued Version 6, the U.S. used primarily U.S. generated data. In return, the Japanese are now using their own evaluated Nuclear Data Library (JENDL) containing largely Japanese updates to ENDF-B4, and the European Fast Reactor project has likewise generated their own updated data file. Since the three updates are largely complementary, it is felt that renewed collaboration will provide substantial mutual benefit.

International collaboration in basic data, including areas which have near-term application such as nuclear data, has traditionally proven to be of overwhelming benefit to all. This spans the range from the esoteric (an abnormal uranium isotopic mix in Gabon unlocks the geological history of the region), to the political (lack of data on the carbon capture cross section was a key element in the fact that Nazi Germany did not develop nuclear weapons), to the practical (standard data and instrumentation allowed immediately understandable tracking of the Chernobyl releases).

If the programs are allowed to drift apart, it is clear that we will lose not only specific data, but also the opportunity to coordinate and consolidate data programs around the world at a time when each suffers from budget pressures.

To mitigate the effects of worldwide budget pressures, international collaborations should be emphasized as a means of sharing program costs, especially those of large expensive facilities. A stable U.S. program is essential to a strong negotiating position in such discussions with other nations.

In view of the above observations, the following suggestions merit considerations:

- U.S. representatives including government officials and scientists should visit major nuclear data facilities in other countries to discuss improved coordination of activities and increased cooperation. Officials from appropriate ministries in these countries as well as scientists should be included in these discussions. Where exploratory discussions are promising, the U.S. should negotiate agreements for cooperation in nuclear data research and data exchange. These agreements could be a series of bilateral arrangements or one multilateral arrangement.

- The U.S. should investigate the possibility of building the next major neutron research facility on a multilateral basis. If the other potential partners express interest, the U.S. could ask the IAEA to organize a conference of interested countries to consider the matter.

- For example, the U.S. could consider the possibility of establishing nuclear data cooperation with Indonesia. The Indonesian Atomic Energy Commission (BATAN) has just built a 60 MW research reactor and is looking for opportunities for collaboration. Indonesia may build power reactors and thus may be interested in a full nuclear data program to support this activity.

- The nuclear data effort at Obninsk is probably facing uncertain times and a number of former Soviet weapons scientists are facing possible unemployment. The U.S. and Germany are establishing a scientific research center to coordinate assistance to the former Soviet Union. High quality scientists are available at relatively modest costs. The U.S. should consider funding a joint nuclear data program with the Russian federation.

APPENDIX B

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APPENDIX C

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LIST OF PRESENTERS

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APPENDIX D

DEPARTMENT OF ENERGY/NATIONAL SCIENCE FOUNDATION CHARGE TO THE NUCLEAR SCIENCE ADVISORY COMMITTEE

Department of Energy
Washington, DC 20585

Professor Peter Paul, Chairman
DOE/NSF Nuclear Science Advisory Committee
Department of Physics
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Dear Professor Paul:

With the accompanying charge, we request that the Nuclear Science Advisory Committee (NSAC) address national nuclear data needs and issues, and provide a written report by summer 1991. In 1988 the Department of Energy (DOE) Division of Nuclear Physics was given the direct responsibility of operating DOE's Nuclear Data Program that had existed within other parts of DOE. Because the priorities and needs of the energy community and the optimum methods of addressing those needs may have changed from those now forming the basis of the data program, we must assess these needs and establish appropriate program priorities. It is important and timely that this program be responsive to the directions identified in the emerging National Energy Strategy.

The goals of this review will be to: 1) determine the national nuclear data needs expected in the 1990's and their appropriate priorities and 2) address the adequacy of present methods of management and determination of priorities. As part of the latter, we wish to have evaluated the mechanism by which the needs of the user community are communicated to the program and suggest ways in which this interaction can be enhanced. The complete charge is given as an enclosure to this letter. We request this review include appropriate representatives from the nuclear data user communities, and representation from basic research.

The Division of Nuclear Physics of DOE would like to work closely with NSAC to maximize the benefit of this review.

Sincerely,

Marcel Bardon
Marcel Bardon
Director, Division of Physics
National Science Foundation

J Decker
James F. Decker
Acting Director
Office of Energy Research
U.S. Department of Energy

Enclosure

NSAC REVIEW OF NATIONAL NUCLEAR DATA NEEDS

GOALS

1. Determine the national nuclear data needs expected in the 1990's and their appropriate priorities
2. Identify ways in which the ongoing DOE Nuclear Data Program can enhance its communication channels to meet new challenges.

CHARGE

NSAC is requested to review the national nuclear data needs and formulate specific recommendations by which these needs can be met in a most effective manner in a period of budget constraints. In this review NSAC is requested to address the following:

Identify the communities that are expected to have significant nuclear data needs in the coming decade. This should include:

- o Clearly specifying new communities or other developments that might alter the priorities of data activities.
- o Evaluating the relevance and completeness of the program in view of current technical developments and national priorities addressed by DOE.

With a knowledge of the breadth and needs of the community of nuclear data users expected in the 1990's, the review should recommend:

1. Ways in which the broad range of communities can participate most effectively in the nuclear data program and in particular how the user communities can collaborate with DOE in carrying out the program by sharing appropriate responsibilities, resources, and expertise.
2. Steps the data program might take to enhance its relevance, timeliness and efficient distribution of resources and an appropriate balance between the following components of the program:
   - Measurement
   - User Availability (Evaluation, Compilation, and Dissemination)
   - Theory.
3. An appropriate level of program effort devoted to fundamental underpinnings that include nuclear modelling and theoretical treatment of data uncertainties.
4. Ways in which DOE's Nuclear Data Program can be enhanced by involvement in international collaborations and bodies.
5. Ways in which the program can respond to:
   - Opportunities for technical training and education
   - Cooperative efforts with other DOE programs.
6. Mechanisms for developing a continuing process for future assessments and provision of periodic input to DOE program managers regarding new and emerging needs, priorities, and opportunities for cooperation.