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THE U.S. NUCLEAR REACTION DATA NETWORK

Summary of the First Meeting
held at the

Colorado School of Mines
Golden, Colorado

March 13 & 14, 1996

Assembled by M.R. Bhat

National Nuclear Data Center
Secretariat

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Brookhaven National Laboratory
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Chair: F. Edward Cecil

Wednesday, March 13, 1996

9:00- 9:30	View from Washington	R.A. Meyer
9:30- 9:50	USNRDN Status Report	M.R. Bhat
9:50-10:10	Astrophysics Task Force Status Report	M.S. Smith
10:10-10:30	Coffee break	
10:30-10:50	Radioactive Ion Beams (RIB) Task Force Status Report	M.B. Chadwick
10:50-11:10	Measurements Status Report	D.L. Smith
11:10-12:00	Charge to the Discussion Groups:	
	Astrophysics	M.S. Smith
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12:00-13:00	L U N C H	
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18:00	Hosted Buffet Dinner	

AGENDA

U.S. NUCLEAR REACTION DATA NETWORK

MARCH 13 & 14, 1996

Physics Department, Paul Meyer Hall
16th & Illinois St.
Colorado School of Mines

Chair: F. Edward Cecil

Thursday, March 14, 1996

8:00- 8:30	Astrophysics Task Force Report	M.S. Smith
8:30- 9:00	RIB Task Force Report	M.B. Chadwick
9:00- 9:30	Measurements Group Report	D.L. Smith
9:30-10:00	Coffee Break	
10:00-12:00	Plenary Session International Data Community & USNRDN How best to interact with the structure data network? How to make data activities relevant to research & vice versa Where do we go from here? Set priorities/projects Long Range Plan for the USNRDN? Approval of Recommendations	
12:00	Adjournment	

Summary of the U.S. Nuclear Reaction Data Network Meeting

M.R. Bhat, BNL

Golden, Colorado, March 13-14, 1996

Attendees: M.R. Bhat (BNL), A.D. Carlson (NIST), F.E. Cecil (Colorado School of Mines), M.B. Chadwick (LANL), J.M. Dairiki (LBNL), S.M. Grimes (Ohio Univ.), R.C. Haight (LANL), G.M. Hale (LANL), C. Kalbach (Duke Univ.), R. MacFarlane (LANL) T.N. Massey (Ohio Univ.), R.A. Meyer (USDOE), D.A. Resler (LLNL), D.L. Smith (ANL), M.S. Smith (ORNL), R.M. White (LLNL), P.G. Young (LANL)

The first meeting of the U.S. Nuclear Reaction Data Network (USNRDN) was held at the Colorado School of Mines, March 13-14, 1996 chaired by F. Edward Cecil. The Agenda of the meeting is attached.

The Network, its mission, products and services; related nuclear data and data networks, members, and organization are described in Attachment 1.

The following progress reports from the members of the USNRDN were distributed prior to the meeting and are given as Attachment 2.

1. Measurements and Development of Analytic Techniques for Basic Nuclear Physics and Nuclear Applications. Donald L. Smith (ANL)

2. Nuclear Reaction Data Activities at the National Nuclear Data Center. (BNL)

3. Studies of nuclear reactions at very low energies. F.E. Cecil (Colorado School of Mines)

4. Nuclear Reaction Data Activities, Nuclear Data Group. (LLNL)

5. Progress in Neutron Physics at Los Alamos -- Experiments. R.C. Haight, S.M. Sterbenz, and F.B. Bateman (Group P-23,LANL)

6. Nuclear Reaction Data Activities in Group T2, LANL

7. Progress Report for the U.S. Nuclear Reaction Data Network Meeting. A.D. Carlson, R.A. Schrack, and O.A. Wasson (NIST)

8. Nuclear Astrophysics Research Group (ORNL)

9. Progress Report from Ohio University. S.M. Grimes and T.N. Massey

10. Exciton Model Phenomenology. Constance Kalbach Walker (TUNL, Duke Univ.)

11. Progress Report for Coordination Meeting USNRDN. Gunter H.R. Kegel and James J. Egan (Univ. of Massachusetts Lowell)

In his talk, View from Washington, R.A. Meyer reviewed the funding for nuclear data activities as a whole and the experimental work in particular which had gone down to zero this year. However, there was support for a measurements program for astrophysics at the ORELA and none for those programs associated with power reactors. The products and services of the Network may be obtained through the National Nuclear Data Center (NNDC) which always has been and continues to be the designated focal point for U.S. nuclear data activities as well as being the contact point for international nuclear data exchange. It is particularly important, especially in these times of more and more stringent budgets, that initial plans, progress and final delivery schedules (for completion and delivery to the NNDC) be coordinated with the NNDC. This is especially relevant to the very active area of development of electronic information services. The products of the Network activities such as experimental data, evaluations, and codes should be sent to the NNDC for distribution to users. He urged all members of the Network to work with the NNDC to make the U.S. data program a success. Data networks such as the World Wide Web (WWW) are the most efficient and versatile tools for data dissemination and the Network should take full advantage of them. Expansion of the data program into new areas relevant to basic research is possible with the approval and support of the research community. Traditionally, the interests of the USNRDN have been mostly in reaction data, though it has used structure data for nuclear model and decay heat calculations and other applications. The USNDN which coordinates nuclear structure data activities, and the USNRDN can both benefit by working together and establishing a closer relationship. The U.S. nuclear data program could also profit from cooperative activities with the Nuclear Data Section of the IAEA and other data centers around the world, involving exchange of experimental and evaluated data, computer codes and systems of data distribution, and personnel.

The status report on the USNRDN was given by M.R. Bhat who reviewed the events that had happened since the August '95 coordination meeting at Del Mar (Attachment 3). The Ad Hoc Working Group formed at Del Mar evolved into the Network Executive Committee (NEC) based on the suggestions for the network coordination received from the members. The NEC recommended formation of the Astrophysics and Radioactive Ion Beam (RIB) Task Forces to work with the respective groups in research. Presentations on the compilation of high energy electron interaction data were made to the Bates Linear Accelerator Users Group and the Continuous Electron Beam Accelerator Facility (CEBAF) Users Group at the APS/DNP meeting in Bloomington, IN, October 25-28, 1995. Network members also attended the Symposium on Nuclear Astrophysics and the Workshop on Compilation and Evaluation of Nuclear Astrophysics Cross Section Data at California Institute of Technology, Dec. 14-16, 1995 and participated in the Workshop discussion in order to publicize the Network. A document describing the nuclear data resources available from the Network was also distributed to the attendees of the symposium and the workshop. Additional high energy heavy-ion data from the AGS are being coded and a Web Homepage describing the Network has also been assembled by T.W. Burrows. An assessment of the redirection of the activities of the USNRDN in support of basic research indicated that while the coordination mechanism of the Network was in place, it has yet to achieve substantive goals in its efforts. It was stressed that acceptance of these projects and their products by the research community is essential for the success of the Network program. To obtain such acceptance, these projects should do good physics, and build bridges to the research community using the good offices of the Network members who work closely with it and participate in joint research projects.

Michael S. Smith summarized the status of the Nuclear Astrophysics Task Force (Attachment 4). It was noted that the members of the Network were engaged in all aspects of data activities related to astrophysics such as data measurements, compilation, nuclear modeling and calculations, evaluations and dissemination. The Task Force had also prepared a Data Resources Reference Document for the Astrophysics Workshop at California Institute of Technology, and participated in it and the Astrophysics Steering Committee meeting there. Details of these activities and the contributions of the individual members of the Network may be found in Attachment 4.

The status of the Radioactive Ion Beam (RIB) Task Force was reviewed by Mark B. Chadwick (Attachment 5). There was a meeting of the Task Force at ORNL on January 9, 1996 at which a number of issues related to future support by the Task Force were discussed. Other highlights are the 58Ni(p,n) GNASH calculations done up to 100 MeV to estimate the production of 58Cu and their comparison with experimental data. Methods of extracting level density parameters from experimental data measured at the LANSCE facility are also described.

The data measurement activities of the members of the USNRDN were reviewed by Donald L. Smith (Attachment 6). These are of interest to nuclear astrophysics, study of nuclear level densities and reaction mechanisms, nuclear model development, and a number of applications. Details of these measurements, such as specific reactions, energy range and other details are given in Attachment 6.

After these presentations and the discussions following them, the attendees broke up into three discussion groups whose main interests were in: (i) astrophysics, (ii) RIB/Model codes, and (iii) measurements. The charge given to these groups was to come up with a plan of action for the immediate future which would involve: (i) good science, (ii) specific projects relevant to Astrophysics or RIB involving measurements, evaluations, and/or modeling and nuclear code calculations and which could be completed in about a year, and (iii) to assess how these projects fit into a program for the network as a whole.

The Astrophysics Task Force/Discussion Group report was presented by M.S. Smith on Thursday morning and a summary is given in Attachment 7. The recommendations of the Task Force on evaluation procedures, its future role in providing the leadership in astrophysics related data evaluations, and its interactions with the Astrophysics Data Evaluation Steering Committee are listed below as items 1-4. In the discussion following this report, D.A. Resler presented a "Proposed new formalism for using Maxwellian-averaged reaction rates in astrophysics applications" (Attachment 8) as an alternative to the analytical parametrization of reaction rates used in astrophysical calculations. D.L. Smith was also requested to provide "Some Guidelines for the Evaluation of Nuclear Data" (Attachment 9) as an introduction to the Bayesian method in data evaluation which has become part of modern data evaluation methodology.

Mark Chadwick presented the RIB Task Force/Discussion Group report (Attachment 10).

This report discusses the calculation of excitation functions for (p,xn) reactions, for various targets and the radioactivity induced on a 238U target under proton bombardment. Analyses of (n,p), (n,alpha) reactions data to determine level density parameters and recent developments in modeling preequilibrium emission spectra are discussed. Other developments are the extension of the ALICE code to higher energies and the extension of the T2 Nuclear Information Service at Los Alamos by the addition of a new RIB Web site. Eight specific recommendations on the above topics and related matters are listed below as items 5-12.

The Measurements Group Report (Attachment 11) reviewed the resources available and the type of experiments planned in the next 1-3 years by the Network members. It was noted that the planned experiments would impact on the astrophysics, RIB and the nuclear level density problems of interest to the Network. Details of the measurements program are given in Attachment 11.

In the Plenary Session of the meeting the following items were discussed:

a. International Data Community and the USNRDN:

The U.S. commitments to the international data community in evaluations and measurements were discussed. These are summarized by P.G. Young (Attachment 12) and by D.L. Smith (Attachment 13), respectively. It was noted that as part of the activities of the Working Party on International Evaluation Cooperation, there were several topics like nuclear model validation, intermediate energy nuclear data evaluation, resonance region and level density studies in 52Cr, 56Fe, and 58Ni which could be useful for nuclear astrophysics and radioactive ion beam problems. The USNRDN endorsed continuation of this participation in a recommendation (see item 13 below). As regards the measurements program, experiments that study nuclear level density properties, and cross section standards could contribute to the basic research programs currently of interest to the USNRDN.

b. How best to interact with the structure data network?

Areas of overlapping interest common to the reaction data network (the USNRDN) and the structure data network (the USNDN) were noted and there was general agreement that establishing a closer working relationship between the two networks would benefit both. Meetings at one site with a few common sessions were suggested and endorsed as one method of establishing such a closer interaction. A joint meeting of the two groups is planned for February or March 1997.

c. How to make data activities relevant to research and vice versa?

The Network has established contacts with the Nuclear Astrophysics Data Evaluation Steering Committee and will contact the North American Steering Committee for the Isospin Laboratory for the RIB related work. It is expected that a group from the high energy heavy-ion community will provide guidelines for the compilation of this type of data. These forums enable the research community to tell the USNRDN members what their data needs are and the Network can tell them what is being done to satisfy these needs. The possibility of forming a Program Advisory Committee (PAC) to the Network with representatives from the different areas of basic research was discussed. Eventually, it was agreed that a consideration of the PAC be postponed to the next Network meeting.

d. Where do we go from here? Set priorities/projects

The discussion in the Astrophysics and the RIB Task Forces and the Measurements Group and the projects and priorities set by them answer this question. The specific recommendations following the discussion in these groups as well as the Plenary Session are given below.

e. Long Range Plan for the USNRDN?

The USNRDN felt that a Long Range Plan for the Network should be deferred for a year and discussed at the next meeting.

Recommendations:

The following recommendations were approved:

1. Evaluation Procedures: A group of nuclear astrophysicists and nuclear data scientists should evaluate a few (2-3) nuclear reactions of astrophysical importance, and provide extremely detailed documentation of the evaluation procedures and problems. This documentation, along with a hands-on demonstration (the details of which will be determined at a later date), should assist prospective evaluators of these reactions in learning modern evaluation procedures by example.

2. Upon consultation with colleagues, the Astrophysics Task Force chairman, will determine the reactions to be evaluated.

3. The future roles of the Astrophysics Task Force include the following:

   a. Contribute to the nuclear data evaluations and expertise of the Nuclear Astrophysics Data Evaluation Steering Committee.

   b. Initiate, encourage, and publicize astrophysics data activities by USNRDN members.

   c. Recruit evaluators for nuclear astrophysics data evaluations.

d. Interface with the Steering Committee and with other nuclear data organizations.

4. The Astrophysics Task Force should help determine the data dissemination needs of the nuclear astrophysics community, and should encourage and publicize ongoing data dissemination efforts.

5. High priority tasks supporting the experimental efforts at Oak Ridge are the calculation of (p,xn) excitation functions, to guide the choice of suitable RIB candidates, and calculations of induced radioactivity when a uranium target is used.

6. A new theoretical effort in the calculation of fission-fragment distributions is needed to guide the experimental efforts in producing neutron-rich products far from stability. The Los Alamos T2 group is well-placed to initiate such an effort.

7. The HERA gamma-ray detector, recently moved to LANSCE at Los Alamos, provides a new measurement tool which will significantly advance our understanding of fission processes and nuclear structure. It is important to closely collaborate with experimentalists working with HERA, particularly J. Becker, R.C. Haight, and R. Nelson, to improve our understanding of nuclear structure and reactions relevant to RIBs.

8. The experimental level density studies undertaken at Los Alamos and Ohio University are very useful in nuclear reaction calculations of RIB production. Theoretical support for these analyses by Group T2 should continue.

9. The Los Alamos WWW T2 Nuclear Information Service should be used as an interim area for posting RIB calculation results. Ultimately, some of these results should be stored in ENDF format at the Brookhaven NNDC. An option should be included on the WWW site so that visitors can request calculations for high-priority reactions.

10. Further research into isospin-dependent optical models, and nuclear masses, far from stability is needed for improved RIB model calculations.

11. The RIB Task Force should contact the North American Steering Committee for the Isospin Laboratory, to inform them of our activities, and to solicit their input on research areas where we can contribute.

12. The RIB Task Force should contact researchers working on RIB physics at Argonne National Laboratory, to explore areas of common interest.

13. The USNRDN endorses continued participation by its members in the following activities of the Working Party on International Evaluation Cooperation because of their relevance to nuclear astrophysics and radioactive ion beam research. These activities are: (i) nuclear model code validation, (ii) intermediate energy nuclear data evaluation, (iii) resonance region and level density studies for 52Cr, 56Fe, and 58Ni.

14. The NNDC should continue the already established contacts with the Relativistic Heavy Ion Collider (RHIC) and the CEBAF communities on the compilation of their data.

15. The USNRDN supports the continued maintenance of the ENDF/B as an archival file of evaluated data of use in astrophysics and radioactive ion beam calculations.

The next meeting of the USNRDN will be held in February or March 1997 and will be a joint meeting with the USNDN which is responsible for the evaluation and dissemination of nuclear structure and decay data.

Attachment 1

Description of the U.S. Nuclear Reaction Data Network

M.R. Bhat, BNL

The U.S. Nuclear Reaction Data Network (USNRDN) is made up of groups funded by the Division of Nuclear Physics, Office of High Energy and Nuclear Physics, U.S. Department of Energy.

MISSION:

The mission of this Network is to provide nuclear data support to basic research in nuclear astrophysics, radioactive ion beams, high energy heavy-ion and electron interactions and high-spin physics. Such support covers all aspects of data stewardship such as: archiving and disseminating data, evaluations, development and maintenance of theory/modeling codes, measurements, and other user services.

PRODUCTS & SERVICES:

The products and services of the Network are divided into the following broad categories for user convenience. Further details may be found in the Web Homepages of the data centers cited below or by contacting individual members of the Network.

A. Nuclear Astrophysics Data:

Work in progress:

a. Nuclear Data Activities for Nuclear Astrophysics (Attachment 4)
b. Summary of the Astrophysics Task Force Meeting (Attachment 7)
c. Astrophysics Task Force in the USNRDN Homepage: *http://www.dne.bnl.gov/~burrows/usnrdn/astrotf.html*

Other relevant documents:

a. Proposed new formalism for using Maxwellian-averaged reaction rates in astrophysical applications (Attachment 8)
b. Some Guidelines for the Evaluation of Nuclear Data (Attachment 9)
c. Review of Experimental Activities for the U.S. Nuclear Reaction Data Network (Attachment 6)
d. Measurements Group Report (Attachment 11)

Bibliographic, experimental, and evaluated nuclear reaction and evaluated structure data;
access: National Nuclear Data Center (NNDC) (BNL)/Nuclear Astrophysics Data

Experimental, and evaluated nuclear reaction and structure data;
access: Group T-2 (LANL) *http://t2.lanl.gov/data/astro/astro.html*

Evaluated nuclear reaction and structure data;
access: Isotopes Project (IP) and the Institute for Nuclear and Particle Astrophysics (INPA) (LBNL) *http://csa5.lbl.gov/~fchu/astro.html*

B. Radioactive Ion Beam Data:

Work in progress:

a. Report of the Radioactive Ion Beam Task Force (Attachment 5)
b. Summary of the Radioactive Ion Beam Task Force Meeting (Attachment 10)
c. Radioactive Ion Beam Task Force in the USNRDN Homepage: *http://www.dne.bnl.gov/~burrows/usnrdn/ribtf.html*

Other relevant documents:

a. Some Guidelines for the Evaluation of Nuclear Data (Attachment 9)
b. Review of Experimental Activities for the U.S. Nuclear Reaction Data Network (Attachment 6)
c. Measurements Group Report (Attachment 11)

Bibliographic, experimental, and evaluated nuclear reaction and evaluated structure data:
access: National Nuclear Data Center (NNDC) (BNL)/Radioactive Ion Beam Data

Experimental, and evaluated nuclear reaction and structure data;
access: Group T-2 (LANL) *http://t2.lanl.gov/data/rib/rib.html*

C. Relativistic Heavy-Ion Data:

Data from relativistic heavy-ion interactions measured at the AGS at Brookhaven have been compiled into the databases at the NNDC and are available for online access. The Web Homepage lists compiled references, work in progress, how to access these data, and how to send similar data to the NNDC.
access: National Nuclear Data Center (NNDC) (BNL)/Relativistic Heavy-Ion Data

D. Other Nuclear Data:

Nuclear structure and decay data including high-spin data are evaluated by the U.S. Nuclear Data Network (USNDN) and the international Nuclear Structure and Decay Data (NSDD) Network organized under the auspices of the IAEA;
access: U.S. Nuclear Data Network: *http://www.dne.bnl.gov/~burrows/usndn/usndn.html*

OTHER NUCLEAR DATA NETWORKS:

Cross Section Evaluation Working Group (CSEWG):
A consortium of national laboratories, universities, and other organizations in the Unites States and Canada which evaluates nuclear reaction and related data for inclusion in the Evaluated Nuclear Data File (ENDF). Principal products: ENDF System made up of the ENDF/B database and related processing and applications codes. Latest release: ENDF/B VI.3.

International Nuclear Structure and Decay Data (NSDD) Network:
An international group of national laboratories, universities and other organizations coordinated under the auspices of the International Atomic Energy Agency (IAEA) for the evaluation of nuclear structure and decay data. Principal products: Evaluated Nuclear Structure Data File (ENSDF) and the Nuclear Science References (NSR).

Nuclear Data Centers:
An international group of national laboratories and universities organized under the auspices of the International Atomic Energy Agency (IAEA) for the compilation, exchange and dissemination of experimental nuclear reaction data. Principal products: Experimental nuclear reaction data file in the Exchange Format (EXFOR) and the Computer Index to Neutron Data (CINDA).

U.S. Nuclear Data Network:
The U.S. Nuclear Data Network (USNDN) is responsible for the compilation, evaluation, and dissemination of nuclear structure and decay data on behalf of the NSDD network. Principal products: Nuclear structure and decay data evaluations for the Evaluated Nuclear Structure Data File (ENSDF), literature coverage, coding and maintenance of the Nuclear Science References (NSR) database, publications of the new ENSDF evaluations as hard copy and on the Web, Table of Isotopes, Nuclear Wallet Cards, a CD-ROM entitled Nuclear Data & References (PCNUDAT & Papyrus NSR), VuENSDF, MacNuclide chart of nuclides, Table of Superdeformed Nuclear Bands and Fission Isomers, and physics and other processing codes. The Services include: NNDC Online Data Service, support services to the NSDD network, and information dissemination using CD-ROM and other magnetic media and hard copy.

MEETINGS:

Summary of the USNRDN meeting at Golden, Colorado, March 13-14, 1996 is part of this report.

Next Meeting:

The next meeting of the USNRDN is planned for February or March 1997. It will be a joint meeting with the USNDN.

MEMBERS:

- Low-energy Nuclear Physics and Nuclear Data Studies, Argonne National Laboratory
- National Nuclear Data Center (NNDC), Brookhaven National Laboratory
- Colorado School of Mines Applied Nuclear Physics Laboratory
- Nuclear Data Group, Lawrence Livermore National Laboratory
- Group P-23, Neutron Science & Applications, Los Alamos National Laboratory
- Group T-2, Nuclear Theory & Applications, Los Alamos National Laboratory
- Nuclear Data Verification and Standardization Project, National Institute of Standards and Technology
- Nuclear Astrophysics Research Group, Oak Ridge National Laboratory
- Institute of Nuclear and Particle Physics, Ohio University
- Program on Nuclear Reaction Phenomenology, Triangle Universities Nuclear Laboratory
- Radiation Laboratory of the University of Massachusetts, Lowell

NETWORK ORGANIZATION:

Network Executive Committee:

Dr. Mulki R. Bhat, Chair, Brookhaven National Laboratory
Prof. F. Edward Cecil, Colorado School of Mines
Dr. Mark B. Chadwick, Los Alamos National Laboratory
Dr. Janis M. Dairiki, E.O. Lawrence Berkeley National Laboratory
Dr. Michael S. Smith, Oak Ridge National Laboratory
Dr. Phillip G. Young, Los Alamos National Laboratory

Astrophysics Task Force:

Dr. Michael S. Smith, Chair, Oak Ridge National Laboratory
Prof. F. Edward Cecil, Colorado School of Mines
Dr. Richard B. Firestone, E.O. Lawrence Berkeley National Laboratory
Dr. Gerald M. Hale, Los Alamos National Laboratory
Ms. Victoria L. McLane, Brookhaven National Laboratory

Dr. David A. Resler, Lawrence Livermore National Laboratory
Dr. Robert G. Stokstad, E.O. Lawrence Berkeley National Laboratory

Radioactive Ion Beam Task Force:

Dr. Mark B. Chadwick, Chair, Los Alamos National Laboratory
Dr. Cary N. Davids, Argonne National Laboratory
Dr. Tony A. Gabriel, Oak Ridge National Laboratory
Dr. Jerry D. Garrett, Oak Ridge National Laboratory
Prof. Steven M. Grimes, Ohio University
Dr. Constance Kalbach Walker, Duke University
Dr. Phillip G. Young, Los Alamos National Laboratory

WWW Homepage Task Force:

Dr. Mulki R. Bhat, Chair, Brookhaven National Laboratory
Dr. Thomas W. Burrows, Brookhaven National Laboratory
Dr. Robert MacFarlane, Los Alamos National Laboratory
Dr. David A. Resler, Lawrence Livermore National Laboratory

Attachment 2

Progress Reports

from

U.S. Nuclear Reaction Data Network Members

Measurements and Development of Analytic Techniques for Basic Nuclear Physics and Nuclear Applications

Donald L. Smith
Technology Development Division
Argonne National Laboratory
Argonne, Illinois 60439

During this reporting period work was completed on a long-term project (since 1988) involving collaboration with the Japan Atomic Energy Research Institute (JAERI) and Los Alamos National Laboratory to measure cross sections relevant to fusion radioactive waste disposal. This project was part of a Coordinated Research Program (CRP) organized by the International Atomic Energy Agency (IAEA). A final report on this work was submitted to the IAEA during a coordination meeting which took place in St. Petersburg, Russia, during June 1995. A journal paper was then prepared and it has been accepted for publication. This work includes neutron cross-section measurements at 10 MeV, 14 MeV and in a continuum neutron spectrum from the ^{9}Be(d,n) reaction. In the course of this work data were acquired for the following reactions: ^{109}Ag(n,2n)^{108m}Ag, ^{151}Eu(n,2n)^{150g}Eu, ^{159}Tb(n,2n)$^{158g+m}$Tb, ^{179}Hf(n,2n)^{178m2}Hf, ^{107}Ag(n,2n)^{106m}Ag, ^{176}Hf(n,2n)^{175}Hf, ^{180}Hf(n,2n)^{179m2}Hf, ^{46}Ti(n,p)$^{46g+m}$Sc, ^{54}Fe(n,p)^{54}Mn, ^{54}Fe(n,α)^{51}Cr, ^{60}Ni(n,p)$^{60g+m}$Co, ^{63}Cu(n,α)$^{60g+m}$Co and ^{238}U(n,f). The ^{58}Ni(n,p)$^{58g+m}$Co and ^{93}Nb(n,2n)^{92m}Nb reactions served as measurement standards.

Data on photofission of ^{238}U by 6+-MeV gamma rays from ^{16}N decay in radioactive water were acquired during a visit to JAERI in November 1994. Preliminary analysis has been completed and the observation of fission events has been confirmed. Further analysis is needed to rule out the possibility that delayed neutrons from ^{16}N might have been entirely responsible for these events.

A journal paper on the use of ^{16}N gamma rays from radioactive water for radiography has been completed and accepted for publication. The U.S. Department of Energy and Japanese government are presently applying for patents to cover potential applications of this process.

Neutron activation cross-section measurements were carried out for the ^{51}V(n,p)^{51}Ti, ^{51}V(n,α)^{48}Sc, ^{52}Cr(n,p)^{52}V and ^{52}Cr(n,2n)^{51}Cr reactions from 5-10 MeV during a visit to Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, during September-October 1995. Analysis of these data is in progress. Visits were also paid to the Forschungszentrum Juelich (KfA), Juelich, Germany, and the Institute for Reference Materials and Measurements (IRMM), Geel, Belgium, during this period. Plans are being developed for measurements at IRMM late in 1996.

A role for neutron activation cross-section processes in nuclear astrophysical applications is being explored. Some 22 high-threshold (n,p) and (n,α) reactions are considered of potential interest because of the related inverse processes, namely, (p,n) and (α,n). Measurements on the neutron-induced reactions near threshold may be beneficial, especially when augmented by results from nuclear model calculations. A "Midwest Chapter" collaboration on nuclear data for astrophysics is being organized to include the University of Chicago, Notre Dame University and Argonne National Laboratory. Various possibilities for cooperative activity to benefit this field are being considered. Among these is the recruitment of students to work on related special projects.

Nuclear Reaction Data Activities at the National Nuclear Data Center

(July 1995-February 1996)

Bibliographic Data Files:

The scanning of nuclear physics literature for the Nuclear Science References (NSR) continues. Coverage for important primary journals, such as Physical Review C, and Nuclear Physics A, is now complete and all articles appearing in these journals are being assigned key numbers. The yearly updates to the NSR were published as Recent References in December 1995.

Reaction Data Library:

Compilation of light charged particle reaction cross sections has been resumed. Approximately 30 data sets are currently being processed. Simplified user manuals are being prepared for both the EXFOR and ENDF formats and will be available online this spring.

Three new data sets of relativistic heavy ion data measured at the AGS, have been coded and are being checked out. A draft World Wide Web (WWW) Homepage describing such data compilation, the data sets that have been compiled, or are being compiled, how to access them, and how data measures can send us their data has been assembled.

User Outreach:

At the Division of Nuclear Physics meeting of the American Physical Society in Bloomington, IN, Oct. 25-28, 1995, presentations were made to the BATES and CEBAF users' groups pointing out the need for archiving and saving the high energy electron interaction data measured at these facilities. It was pointed out that the infrastructure of data file formats, checking and plotting codes and an online system for data dissemination developed and tested for low energy data were in place and could be readily adopted for use with electron data and that the NNDC would be happy to work with them in coding these data. The BATES project has plans to code and archive their data; it is not clear what the CEBAF facility plans on doing.

An article ``Nuclear Data Resources" by M.R. Bhat and J.M. Dairiki describing the resources on nuclear structure and reaction data available for users was distributed to the attendees of the Symposium on Nuclear Astrophysics held at the California Institute of Technology and the Workshop on Compilation and Evaluation of Nuclear Astrophysics Data. NNDC personnel participated in this Workshop and two hundred copies of the 1995 Nuclear Wallet Cards with the extended centerfold: Electronic Nuclear Data Access were distributed to publicize this service and the databases available through it.

A draft WWW Homepage for the U.S. Nuclear Reaction Data Network (USNRDN) has been assembled with contributions from the ten member data centers of this network. This is meant to inform new users the data activities and resources available from the USNRDN and how to access them. It also describes the Executive Committee, the Astrophysics and Radioactive Ion Beam (RIB) Task Forces of the network, their membership and a brief summary of their activities, and work in progress.

A presentation on the nuclear data services of the NNDC was made at the Del Mar '95 Workshop on Nuclear Data for Fusion Applications; a paper on these will also be published in Fusion Engineering and Design.

Studies of nuclear reactions at very low energies
U.S. Department of Energy Contract #DE-FG03-93ER40789
F.E. Cecil, Department of Physics, Coloradò School of Mines
Golden, Colorado 80401

This report summarizes the status of the major projects of our research program in pure and applied nuclear physics as of February 1996.

A study of the $d(\alpha,\gamma)^6Li$ reaction at low energies at its application to the primordial nucleosynthesis of ^6Li. F.E. Cecil, J. Yan and C.S. Galovich. This concludes a multiyear effort at observing this reaction. Although the capture gamma ray was not observed, we were able to place a stringent limit on the low energy S-factor for this reaction; ($S < 2x10^{-7}$ MeV-b at a 90% confidence level). Consequently we are able to place a limit of 0.9% of the present galactic abundance of ^{6}Li as being primordial in origin. Equivalently, we are able to conclude that the $^6Li/^7Li$ isotopic abundance ratio emerging from a standard big-bang can be no greater than 0.85 %; considerably less than the present abundance ratio of 7.2%. In both cases, we find support for the hypothesis that most of the present universal abundance of ^{6}Li is the result of cosmic ray interaction. This work has been accepted for publication in Phys. Rev. C.

Deuteron induced reactions on ^{9}Be, ^{10}B and ^{11}B. J. Yan, F.E. Cecil, J.A. McNeil, M.A. Hofstee and P.D. Kunz. This work represents the completion of one of the major recent goals of the program. In this work, we have measured angular distributions, total cross sections and astrophysical S-factors for all the positive Q-value deuteron induced reactions on these three nuclei at deuteron bombarding energies between about 60 and 160 keV. This represents transitions to sixteen levels in the product nuclei. We observed a remarkable degree of anisotropy in many of the angular distributions. We were unable to expain these angular distributions in terms of ordinary the DWBA. However, by including a *positive* term in the volume potentials used in the DWBA calculation, as an *ad hoc* method for simulating the S-wave suppression expected from the Pàuli exclusion principle, the calculated angular distributions were brought into *excellent* agreement with measured distributions. These results have been submitted to Phys. Rev. C.

The reaction $^7Li(^3He,p)^9Be$ at low energies. J. Yan, F.E. Cecil, R.J. Peterson and R.A. Ristenin. We have completed our measurement of this reaction. A manuscript for publication is in progress. The cross section, astrophysical S-factor and the corresponding reactivity for this reaction at ^{3}He bombarding energies of 160 and 170 keV has been determined. These results are being used to understand late-time primordial production of ^{9}Be as well as the production of ^{9}Be in hot stellar nucleosynthesis.

The reaction $^7Li(d,\alpha)^5He$. J. Yan, F.E. Cecil, J.A. McNeil and G.M. Hale. We have measured the angular distribution, total cross section and astrophysical S-factor for this reaction between c.m. energies of 118 and 38 keV. By comparison to other transfer reactions at low energies, the cross section for this reaction is quite large and hence one application of this reaction is the primordial destruction of ^{7}Li. The deduced reactivity for this reaction has been compared to an earlier estimate by the Ohio group[R.N. Boyd et al, Phys. Rev. **C47**, 2369 (1993)]. The incorporation of our results into this calculation nearly triples the destruction rate in comparison to the earlier work.

Detector development. F.E. Cecil, M. Loughlin, O.N. Jarvis, G. Sadler and P. v. Belle. We are developing a high flux, charged particle spectrometer based upon the concept of a series of thin Faraday collector foils. This work is supported primarily by the DOE Office of Fusion Energy since its initial application is intended as a charged particle flux monitor at the first walls of tokamak plasma devices. However, we expect that such a device may also find applicability to a broad spectrum of accelerator diagnostic efforts. A prototype was installed on the first wall of the JET tokamak for the 1995 run period and performed nominally during a series of fairly high yield d-d plasmas. The expected insensitivities to the neutron, gamma ray, heat and x-ray flux was observed. A complete set of these detectors is being fabricated for installation summer 1996 in preparation for the upcoming d-t program on JET.

Nuclear Reaction Data Activities
Nuclear Data Group
Lawrence Livermore National Laboratory
(July 1995 — February 1996)

High-Energy Evaluated Data Files

Evaluations of hydrogen, carbon, nitrogen, oxygen, fluorine, phosphorus and calcium have been completed for incident neutrons with energies up to 100 MeV. Because of the large number of reaction channels that open with increasing energies, the data have been generated in particle production format. These evaluations include cross sections and energy-angle correlated distributions for the secondary production of neutrons, protons, deuterons, tritons, helium-3s, alphas and gamma rays and the average kinetic energy released in the recoil fragments—an important factor in determining total energy deposition. The total kerma (kinetic energy released in matter) has been calculated from the evaluated files for each of these elements as a function of energy and compared with integral experimental measurements as one check on the quality of the evaluations. We have upgraded our capability to process the high-energy data files and have carried out the first all-particle Monte Carlo transport calculations to 100 MeV based upon evaluated and processed data files.

Experimental Electronic Information Development

For increased efficiency in data base use and intercomparison, we have established a World Wide Web server to facilitate portability in the platforms users can employ when accessing nuclear data and to allow flexibility in how large data bases can be accessed through simple point-and-click interfaces. The developmental system employed on our WWW server provides access to tabular and graphical representations of evaluated data. Currently, we have available LLNL's ENDL (evaluated neutron data library), ECPL (evaluated charged particle library), ACTL (neutron activation library), EGDL (evaluated gamma-ray interaction data library), EADL (evaluated atomic data library), EEDL (evaluated electron data library), EPDL (evaluated photon-interaction data library), and PCSL (production/high energy cross section library).

In addition, we have translated ENDF/B-V and -VI, JENDL-3, and JEF-2 into a simplified format for ease of comparing evaluations in different libraries. Other information frequently required by users of nuclear data, including elemental and isotopic properties such as abundances, masses (both atomic and nuclear), half-lives, binding energies, Q-values, reaction thresholds and separation energies, are included. We are currently evaluating several approaches for including experimental neutron and charged-particle data and corresponding bibliographic information into this system. We anticipate availability for trial use by the U.S. Nuclear Reaction Data Network within the year.

Progress in Neutron Physics at Los Alamos -- Experiments

July 1995 - February 1996

R. C. Haight, S. M. Sterbenz, and F. B. Bateman
Group P-23, Los Alamos National Laboratory

This report is of research carried out by Los Alamos in collaboration with researchers from Ohio University, the National Institute of Standards and Technology, the University of Vienna, the Technical University of Munich, the Institute of Geophysics and Nuclear Sciences (New Zealand), the Institute of Physics and Power Engineering at Obninsk, Beijing Normal University and the University of Saskatchewan.

WNR Experimental Status: The Los Alamos Neutron Science Center (LANSCE) continues to provide an excellent source of fast neutrons from spallation reactions at the Weapons Neutron Research Facility. In this period, data were obtained for (n,xp), (n,xd) and (n,xalpha) reactions on Si, SiO2, 51V, 89Y, 93Nb, and 181Ta from threshold to over 50 MeV. Because backgrounds have been decreased significantly by experimental improvements, measurements on targets approaching mass=200 are now possible.

(n,z) Studies: Previous data on 59Co(n,xalpha) have been analyzed and submitted for publication. The results show (1) good agreement with previous data up to 14 MeV, (2) an extension of the data base up to 50 MeV, (3) predominance of the compound nuclear reaction mechanism even at the highest energies, and (4) agreement with model calculations when suitable input parameters are used. Analysis of the 59Co(n,xalpha) data pointed out the importance of knowing the neutron non-elastic cross sections especially above 30 MeV. We made preliminary runs to assess the feasibility of measuring non-elastic cross sections over this range. If the approach is successful, we will be able to measure non-elastic cross sections up to above 100 MeV in a range where few data are presently available. New data on 58,60Ni(n,xalpha) have been obtained from threshold to 50 MeV. These data are being analyzed to obtain nuclear level densities using the approach of Vonach [Phys. Rev. **C30**, 72 (1984)]. The data should make possible the extraction of level densities for excited states in the target nuclei over a range of excitation energies, as opposed to that at the single energy obtained from monoenergetic data.

Gamma-ray production: Nuclear level densities at high excitation (up to 100 MeV) had been tested previously through the 208Pb(n,xn gamma) reactions, where gamma-rays in the residual nuclei were measured with good resolution. We are extending this study with preliminary measurements at the University of Saskatchewan to 208Pb(gamma, xn gamma) reactions with tagged photons. With photons incident, lower angular momentum states are favored, and we hope to obtain information on level densities as a function of angular momentum. A preliminary run has shown that many of the expected transitions can be observed with this technique.

Astrophysics: One of the applications of the nuclear level density research is to calculations for astrophysics. A direct measurement is also underway: the 17O(n,alpha) reaction for En = 10 keV to 1 MeV, a reaction that determines whether the nucleosynthesis of heavier nuclei is possible or whether the mass flow cycles back to 14C. We fabricated 17O targets and the first measurements have been performed at Obninsk.

N-P interaction: The neutron-proton elastic scattering angular distribution was measured at En=10 MeV at Ohio University to shed light on discrepancies between predictions of boson-exchange potentials and the ENDF/B-VI evaluation at the level of 3%. We found better agreement with the former, but more measurements are needed to clarify the situation especially in light of a recent report from Tuebingen.

The HERA gamma-ray detector array is moving to Los Alamos for use with the LANSCE neutron sources. We anticipate beam time with this detector next fiscal year and plan measurements to complement the earlier 208Pb(n,xn gamma) studies with targets not near closed shells. Nuclear level densities at high excitation can be studied with these reactions.

Nuclear Reaction Data Activities in Group T2, LANL
(July 1995 - February 1996)

Radioactive Ion Beam (RIB) Task Force:

The RIB Task Force first met at Oak Ridge on January 9, 1996. Current members include M.B. Chadwick (chair), J.D. Garrett, T. Gabriel, S. Grimes, C. Kalbach, P.G. Young. The Task Force is exploring ways in which nuclear theory and modeling can support RIB projects. Two areas we have highlighted are: (1) model predictions of the yields of radionuclides far from stability in (p,xn), (p, fission) and (n, fission) reactions, to optimize experimental conditions for the production of RIBS; (2) Model calculations of radioactivity produced within the target/shielding experimental configuration. Various aspects of the Task Force research supporting RIBS is described on a WWW page.

The following work has been completed in Group T2 in support of RIBS: (1) Benchmarking of the GNASH code for predicting yields in proton reactions; (2) Model calculations for 58Ni(p,xn) for producing proton-rich products (calculations for 64Zn and 70Ge targets are underway); (3) We have initiated calculations of induced radioactivity in reactions on 238U targets, as well as the yield distributions of fission fragments for producing neutron-rich nuclei.

Nuclear Astrophysics:

Some of the light-element reactions we have studied previously for other reasons are also of interest in primordial and stellar nucleosynthesis. We have put this information in a form useful to astrophysicists (S-factors and reaction rates) on the WWW for reactions in light systems ranging from A = 4 - 12. In addition, we are performing new R-matrix analyses to obtain improved cross-section extrapolations for reactions of astrophysical significance, including the crucial process 12C (alpha,gamma) 16O, and 13C (alpha,n) 16O.

One of us (G. Hale) serves on an astrophysics data "steering" committee, chaired by Peter Parker, that had its organizational meeting in early February at Caltech. The committee expects to get input from the astrophysical community at large during the "Cosmos IV" international conference at Notre Dame this summer about how best to continue and expand the compilation and evaluation work on astrophysical data pioneered by Willy Fowler's group at Caltech.

Nuclear Theory in Support of LANSCE Experiments:

Model calculations of Ni(n,xa) and Co(n,xa) reactions have been performed to analyze new data measured by R.C. Haight, to extract nuclear level densities as a function of excitation energy. The calculational procedure employed largely removes the impact of any uncertainties in the optical potentials, and allows level densities to be extracted up to relatively high excitation energies.

Model calculations of (n,x gamma) reactions on 238U and 239Pu have been performed to support new LANSCE measurements by John Becker (LLNL) and Ron Nelson (LANL). These calculations enable total cross sections for various decay channels to be determined from measured partial cross sections, providing a new technique for studying fission, and competing, processes.

Data Dissemination:

The T-2 Nuclear Information Service has been upgraded by adding a pilot area for nuclear astrophysics containing plots and data for charged-particle reactions and links to nuclear masses and other nuclear properties for astrophysical calculations. The Nuclear Data Viewer has also been enhanced with more data, enhanced help information, and improved error recovery. Additional publications have been made available on-line.

Publications:

In the last few months the group has published journal papers on topics including scattering theory, quantum molecular dynamics, analysis of LANSCE experimental data, photonuclear reactions, microscopic-macroscopic mass models, activation and transmutation calculations, heavy-ion reactions, and high-energy evaluations for biological elements. Many of these papers can be viewed on the WWW T-2 Nuclear Information Service.

Progress Report for the U.S. Nuclear Reaction Data Network Meeting
July 1995 to February 1996
National Institute of Standards and Technology, Gaithersburg, MD 20899
(A. D. Carlson, R. A. Schrack, and O. A. Wasson)

I. International Coordination of Measurements and Evaluation (Carlson)

The collaboration to improve the $^{10}B(n,\alpha)$ standard cross sections has produced a series of important measurements. These include the $^{10}B(n,\alpha_1\gamma)$ and ^{10}B total neutron cross section measurements at the ORNL-ORELA and WNR-LANL facilities in the U.S. and at the GELINA and Van de Graaff facilities at the IRMM in Belgium. Measurements are also planned at the IRMM using gridded ionization chambers to obtain angular distributions and branching ratio data. These measurements will significantly improve the data base for use in an improved R-matrix analysis of the ^{11}B system. Efforts are now underway to obtain the most recent measurements and their uncertainties for an R-matrix analysis by G. Hale at LANL. This analysis will produce a new evaluation which should extend the energy range over which this cross section can be used as a standard so that a smooth and easy transition to higher energy standards such as H(n,n) can be obtained.

II. The H(n,p) Angular Distribution at 10 MeV Neutron Energy

(Haight[1], Bateman[1], Brient[2], Carlson, Grimes[2], Massey[2], Wasson, and Zhou[3])

Measurements of this important standard were initiated in order to resolve the approximately 3% differences between recent evaluations of this cross section in the 10 MeV energy region. The experiment was performed at the Ohio University Tandem Accelerator facility. Measurements were made of the angular distribution from 60 to 180 degrees in the center of mass by detecting recoil protons. The analysis of this data indicates that the shape of the angular distribution is somewhat more consistent with the SM95 analysis of Arndt than with the ENDF/B-VI evaluation. A paper on this work was presented at the Del Mar '95 Workshop on Nuclear Data for Fusion Applications. Further analysis is underway and new measurements are under consideration.

III. Measurements of the $^{10}B(n,\alpha_1\gamma)$ Standard Cross Section Above 0.2 MeV Neutron Energy

(Schrack, Carlson, Wasson, Staples[1] and Haight[1])

The purpose of this relative measurement is to extend the usefulness of the $^{10}B(n,\alpha_1\gamma)$ standard cross section to higher neutron energies. Final measurements were obtained last fall at the WNR facility at the LAMPF accelerator at Los Alamos National Laboratory. The neutron fluence was measured using the $^{235}U(n,f)$ standard while the 478 keV photons from the $^{10}B(n,\alpha_1\gamma)$ reaction were detected in an intrinsic Ge detector. Significant improvements were made to these final experimental data runs to minimize overlap effects, allow data to be obtained to lower energies, and evaluate/minimize backgrounds. The relative cross section was obtained from 0.2 to above 12 MeV. The data is presently under analysis. Preliminary results are in good agreement with our earlier measurement [Nucl. Sci. Eng., 114, 352-362 (1993)] in the 0.2 to 4 MeV neutron energy region carried out at ORNL and thus verifies the deviation from the ENDF/B-VI values for energies greater than 2 MeV.

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2. Ohio University, Athens, OH 45701
3. Bejing Normal University, Bejing, China

Nuclear Astrophysics Research Group
Physics Division, Oak Ridge National Laboratory

USNRDN Progress Report
July 1995 - February 1996

The Nuclear Astrophysics Research Program at Oak Ridge National Laboratory includes efforts in Experimental Measurements, Nuclear Data Evaluation, and Theoretical Nuclear Astrophysics. Some of the recent progress relevant to USNRDN Mission are listed below.

1. Progress in Nuclear Data Evaluation

1.A. Systematic Calculations of Stellar Neutron Capture Reaction Rates from Evaluated Nuclear Data Files (N.M. Larson, D.C. Larson, M.S. Smith, R.Q. Wright, A.R. Braeutigam, R.R. Winters). Recently completed: extraction of ENDF resonance parameters for approximately 150 neutron capture reactions, reconstruction of cross sections, and calculation of stellar reaction rates. Functional forms for fitting these rates as a function of stellar temperature are currently being investigated. A presentation of this work was made by N.M. Larson at the APS Division of Nuclear Physics Meeting, Bloomington, IN, Oct. 28, 1995.

1.B. Producing the document "U.S. Nuclear Data Resources for a Coordinated U.S. Effort in Nuclear Data for Nuclear Astrophysics" (M.S. Smith, F. E. Cecil, R.B. Firestone, G.M. Hale, D.C. Larson, D.A. Resler). This document, which details data community resources appropriate for nuclear astrophysics research, was produced by the USNRDN Astrophysics Task Force and distributed to participants in the Symposium on Nuclear Astrophysics - A Celebration of Willy Fowler, Caltech, Dec. 13 - 15, 1995, and to participants in the Workshop on Evaluation and Compilation of Nuclear Astrophysics Data, Caltech, Dec. 16, 1995. The document is available online at http://www.dne.bnl.gov/~burrows/usnrdn/usnrdn.html, the USNRDN website. A companion document, "Projects for a Nuclear Data Effort in Nuclear Astrophysics" (M.S. Smith), lists some important evaluation and dissemination projects relevant for nuclear astrophysics research. This document was distributed at the Symposium and the Workshop mentioned above, and is available from the author (msmith@orph01.phy.ornl.gov). A more detailed paper, "Nuclear Data Needs for Nuclear Astrophysics" (M.S. Smith), is in preparation.

1.C. Presentations on Nuclear Astrophysics Data Needs and Nuclear Data Community Resources for Nuclear Astrophysics have been made by M.S. Smith at: the Coordination Meeting for U.S. DOE Supported Nuclear Reaction Data Projects, Del Mar, Aug. 7, 1995; the Cross Section Evaluation Working Group (CSEWG) Meeting, Brookhaven, Oct. 17, 1995; the Del Mar '95 Workshop on Nuclear Data for Fusion Applications, Dec. 4, 1995; the Workshop on Evaluation and Compilation of Nuclear Astrophysics Data, Caltech, Dec. 16, 1995; and Clemson University, Feb. 23, 1996.

1.D. Participating in the Nuclear Astrophysics Data Evaluation Steering Committee, formed in Dec. 1995 at the Workshop on Evaluation and Compilation of Nuclear Astrophysics Data at Caltech. A Steering Committee meeting was held on Feb. 3, 1996 at Caltech. A summary of this meeting is available from the Chair of the Steering Committee, Peter Parker (Yale University – peter@riviera.physics.yale.edu). Upcoming activities will include surveying the community to prioritize nuclear astrophysics evaluation projects.

2. Progress in Experimental Measurements

Neutron-induced reactions important in a variety of astrophysical problems are being studied at the Oak Ridge Electron Linear Accelerator (ORELA). Recent cross section measurements that have been completed include:

2.A. $^{7}Li(n,\gamma)^{8}Li$ reaction, important for the solar neutrino problem and for inhomogeneous big bang nucleosynthesis. A paper on this work has been submitted to Phys. Rev. C, and a presentation was made by J.C. Blackmon at the APS Division of Nuclear Physics Meeting, Bloomington, IN, Oct. 27, 1995.

2.B. $^{134}Ba(n,\gamma)^{135}Ba$ and $^{136}Ba(n,\gamma)^{137}Ba$, important for heavy element nucleosynthesis through the s-process. A paper on this work is in preparation, and presentations were made by P.E. Koehler and R.R. Spencer at the APS Division of Nuclear Physics Meeting, Bloomington, IN, Oct. 27, 1995.

2.C. $^{142}Nd(n,\gamma)^{143}Ba$ and $^{144}Nd(n,\gamma)^{145}Nd$, important for heavy element nucleosynthesis through the s-process. A paper on this work is in preparation, and presentations were made by K.H. Guber and R.R. Winters at the APS Division of Nuclear Physics Meeting, Bloomington, IN, Oct. 27, 1995.

Research sponsored by the Oak Ridge National Laboratory, managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under contract number DE-AC05-96OR22464.

PROGRESS REPORT FROM OHIO UNIVERSITY

S.M. Grimes and T.N. Massey

July-December 1995

The production of neutrons from stopping targets of beryllium by both protons and deuterons is of interest for applied and medical physics. This work has been a collaboration with Argonne and MIT. To investigate the production of neutrons from a stopping beryllium target, we have made measurements with both NE213 and lithium glass detectors. The Al(d,n) reaction at 120° and 7.44 MeV incident energy was used to obtain the detector efficiency from 0.2 to 15.0 MeV.

The neutron production from proton bombardment of beryllium is being considered as a source reaction for the boron neutron therapy treatment of cancer. Thus, the low energy portion of the spectrum is extremely important. We have completed measurements at incident energies of 2.0-4.0 MeV. Of special interest in our preliminary results is the relative importance of the neutrons produced from inelastic scattering to the first and second excited states of ^{9}Be.

We have completed precision measurements of the angular and energy dependence of neutrons from the ^{9}Be(d,n) reaction at incident deuteron energies of 2.6, 3.0, 3.4, 3.8, 4.2, 4.6, 5.0, 5.4, 5.8, 6.2, 6.6 and 7.0 MeV using NE213 detectors. We have reduced the statistical accuracy of the measurement to under 1% for measurements using NE213 detectors. A measurement of the low energy neutrons has been completed from 3.0 and 7.0 MeV incident deuteron energy using a Li glass detector array.

An investigation into the deuteron optical model near the Coulomb barrier in ^{56}Fe and ^{27}Al is in progress. We have completed initial measurements of the neutron, proton, deuteron and alpha channels at energies from 2.5 to 7.0 MeV. This set of data includes all of the open channels available in the bottom part of this energy range. The result of these studies will help improve our knowledge of transmission coefficients near the Coulomb barrier for Hauser-Feshbach calculations.

We have measured the spectral distribution of neutrons from the reaction ^{27}Al(d,n) on a pure stopping aluminum target. At 7.44 MeV incident deuteron energy, measurements were made at 90, 110 and 120 degrees using NE213 detectors. Further measurements were made at 120 degrees using a ^{235}U fission chamber provided by Argonne National Laboratory. The absolute neutron fluence was determined at each energy bin to better than 5%. Additional experiments are planned to improve the absolute normalization of the spectra and improve the statistics for energies below 200 keV and above 10 MeV.

We have developed a technique of calculation of the widths of various reaction channels using wave functions obtained from shell model diagonalization. These widths are then used to predict the cross section of reactions which cannot be directly measured. We have extensively studied the ^{10}Be and ^{14}C compound nuclei and are beginning studies of ^{11}B and ^{12}B. These will be studied with (p,n) and (d,n) reactions on a ^{10}Be target.

EXCITON MODEL PHENOMENOLOGY
Progress from July 1995 through February 1996

Constance Kalbach Walker
T.U.N.L., Duke University

The long-range goal of the nuclear reaction modeling program at T.U.N.L. is to develop the exciton model code PRECO-E with an associated set of global input parameters so that calculations can be performed for unmeasured or unmeasureable reactions on a wide range of target masses and incident energies. This code package is suitable for inclusion in Hauser-Feshbach model codes. Current work is focussed on the energy spectra from *(N,N)* reactions and is aimed at testing and refining a preliminary global set of model input. Accomplishments during the past nine months include:

- Preliminary investigations of data at 80, 90 and 160 MeV indicate that surface effects (which are important at 40 to 90 MeV) may wash out or disappear by 160 MeV and that the mean square matrix elements for the effective residual two-body interactions may be higher at 160 MeV than the extrapolated trend from lower incident energies.
- Use of the revised $M^2 = f(E)$ rather than $M^2 = f(E/n)$ was confirmed with calculations for the 55 previously studied spectra with $A = 90 - 120$ at 18 to 25 MeV.
- The preliminary set of global input was tested on the remaining available data at 18 to 25 MeV consisting of 44 energy spectra with $A = 27 - 65$ and $A = 159 - 209$.
- The model and input were tested on a full set of 39 energy spectra (mainly from neutron induced reactions) for targets of $A = 27 - 209$ at 14 to 15 MeV. Preliminary conclusions (other than the general success of the calculations) are:
  - $M^2_{nn} = M^2_{np}$. (Previously, $M^2_{np}/M^2_{pp} = 0.6$ was determined from proton induced reaction data, and it had been assumed that M^2_{nn} would equal M^2_{pp}.)
  - The (n,p) evaporation components for some of the weak channels are overestimated by a factor of two or more relative to the data. This does not appear to be related to pairing or shell effects.
- The (n,n') spectra at 14 MeV do not show any significant deficit (beyond what would be expected for collective excitations) in the calculated cross section at high emission energies such as was seen for the 20 to 26 MeV data, particularly for higher mass targets. The 18 MeV data show only a small deficit.

Progress Report for Coordination Meeting USNRDN
Golden, CO, March 13-14, 1996

Gunter H. R. Kegel and James J. Egan
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During the reporting period we have been involved in an investigation of neutron scattering in ^{197}Au and ^{235}U, the initiation of neutron scattering studies on ^{169}Tm, and in fission neutron energy spectroscopy. The results of two previous studies were published during this period.

Neutron Scattering Studies

The ^{197}Au work includes the measurement of neutron scattering angular distributions for the ground state, the 77-keV level, and the 269+279-keV level combination at incident energies of 1.0, 1.5 and 2.0 MeV. Angular distributions of ^{235}U were measured for the ground+77-eV+13-keV combination as well as the 48-keV+52-keV combination at incident neutron energies of 500 and 700 keV. Our earlier angular distribution measurements on ^{239}Pu are scheduled for publication in *Nuclear Science and Engineering* in March 1996.

The ^{169}Tm studies are being undertaken because ^{169}Tm is a highly deformed odd-A nucleus with a level scheme amenable to investigation by the neutron time-of-flight technique. There is a dearth of scattering data on this nuclide and it is anticipated that elastic and inelastic measurements on such a nucleus will help to elucidate the competition between direct interaction and compound nucleus processes which could then be extended to cases where measurements are unfeasible.

Fission Neutron Spectrum Studies

We have been involved for some time in measurements of the shape of fission neutron spectra for fission events induced by fast neutrons. A motivation for this work was to test the theoretical predictions of the "Los Alamos Model" developed by Madland and Nix. The initial studies, concentrating on the portion of the fission neutron spectra above the energy of the incident neutrons for ^{235}U and ^{239}Pu comparing our results to the theory and examining the dependence of the shape of the spectra on incident neutron energy and mass of the fissioning nucleus, were published in *Nuclear Physics A* last summer. We are now extending this work to the portion of the fission neutron energy spectrum below the incident neutron energy. This task involves the use of three fast BaF_2 scintillators to detect fission gamma rays in coincidence to signal the occurrence of fission events and to distinguish them from neutron scattering events. Preliminary measurements indicate a factor of 10 reduction in background due to elastic and inelastic neutrons and an almost complete elimination of gamma-ray background.

U.S. Nuclear Reaction Data Network (USNRDN) Status Report

Mulki R. Bhat, BNL

U.S. Nuclear Reaction Data Network Meeting, Golden, CO
March 13-14, 1996

What has happened since the Del Mar meeting?

1. Ad Hoc Working Group formed: Bhat, Cecil, Dairiki & Young (Aug. '95)

2. Network Executive Committee (NEC): Bhat, Cecil, Chadwick, Dairiki & Young (Oct. '95)

3. NEC met at CSEWG (Oct.'95) and recommended formation of:

   Astrophysics (AP) Task Force: Smith (chair), Cecil, Firestone, Hale, Larson, Resler & Stokstad

   Radioactive Ion Beam (RIB) Task Force: Chadwick (chair), Gabriel, Garrett, Grimes, Kalbach-Walker & Young

4. BATES, CEBAF Users' Group Presentations (Oct. ;95)

5. User outreach: Nuclear Data Resources by Bhat & Dairiki (Nov. '95) Distributed 200 Nuclear Wallet Cards (Dec.'95)

6. Workshop on Compilation and Evaluation of Nuclear Astrophysics Cross-Section Data by Stokstad (Dec. '95)

7. Web Homepage Task Force: Bhat, Burrows, MacFarlane & Resler (Dec. '95)

8. Coding of Heavy-Ion Data (Jan. '96)

9. USNRDN WWW Homepage: Burrows (March '96)

Redirection of the Reaction Data Program---An Assessment:

1. Coordination mechanism is in place

2. Specific projects are in their initial phase

3. Substantive goals remain to be achieved

4. Acceptance of these projects/products by the basic research community is essential for the success of this program

The Network Executive Committee, the Astrophysics & Radioactive Ion Beam Task Forces always welcome your ideas & suggestions

Your active participation & help in carrying out their mission is essential

Is the coordination mechanism working properly?

Are the channels of communication satisfactory?

Do you have any suggestions for improvements?

Some Highlights of Progress Reports:

1. Nuclear level density as a function of excitation energy, angular momentum (LANL)

2. Neutron production from proton bombardment of Be (Ohio U)

3. Evaluated neutron data upto 100 MeV for H, C, N, O, F, P, and Ca (LLNL, LANL)

4. Improvements in data dissemination (BNL, LANL, LBNL, LLNL)

Future Outlook:

1. International Data Community & USNRDN

2. How best to interact with the structure data network?

3. How to make data activities relevant to research & vice versa

4. Where do we go from here? Set priorities & projects

5. Long range plan for USNRDN?

Nuclear Data Activities for Nuclear Astrophysics

Michael Smith
Physics Division
Oak Ridge National Laboratory

Meeting of the
U.S. Nuclear Reaction Data Network
Golden, Colorado
March 13-14, 1996

Overview

- USNRDN Members are Implementing Nuclear Astrophysics Projects in
  - Measurements
  - Nuclear Modeling
  - Calculations
  - Compilations
  - Evaluations
  - Disseminations
- USNRDN Astrophysics Task Force
  - Data Resources Reference Document
  - Outreach Activities
  - Future Activities
- Organizational Efforts for Nuclear Astrophysics Data Evaluation
  - Workshop at Caltech
  - Steering Committee Meeting
  - Future Activities

USNRDN Astro Activities

● In Progress
○ Planned

	Measure	Compile	Model	Evaluate	Calculate	Dissem-inate
ANL	○			○		
NNDC		●				●
CSM	●		●			
LLNL						○
LANL			●	●		●
ORNL	●			○	●	

Measurements

ANL

- **Proposed measurement of some (n,p) & (n,α) reactions** (e.g., ^{27}Mg(n,p)^{27}Al)
  - ▶ inverse of astrophysical (p,n) & (α,n) reactions

CSM

- **d(α,γ)^{6}Li ; ^{7}Li(^{3}He,p)^{9}Be, ^{7}Li(d,α)^{5}He**
  - ▶ Big Bang ^{6}Li, ^{7}Li abundances
- **d + ^{9}Be,^{10}B,^{11}B**
  - ▶ Big Bang Be, B abundances
  - ▶ DWBA Modifications ?

ORNL

- **^{7}Li(n,γ)^{8}Li**
  - ▶ Solar Neutrino Problem
  - ▶ Big Bang ^{8}Li production
- **$\sigma_{(n,\gamma)}$ and σ_{tot} on ^{134,136}Ba, ^{142,144}Nd**
  - ▶ Heavy Element Nucleosynthesis via the s-process

Compilations

NNDC

- Compilation of cross sections of Low-Mass, Charged Particle-Induced Reactions
  - 30 data sets
  - some of astrophysical interest

Modeling

CSM

- d + ^{9}Be,^{10}B,^{11}B Measurements for Big Bang Be, B production
  - standard DWBA doesn't fit $d\sigma/d\Theta$
  - can fit by adding positive term to Nucleon-Nucleus Potential
  - need anti-symmetrized DWBA calcs for transfer reactions

LANL

- $^{12}C(\alpha,\gamma)^{16}O$ Reaction
  - Crucial for Stellar Element Synthesis
  - New R-Matrix analysis to extrapolate $\sigma(E)$ to stellar energies
- Nuclear Reaction Modeling for RIB facilities
  - Important for Nuclear Astrophysics with Radioactive Beams

Evaluations

ANL

- Proposed Collaboration of ANL, Notre Dame, & Univ. of Chicago for some astro evaluation projects

LANL

- $^{12}C(\alpha,\gamma)^{16}O$ Reaction
  - ▶ New R-Matrix analysis
- $^{13}C(\alpha,n)^{16}O$ Evaluation
  - ▶ Crucial as neutron source for s-process Heavy Element Synthesis

ORNL

- $^{134,136}Ba(n,\gamma)$, $^{142,144}Nd(n,\gamma)$

  ⇒ Planned Evaluations to Incorporate New Measurements
- Plan to evaluate reactions on proton-rich radioactive isotopes (also measure at HRIBF)

Calculations

ORNL

- s-Process Heavy Element Nucleosynthesis Reactions

  ⇒ Improve Standard (n,γ) Reaction Rate Compilation

  ⇒ Use Standardized Evaluated Nuclear Data Files

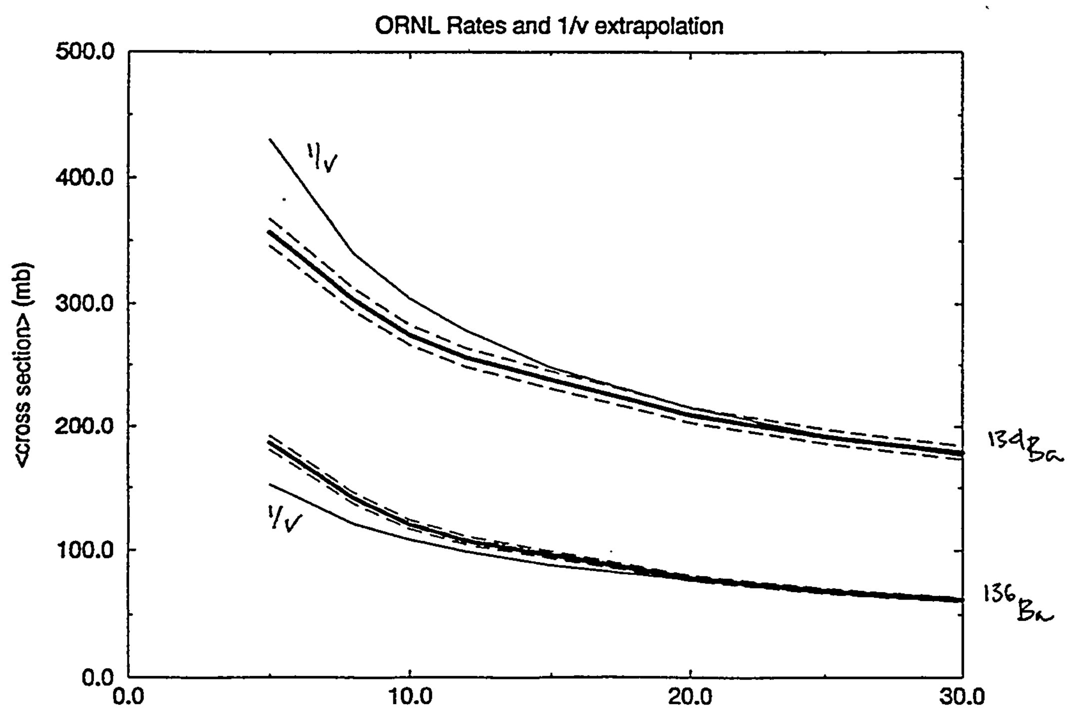
Heavy Element Nucleosynthesis Reactions: Improve Standard (n,γ) Reaction Rate Compilation

(N. Larson, Brauetigam, Smith, Winters)

▶ Shortcomings of Bao & Kaeppler 1987 Evaluation

- Reaction Rates at only ONE
  Stellar Temperature (kT=30 keV)
  - ▶ New Dynamical Models Need kT=8-12 keV
  - ▶ Models in general need analytic expression
    Rate as function of Temp: Rate(T)
- Does NOT use ENDF !
- No Reaction Rate Uncertainties

134,136Ba(n,gamma) Rates



Normal Use of SAMMY

- (n,γ) raw data
- σ_{tot} raw data

↓

SAMMY:
Multilevel R-Matrix
fits via Bayes Eqns.

↓

- resonance parameters
- uncertainties
- covariances

↓

ENDF
Evaluated Nuclear
Data File

New Use of SAMMY

ENDF

↓

resonance parameters

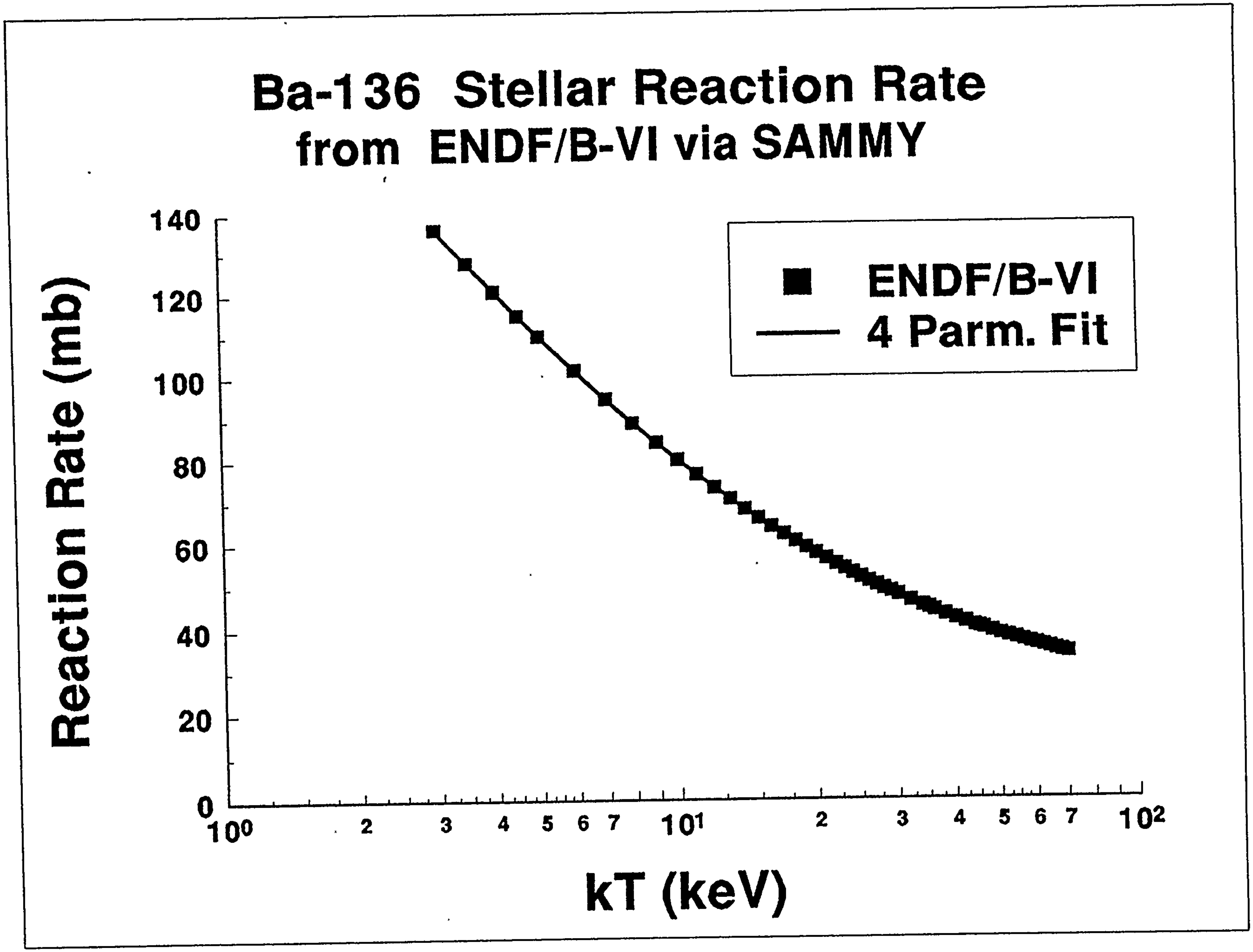
↓

SAMMY

- cross sections
- thermally-averaged cross sections (reaction rates)
- analytic fits to reaction rates
- rate uncertainties

↓

Astro Models


Ba-136 Stellar Reaction Rate
from ENDF/B-VI via SAMMY
ENDF/B-VI
4 Parm. Fit
Reaction Rate (mb)
kT (keV)
0
20
40
60
80
100
120
140
10^0
2
3
4
5
6
7
10^1
2
3
4
5
6
7
10^2

Disseminations

NNDC • **USNRDN WWW Pages**

(http://www.dne.bnl.gov/~burrows/usnrdn/usnrdn.html)

Astrophysics Task Force

- General Information Page
- Data Resources Document

LANL • **Developed Prototype**

(http://t2.lanl.gov)

Nuclear Astrophysics Data Webpage

- Charged particle induced reactions
- S-factors, Reaction Rates, Tabular Data
- Tabular Data with uncertainties
- Postscript Plots, Online Data Viewer
- Links to ENDF, Moller et al. Mass Calcs

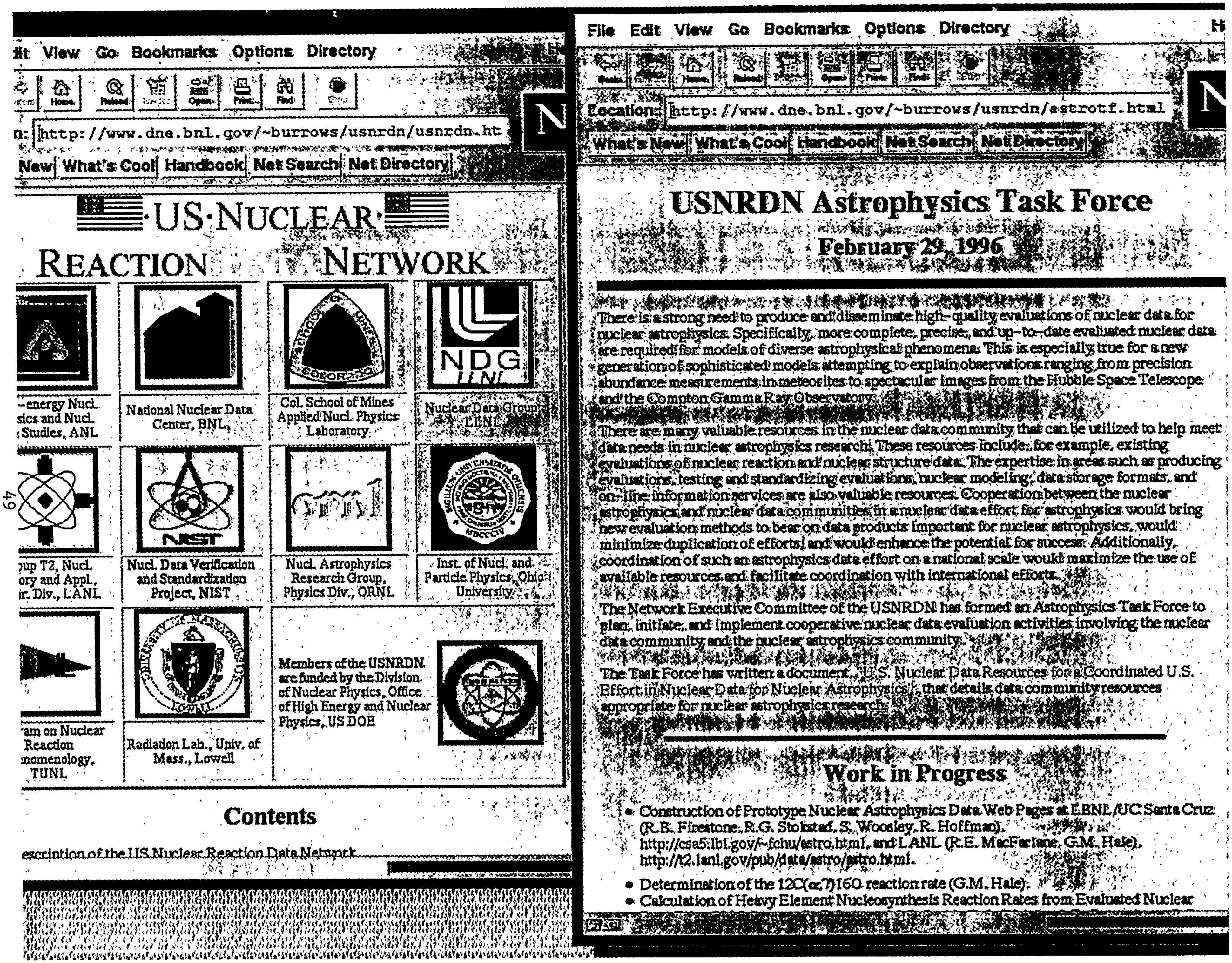
LBNL • **Prototype Astro Data Webpage**

(http://csa5.lbl.gov/~fchu/astro.html)

LLNL • **Experimental Electronic Information Development**

- **Website (available soon)**
- **Streamlined Interface & Format for Data, Reaction Rates ...**

ORNL • **Scanning CF88 Rate Compilation**



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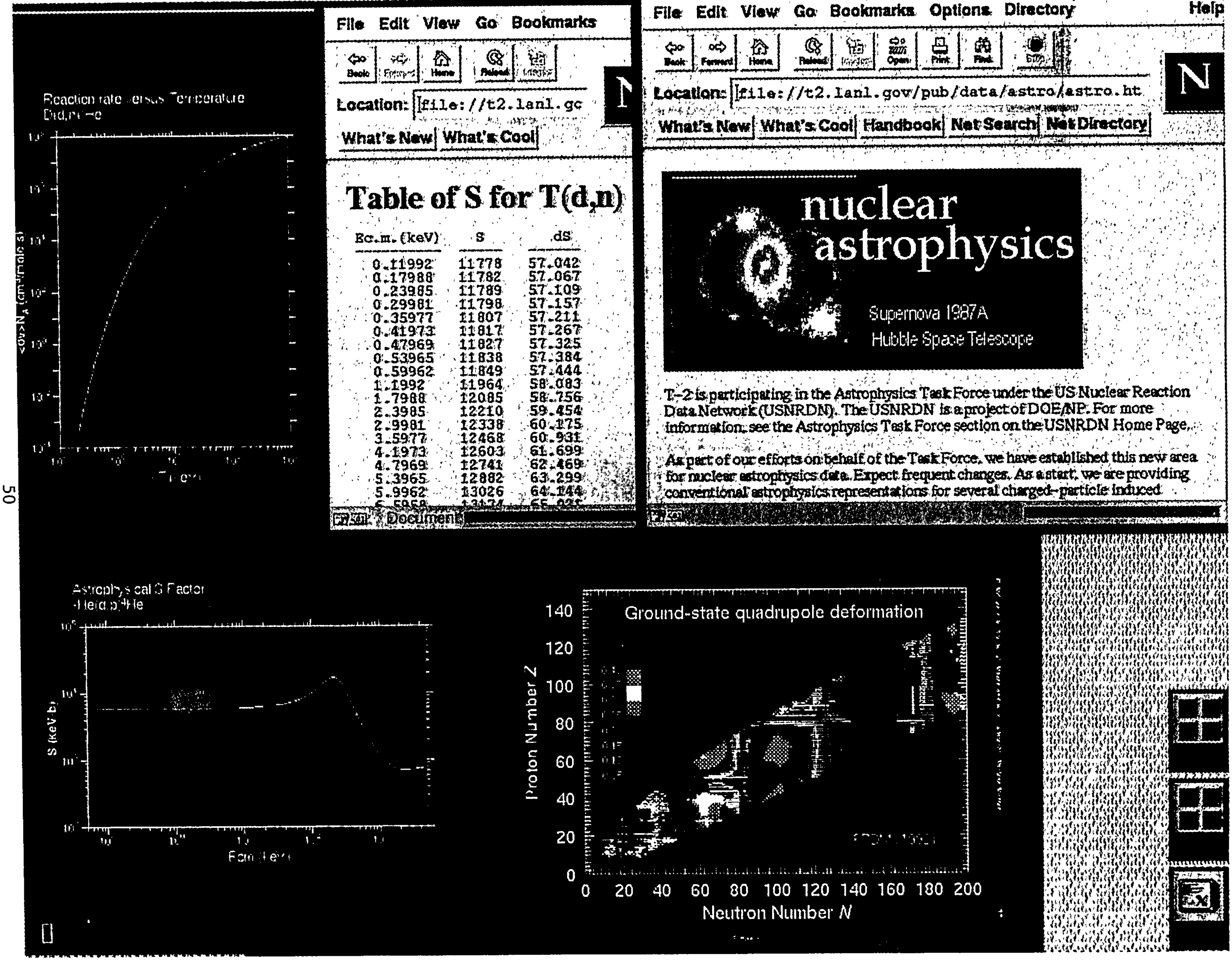
http://www.dne.bnl.gov/~burrows/usnrdn/usnrdn.ht
New What's Cool Handbook Net Search Net Directory
US·NUCLEAR
REACTION NETWORK
NDG LLNL
-energy Nucl. sics and Nucl. Studies, ANL
National Nuclear Data Center, BNL
Col. School of Mines Applied Nucl. Physics Laboratory
Nuclear Data Group LLNL
oup T2, Nucl. ory and Appl. r. Div., LANL
Nucl. Data Verification and Standardization Project, NIST
Nucl. Astrophysics Research Group, Physics Div., ORNL
Inst. of Nucl. and Particle Physics, Ohio University
am on Nuclear Reaction nomenology, TUNL
Radiation Lab., Univ. of Mass., Lowell
Members of the USNRDN are funded by the Division of Nuclear Physics, Office of High Energy and Nuclear Physics, US DOE
Contents
escription of the US Nuclear Reaction Data Network
File Edit View Go Bookmarks Options Directory
Location: http://www.dne.bnl.gov/~burrows/usnrdn/astrotf.html
What's New What's Cool Handbook Net Search Net Directory
USNRDN Astrophysics Task Force
February 29, 1996
There is a strong need to produce and disseminate high-quality evaluations of nuclear data for nuclear astrophysics. Specifically, more complete, precise, and up-to-date evaluated nuclear data are required for models of diverse astrophysical phenomena. This is especially true for a new generation of sophisticated models attempting to explain observations ranging from precision abundance measurements in meteorites to spectacular images from the Hubble Space Telescope and the Compton Gamma Ray Observatory.
There are many valuable resources in the nuclear data community that can be utilized to help meet data needs in nuclear astrophysics research. These resources include, for example, existing evaluations of nuclear reaction and nuclear structure data. The expertise in areas such as producing evaluations, testing and standardizing evaluations, nuclear modeling, data storage formats, and on-line information services are also valuable resources. Cooperation between the nuclear astrophysics and nuclear data communities in a nuclear data effort for astrophysics would bring new evaluation methods to bear on data products important for nuclear astrophysics, would minimize duplication of efforts, and would enhance the potential for success. Additionally, coordination of such an astrophysics data effort on a national scale would maximize the use of available resources and facilitate coordination with international efforts.
The Network Executive Committee of the USNRDN has formed an Astrophysics Task Force to plan, initiate, and implement cooperative nuclear data evaluation activities involving the nuclear data community and the nuclear astrophysics community.
The Task Force has written a document, "U.S. Nuclear Data Resources for a Coordinated U.S. Effort in Nuclear Data for Nuclear Astrophysics", that details data community resources appropriate for nuclear astrophysics research.
Work in Progress
Construction of Prototype Nuclear Astrophysics Data Web Pages at LBNL/UC Santa Cruz (R.B. Firestone, R.G. Stokstad, S. Woosley, R. Hoffman), http://csa5.lbl.gov/~fchu/astro.html, and LANL (R.E. MacFarlane, G.M. Hale), http://t2.lanl.gov/pub/data/astro/astro.html.
Determination of the 12C(α,γ)16O reaction rate (G.M. Hale).
Calculation of Heavy Element Nucleosynthesis Reaction Rates from Evaluated Nuclear



File Edit View Go Bookmarks
Location: file://t2.lanl.gc
What's New What's Cool
Table of S for T(d,n)
Ec.m. (keV) S dS
0.11992 11778 57.042
0.17988 11782 57.067
0.23985 11789 57.109
0.29981 11798 57.157
0.35977 11807 57.211
0.41973 11817 57.267
0.47969 11827 57.325
0.53965 11838 57.384
0.59962 11849 57.444
1.1992 11964 58.083
1.7988 12085 58.756
2.3985 12210 59.454
2.9981 12338 60.175
3.5977 12468 60.931
4.1973 12603 61.699
4.7969 12741 62.469
5.3965 12882 63.299
5.9962 13026 64.144
Document
File Edit View Go Bookmarks Options Directory Help
Location: file://t2.lanl.gov/pub/data/astro/astro.ht
What's New What's Cool Handbook Net Search Net Directory
nuclear astrophysics
Supernova 1987A
Hubble Space Telescope
T-2 is participating in the Astrophysics Task Force under the US Nuclear Reaction Data Network (USNRDN). The USNRDN is a project of DOE/NP. For more information, see the Astrophysics Task Force section on the USNRDN Home Page.
As part of our efforts on behalf of the Task Force, we have established this new area for nuclear astrophysics data. Expect frequent changes. As a start, we are providing conventional astrophysics representations for several charged-particle induced
Ground-state quadrupole deformation
Proton Number Z
Neutron Number N
0 20 40 60 80 100 120 140 160 180 200
0 20 40 60 80 100 120 140
S (keV-b)

USRNDN Astrophysics Task Force

- **Members**

  Michael S. Smith (ORNL), Chair
  Richard B. Firestone (LBNL)
  Duane Larson (ORNL)
  Robert G. Stokstad (LBNL)
  F. Edward Cecil (CSM)
  Gerald M. Hale (LANL)
  David A. Resler (LLNL)

- **U.S. Nuclear Data Resources for a Coordinated U.S. Effort in Nuclear Data for Nuclear Astrophysics**
  - Document Created for the Caltech Astro Data Wkshp
  - Available Online (USRNDN WWW site)
  - Companion Documents

- **Outreach: Presentations at CSEWG, Del Mar '95, Caltech Astro Data Wkshp, Clemson Univ.**

- **Participation in Steering Committee Activities**

U.S. Nuclear Data Resources for a Coordinated U.S. Effort in Nuclear Data for Nuclear Astrophysics

Astro Task Force
Possible Future Activities

❓ GLUCS / BAYES Demo

- Convince Astro Community to Adopt Statistically Robust Eval Codes

❓ Evaluation Procedures

- Well-Documented Procedures for "typical" astro reaction evaluations
  - ▶ Ensure Uniform, High Quality Evaluations

❓ Dissemination Projects

- Address Dissemination Issues
- Astro Data Center Proposal(s)

❓ Recruit Manpower for Astro Evaluations

❓ Interface w/other Organizations

- Steering Committee ...

Astro Data Workshop

- Caltech 12/16/95
- Following Willy Fowler Memorial Symp.
- Organizers: Bob Stokstad (LBNL)

  with Ralph Kavanagh (Caltech), Peter Parker (Yale),

  Michael Smith (ORNL), Michael Wiescher (Notre Dame),

  Stan Woosley (UC Santa Cruz)
- WWW Page with Advance Information
  (http://csa5.lbl.gov/~fchu/astro.html)
- 40 attendees
- Email Network of ≈ 80 scientists
- 9 Presentations, Much Discussion
- Recommendations Made
- Endorsed & Formed a Steering Committee

Workshop Recommendations

1. The **stewardship of data** - compilation, evaluation, and dissemination - is a **crucial** part of Nuclear Astrophysics.

2. Nuclear Astrophysics has progressed to the point where future **stewardship** must be **planned, coordinated, and funded.**

3. The **U.S. nuclear data community** can be a **valuable resource** for the astrophysics community - efforts to develop this resource through increased interaction and collaboration are strongly encouraged.

4. **Cooperation** with the **European** Nuclear Astrophysics Network is especially important. Mutual support and exchange of information will benefit all participants. A larger role in data evaluation by colleagues from **Japan**, commensurate with their increased activity in nuclear astrophysics, is warmly welcomed.

5. **Support** for the stewardship of nuclear astrophysics data should be actively **sought from** the **DOE** and **NSF**, and from other agencies as appropriate

6. An **Organizing/Steering Committee** has been **formed** at this Workshop, with a set of recommended **responsibilities.**

Steering Committee

Members		Responsibilities
Peter Parker (Chair)	**Yale**	**Set priorities**
Charles Barnes	Caltech	**Solicit help !**
Lothar Buchmann	Triumf	**Review evaluated data**
Gerry Hale	Los Alamos	**Point of contact for astro community**
Franz Kaeppeler	Karlsruhe	**Plan for archival and dissemination**
Shigeru Kubono	Tokyo	**Facilitate cooperative efforts**
Claus Rolfs	Bochum	**Seek Funding**
Michael Smith	Oak Ridge	**Encourage proposals**
Bob Stokstad	Berkeley	
Friedel Thielemann	Basel	
Michael Wiescher	Notre Dame	
Stan Woosley	Santa Cruz	

▶ Meeting at Caltech 2/96

- **Topics:** **Evaluation Projects**
  Surveying Astro Community
  Contributions of SC Members
  Evaluation Procedures
  Archiving Data
- **detailed meeting summary available**
- **SC will survey community by 6/96**
- **tentatively recommended eval projects:**
  - A = 30 - 45 H, He Burning Reactions Evaluation
  - Hot CNO Cycle / rp-process Rate Evaluation
- **Now Investigating Eval Tools, Eval Procedures**
- **Next Meeting 6/96 Cosmos IV (Notre Dame)**

Summary

- USNRDN Members
  Implementing & Planning
  Very Useful, Interesting
  Nuclear Astrophysics
  Data Projects

- Task Force May Aid
  Astro Community in
  - Adopting Proven
    Evaluation Techniques
  - Developing Well Documented
    Evaluation Procedures
  - Performing Evaluations

Report of Radioactive Ion Beam Task Force

M.B. Chadwick

Group T2, Los Alamos National Laboratory

March 13, 1996

Introduction

- RIB Task Force meeting, ORNL, January 1996
- Research work performed supporting RIBs
- Future research
- Level density studies

RIB Meeting, ORNL, January 9 1996

Present at meeting: J.D. Garrett, T. Gabriel, J. Ball, D. Olson, C. Jones, D. Larson, M. Smith, B. Piercey, J. Gomez Del Campo, J. Beene, F. Bertrand, M.B. Chadwick, P.G. Young

Research areas of importance for RIB support:

- Nuclear model calculations of RIB radionuclide production using codes such as GNASH and ALICE
- Preequilibrium reactions, and isospin dependence
- Calculate masses and separation energies for nuclides far from stability
- Study isospin-dependence of optical potentials and level densities
- Determine transport and activation for the beam+target system using LAHET,MCNP, and CINDER
- Nuclear structure and level density studies of nuclei far from stability (e.g. WNR (n,z) measurement, and HERA measurements)

Theory/modeling work in progress:

- Calculated ^{58}Ni$(p,n)^{58}$Cu excitation function, and benchmarked GNASH calculated yields against measurements
- (p,xn) reactions on ^{64}Zn and ^{70} Ge in progress
- Model improvements are being made for FKK-GNASH code, and PRECO
- LAHET–CINDER activation calculations for $p+^{238}$U are in progress

Other future research areas:

- Theoretical studies of fission fragment distributions for production of neutron-rich RIBS. Utilize planned LANSCE/HERA measurements
- Further research in level densities and optical models, at higher excitation energies and for systems far from stability

Los Alamos
NATIONAL LABORATORY
memorandum
Theoretical Division
Group T-2, Nuclear Theory and Applications

To/MS: J.D. Garrett, RIB Task Force, and R.A. Meyer (DOE)
From/MS: Mark Chadwick and Phil Young, T-2, B243
Phone/FAX: 667-9877/667-9671
Symbol: T–2–
Date: March 6, 1996

RIB p+^{58}Ni GNASH calculations and benchmarking of results

Abstract

We describe model calculations up to 100 MeV for the production of the proton-rich nucleus ^{58}Cu via the ^{58}Ni(p,n) reaction. This reaction is particularly sensitive to the modeling of the neutron preequilibrium spectrum. To benchmark our results, we compare our calculations against other experimental data (emission spectra and yields). We estimate that our calculated yields are accurate to approx. 50%, a conservative estimate based on differences between theory and experiment for: (1) other nuclide yields (where data exists); and (2) comparisons between measured and calculated neutron emission spectra.

We have completed GNASH calculations of ^{58}Ni(p,xn) reactions up to 100 MeV for RIB applications. In this memo, we wish to describe our calculational approach, present results for the production of the proton rich ^{58}Cu product, and present comparisons of theory with experimental radionuclide yield data, and emission spectra data, to benchmark the calculations.

Summary of model calculations:

The GNASH code applies sequential Hauser-Feshbach compound nucleus theory, with preequilibrium processes calculated with the exciton model, as formulated by Kalbach. Multiple preequilibrium processes are included for nucleon emission, and preequilibrium mechanisms are also included for the emission of deuteron and alpha clusters.

We used local optical potentials which have been developed specifically for fitting reaction and total cross section data on ^{58}Ni. For nucleons, the optical potential of Harper was used to 27 MeV, above which we used Madland's intermediate energy potential. The Perey potential was used for deuterons, and the Strohmaier-Uhl structural-element potential was used for alpha particles. Transmission coefficients for gamma-ray emission were calculated using the Kopecky-Uhl formalisms, which includes deviations from the Brink-Axel hypothesis.

Level densities were obtained from Gilbert and Cameron's model, with the Cook parameters to determine a, and the pairing shifts. At low excitation energies, discrete nuclear levels were included.

Results for the ^{58}Ni(p,n)^{58}Cu reaction

Below we tabulate the calculated excitation function for the production of ^{58}Cu, which may be of use as a proton-rich RIB. Fig. 1 shows these results in graphical form. We also tabulate excitation function calculations for the production of ^{56}Ni which, with a 6.1-day half life, may be a suitable proton-rich RIB candidate and is of interest as it is doubly magic (though difficult to extract from the target). Additionally, there is some experimental data for ^{56}Ni production (see Fig. 2) which indicates that the calculated ^{56}Ni cross sections below may be about 50% too small.

E_p (MeV)	(p,n)^{58}Cu Yield (b)	(p,p2n)^{56}Ni yield (b)
10	0.813E-02	–
12	0.348E-01	–
14	0.509E-01	–
16	0.386E-01	–
18	0.283E-01	–
20	0.217E-01	–
22	0.173E-01	0.263E-09
25	0.136E-01	0.182E-03
30	0.105E-01	0.528E-02
35	0.869E-02	0.103E-01
40	0.766E-02	0.143E-01
50	0.569E-02	0.123E-01
60	0.465E-02	0.107E-01
70	0.370E-02	0.995E-02
80	0.313E-02	0.954E-02
90	0.218E-02	0.913E-02
100	0.201E-02	0.763E-02

Benchmarking calculations by comparisons with measurements:

In order to test the predictive capabilities of our GNASH calculations, we have compared calculations of protons incident on ^{58}Ni with all experimental data (obtained primarily from the CSISRS database at the National Nuclear Data Center). The following experimental results are shown in figures:

Experimental database for p+^{58}Ni:

- Tanaka *et al.* J. Inorg. Chem. 34, 2419 (1992) – Many excitation functions up to 56 MeV.
- Cohen *et al.* Phys. Rev. 99, 723 (1955 – (p,2p) at 21.5 MeV.
- Kaufmann *et a.l*, Phys. Rev. 117, 1532 (1960) – Many excitation functions up to 19 MeV.
- Michel *et al.* Z. Phys. A286, 393 (1978) – limited use since excitation functions are for ^{nat}Ni
- Data from Levkovski, Tarkanyi, Zhuravlev, tabulated in the CSISRS database.
- (p,xn) emission spectra at 22 MeV, Biryukov, Yad Fiz., 31, 291 (1980).

- (p,xp) emission spectra at 65 MeV, Sakai, N. Phys. A344, 41 (1981)
- (p,xn) emission spectra at 90 MeV, Kalend, Phys. Rev. C28. 105 (1983). Also, (p,charged-particle) spectra at 90 MeV by Wu et al., Univ. Maryland report NSF-3-78 (1978).
- (p,xp) at 100, 120, 150, ... MeV from South Africa: Richter, Phys. Rev. C46, 1030 (1992).

Comparison between theory and experiment

Figures 2-9 compare our calculated excitation functions with experimental measurements. Generally the theoretical predictions are in fairly good agreement with the data. In most cases the differences are less than about 20-30% in the peak regions of the excitation functions. The most significant deviation is seen for the $(p, 2p2n)$ reaction at 60 MeV, where differences as high as a factor of 3 are seen. The agreement between theory and experiment is due partly to the modeling of preequilibrium processes, which remove a large fraction of the projectile energy. For instance, the $(p, 2p)$ and (p, pn) cross section are predicted well at high incident energies (Figs. 2,3) because multiple preequilibrium processes are included in GNASH, where two fast particles are emitted. Also, the calculations appear to account for the measured partitioning between neutron and proton emission in the reaction.

Figures 10-13 compare emission spectra calculations with measurements. This is importance since the (p, n) reaction producing the proton-rich ^{58}Cu nucleus is governed to a large extent by the preequilibrium neutron spectrum for high neutron ejectile energies. From Fig. 10 it is evident that at 22 MeV incident energy the neutron emission spectrum is predicted reasonably well, though the preequilibrium contribution is overpredicted in the range 7-10 MeV. To some extent the influence on the (p,n) excitation function of this overprediction is partly compensated by the underprediction of the data at 12 MeV emission energy, since our calculations do not include the enhancement due to the excitation of the isobaric analogue state.

At 90 MeV there is data for the emission of n, p, d, α particles, allowing a rigorous test of our models. Figure 12 shows these data, along with our calculations, and in general the agreement is good. The neutron emission spectrum is predicted well, though at the highest energies the calculations fall below the data. The proton emission spectrum is underpredicted by about 20% in the preequilibrium regime. Also, the alpha and deuteron spectra are described quite nicely by the calculations (the overprediction of preequilibrium alpha particles is of small importance due to the very small cross sections). Figures 12 and 13 compare calculations of the proton emission spectra at 65, 100, and 120 MeV with data. While the agreement at 65 MeV is good, at 100 and 120 there is an underprediction for intermediate emission energies of approximately 20%.

MBC:mbc

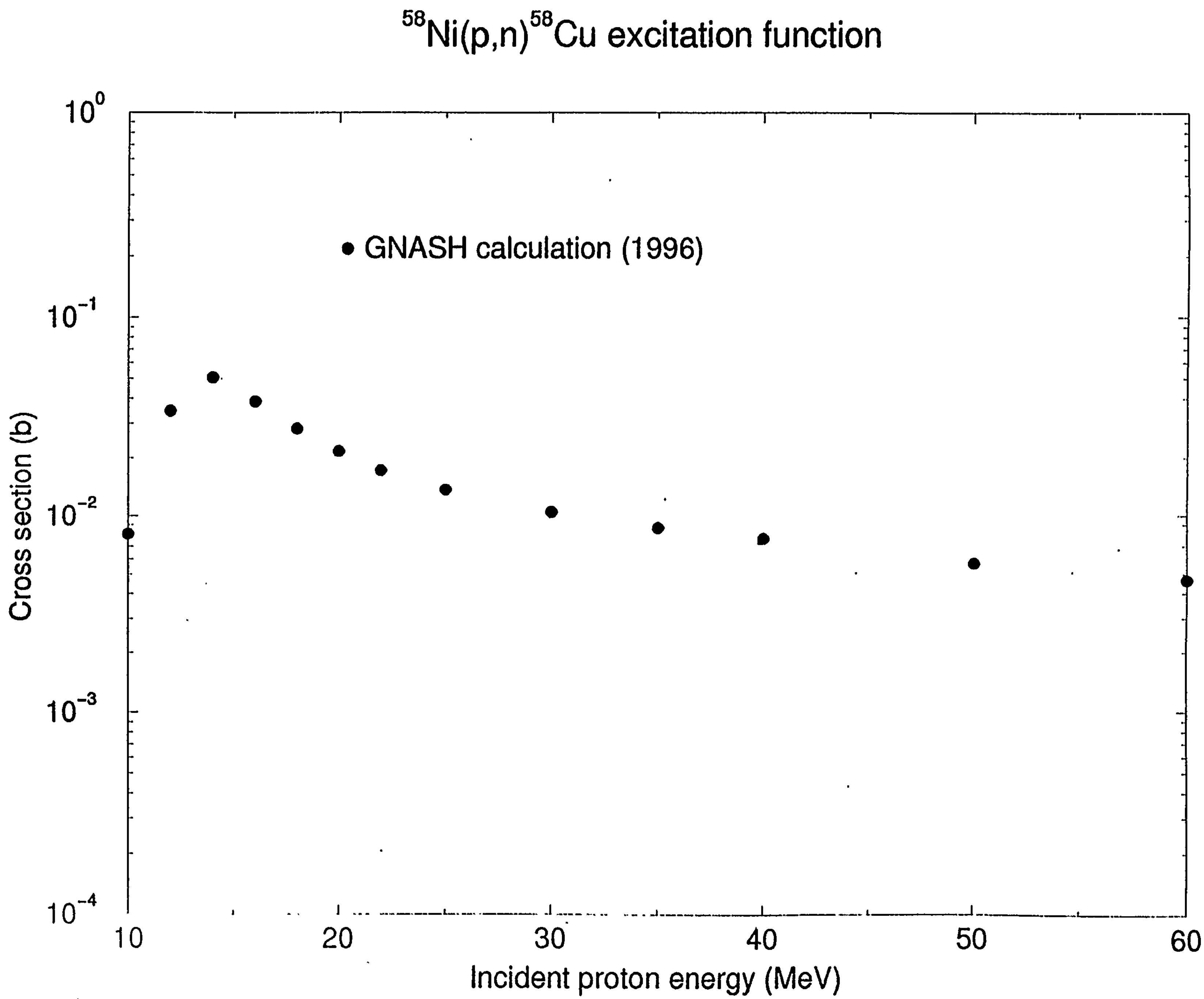

^{58}Ni(p,n)^{58}Cu excitation function
GNASH calculation (1996)
Cross section (b)
Incident proton energy (MeV)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
20
30
40
50
60

Fig. 1

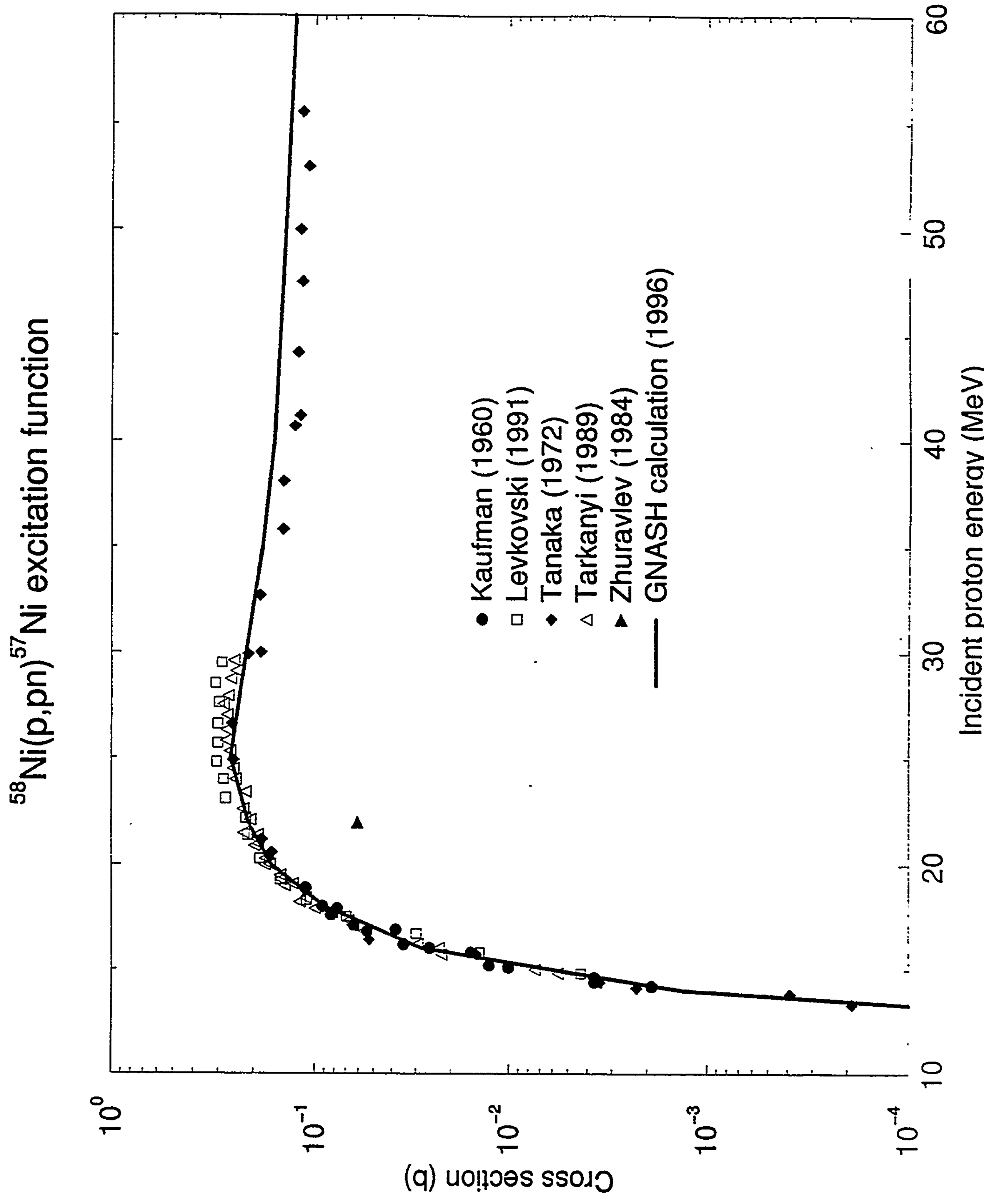

^{58}Ni(p,pn)^{57}Ni excitation function
Kaufman (1960)
Levkovski (1991)
Tanaka (1972)
Tarkanyi (1989)
Zhuravlev (1984)
GNASH calculation (1996)
Cross section (b)
Incident proton energy (MeV)
10
20
30
40
50
60
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}

Fig 2

$^{58}Ni(p,2p)^{57}Co$ excitation function

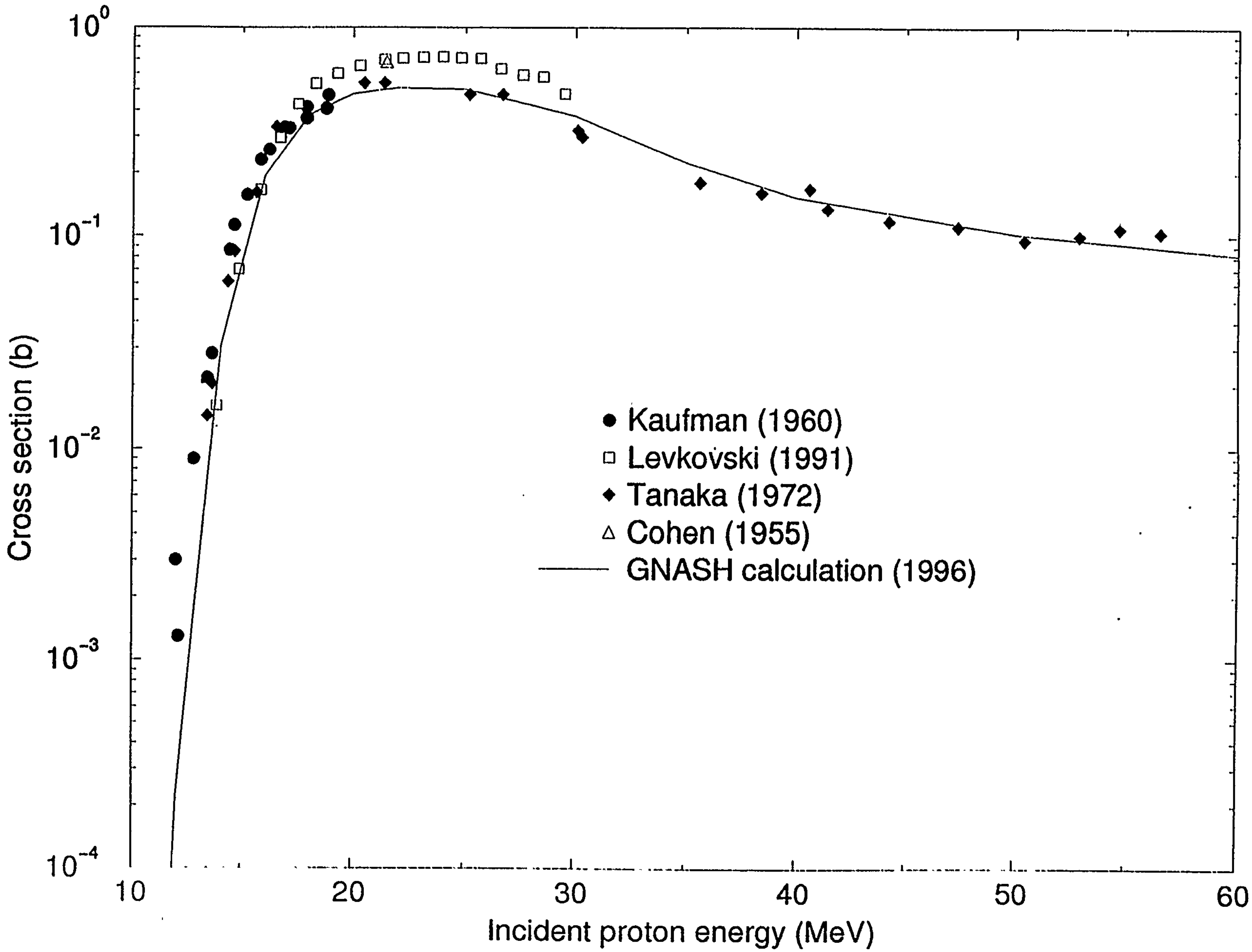
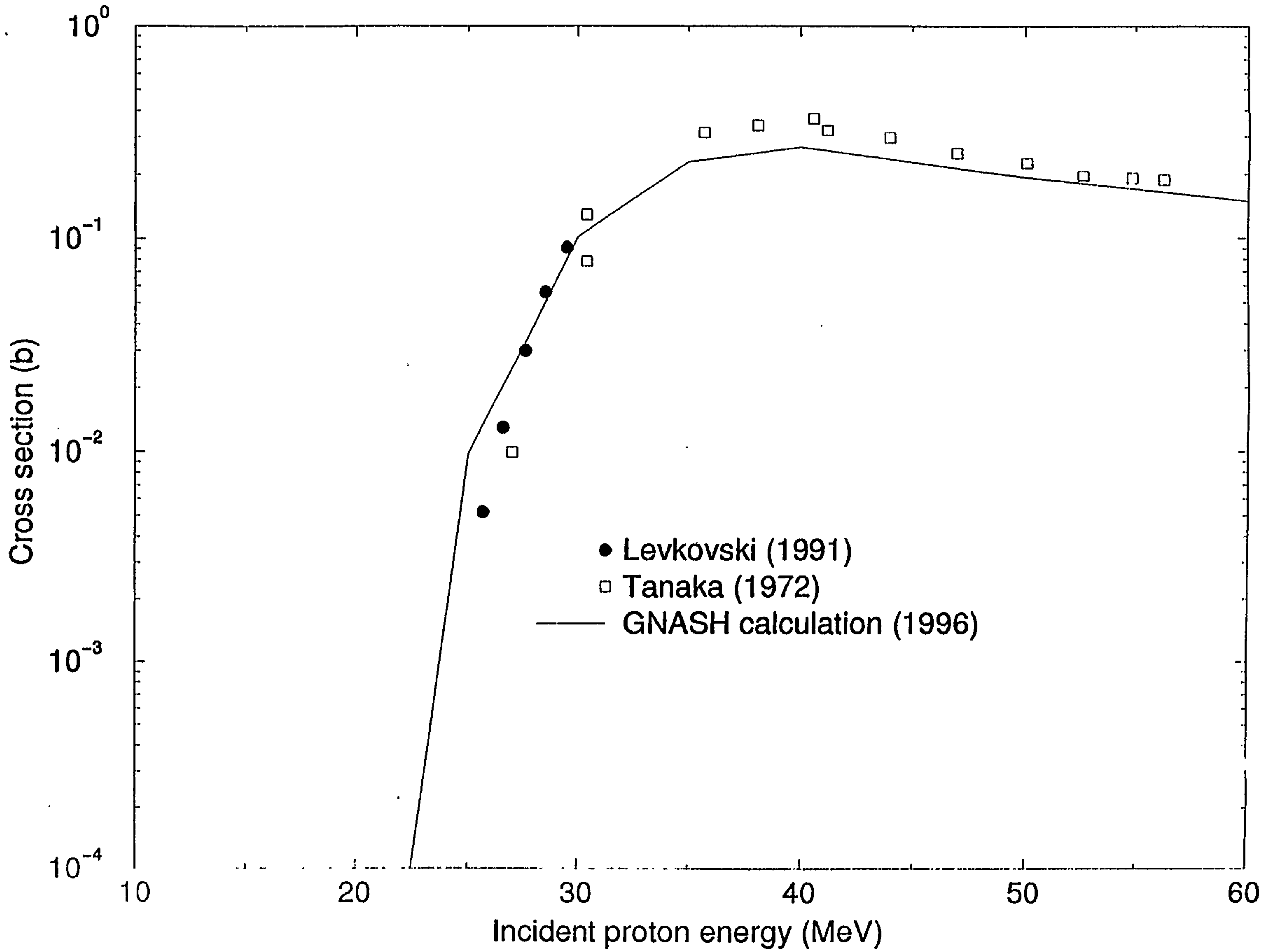
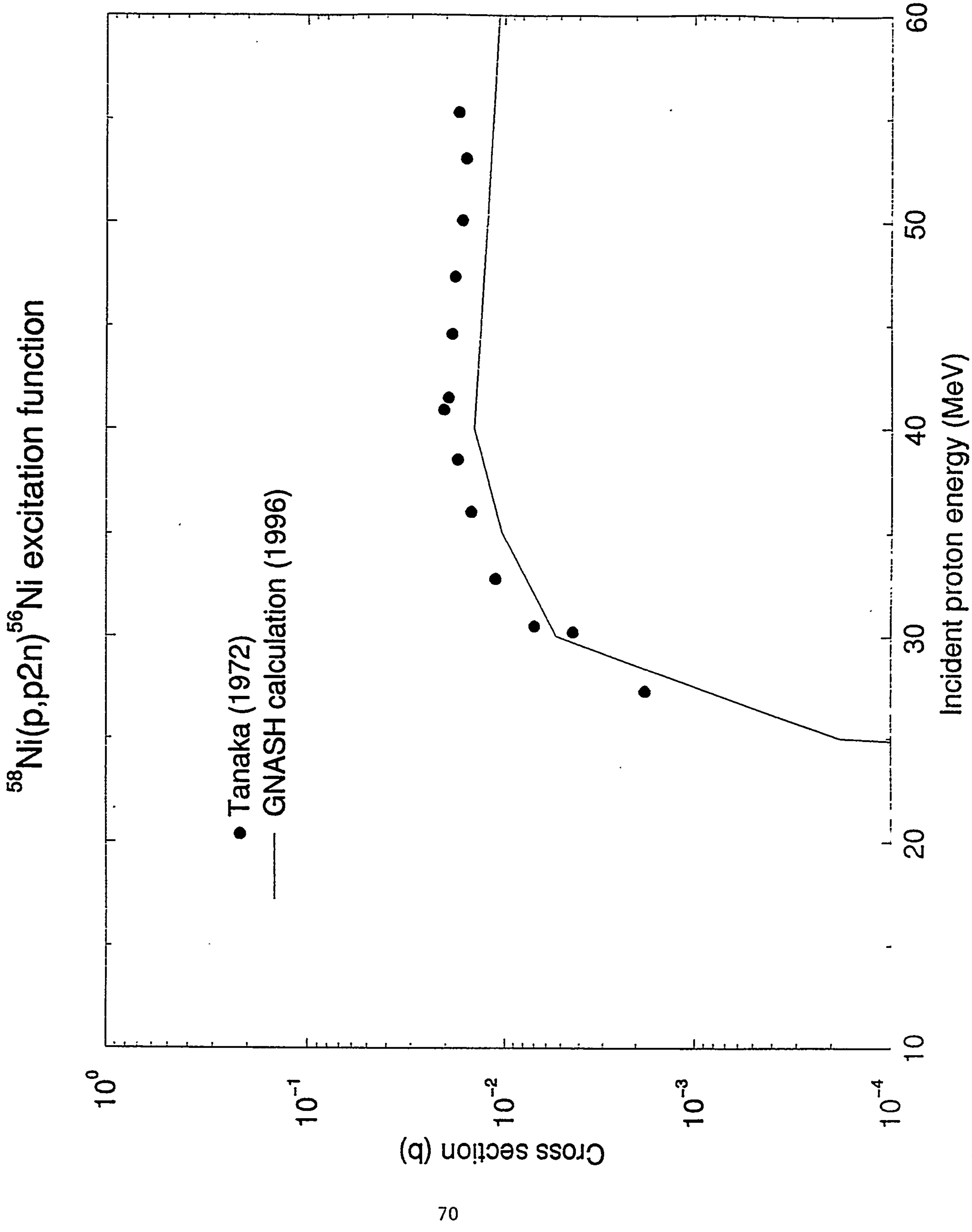


Fig 3

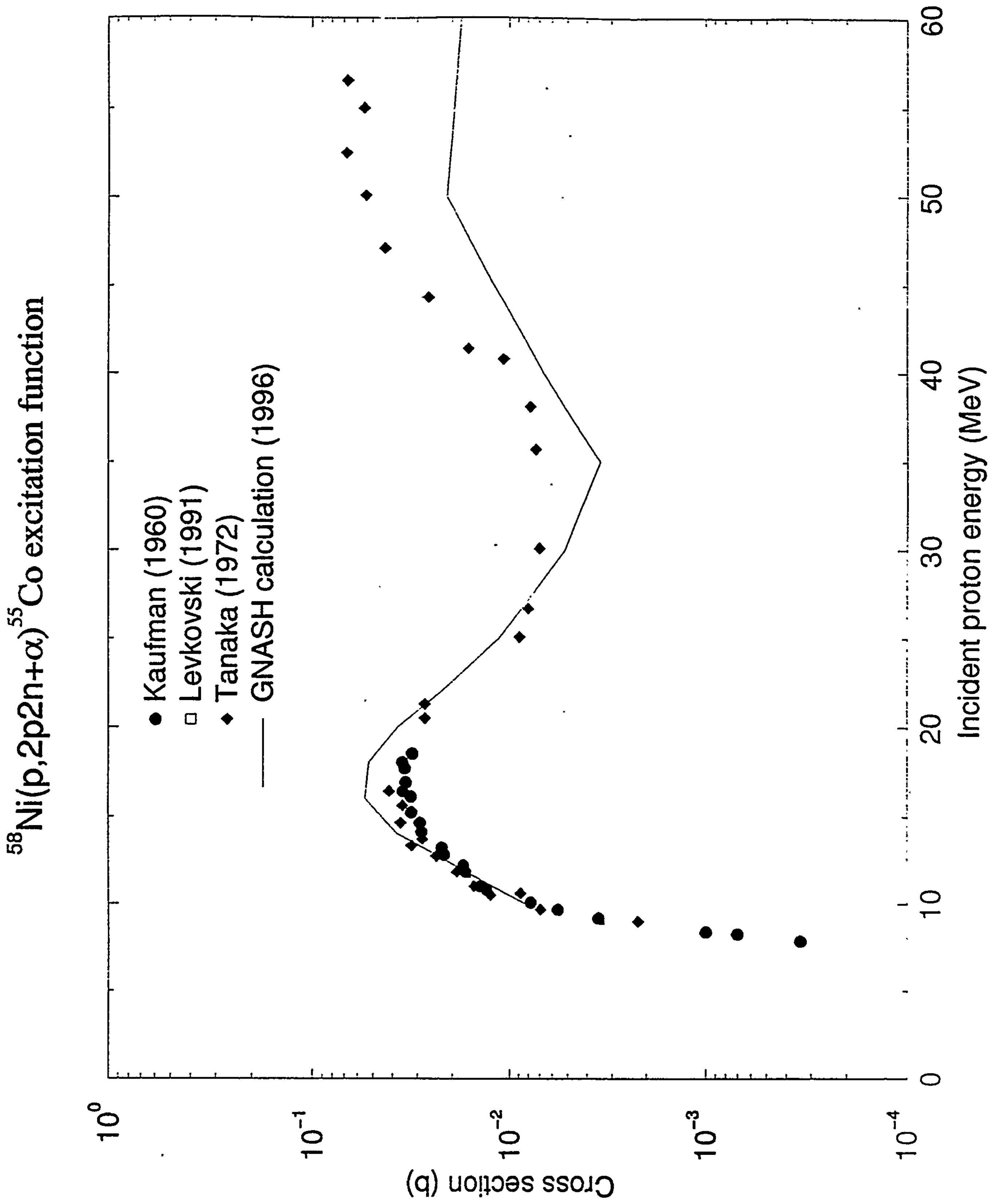
$^{58}Ni(p,2pn)^{56}Co$ excitation function



Fia 4

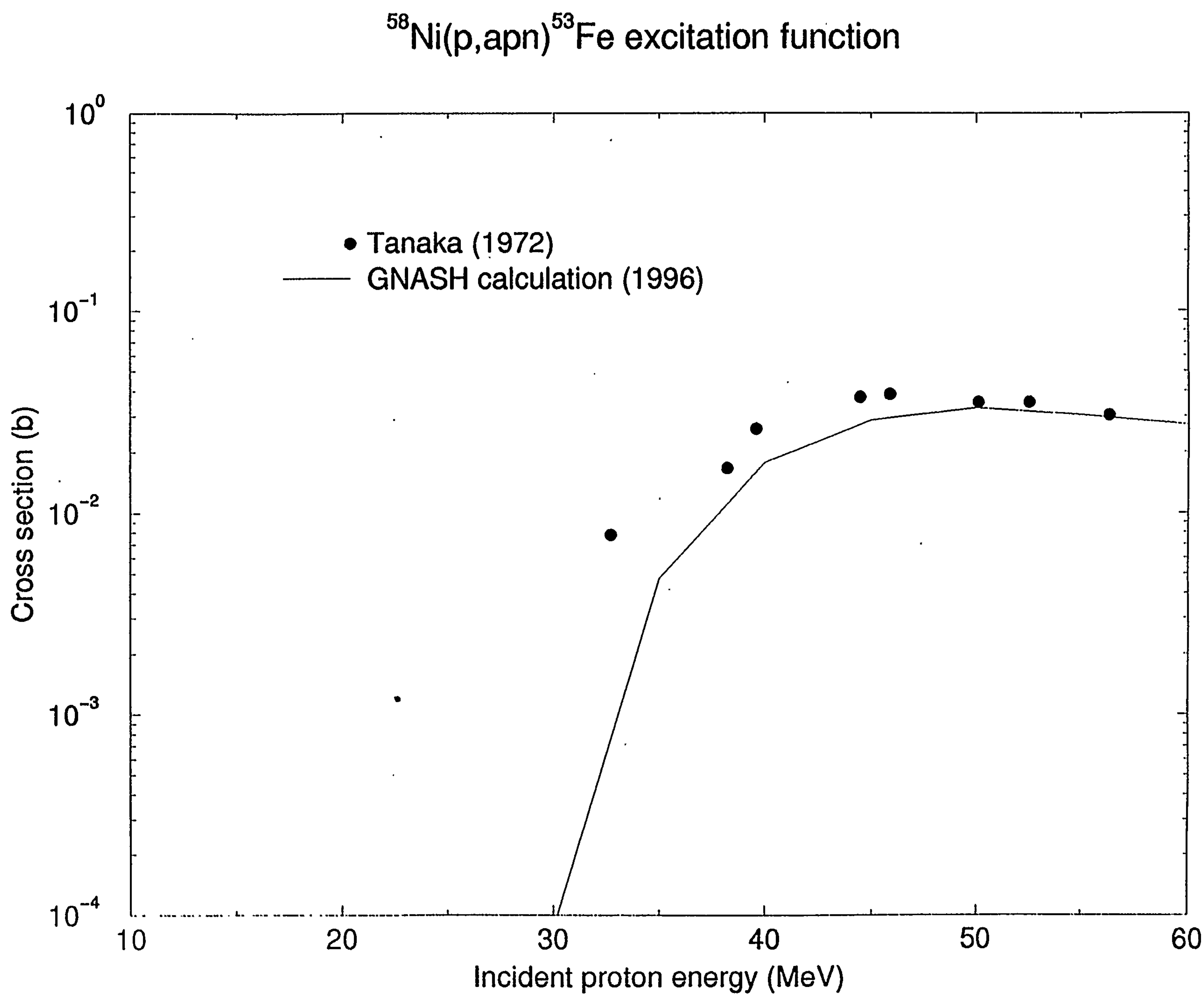


58Ni(p,p2n)56Ni excitation function
Tanaka (1972)
GNASH calculation (1996)
Cross section (b)
10^0
10^-1
10^-2
10^-3
10^-4
Incident proton energy (MeV)
10
20
30
40
50
60



^{58}Ni(p,2p2n+α)^{55}Co excitation function
Kaufman (1960)
Levkovski (1991)
Tanaka (1972)
GNASH calculation (1996)
Cross section (b)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Incident proton energy (MeV)
0
10
20
30
40
50
60

Fig 6



$^{58}Ni(p,apn)^{53}Fe$ excitation function
Tanaka (1972)
GNASH calculation (1996)
Cross section (b)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10
20
30
40
50
60
Incident proton energy (MeV)

Fig. 2

$^{58}Ni(p,a2pn)^{52}Mn$ excitation function

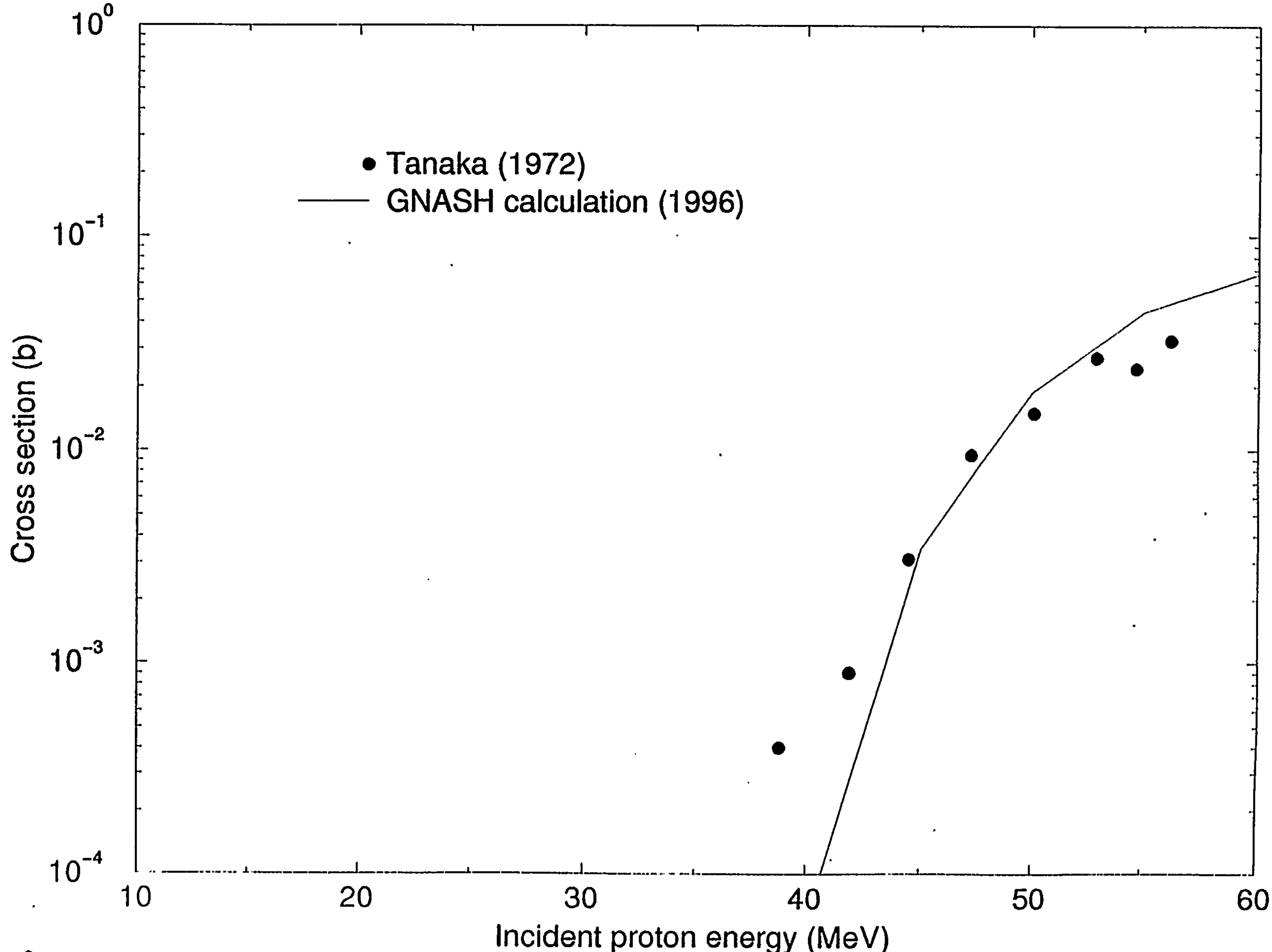


Fig 8

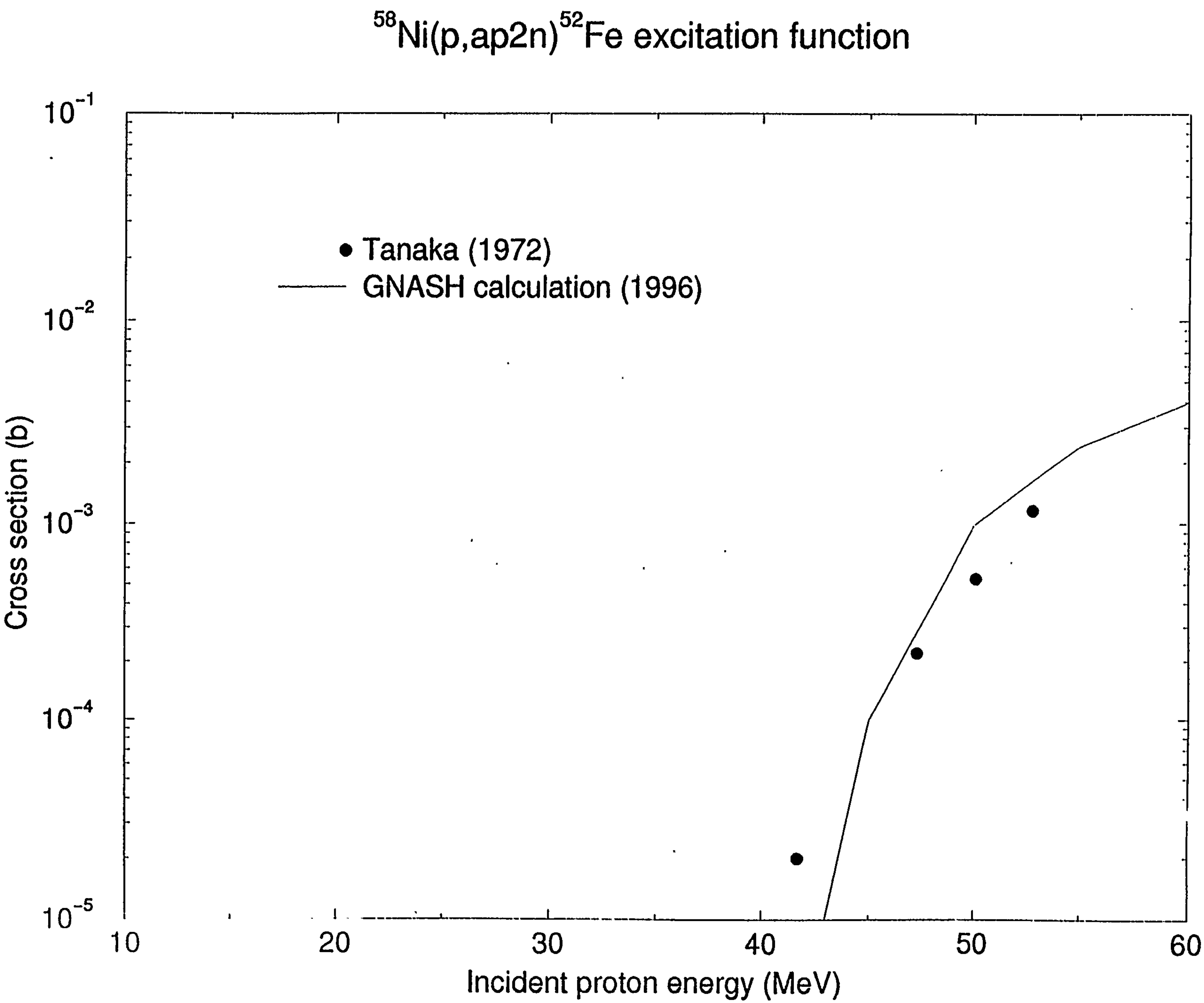

58Ni(p,ap2n)52Fe excitation function
Tanaka (1972)
GNASH calculation (1996)
Cross section (b)
10-1
10-2
10-3
10-4
10-5
10
20
30
40
50
60
Incident proton energy (MeV)

Fig 9

22 MeV ^{58}Ni(p,xn) emission spectrum

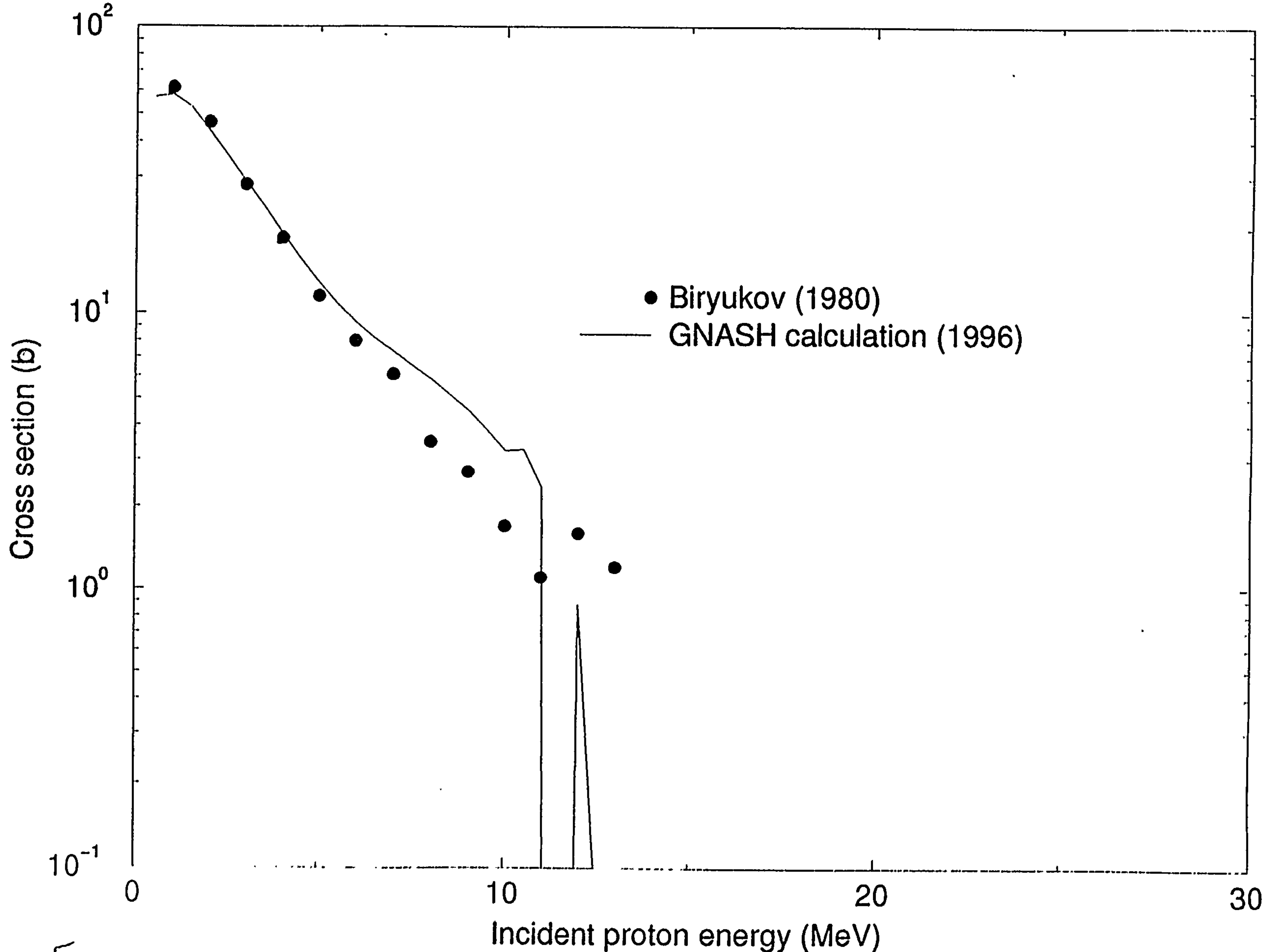


Fig 10

90 MeV p+^{58}Ni emission spectra

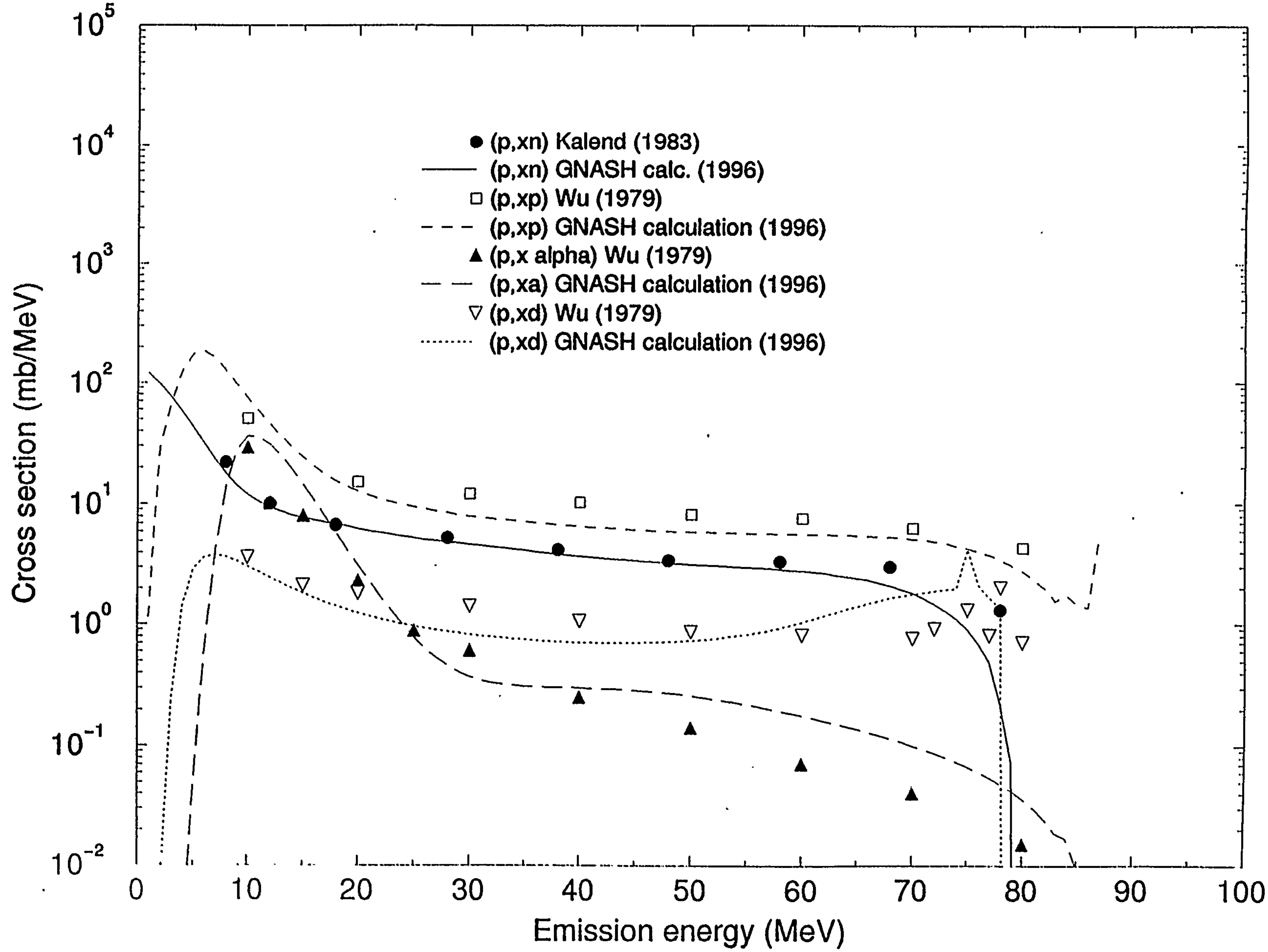


Fig 11

65 MeV (p,xp) on ^{58}Ni

Angle–integrated spectrum

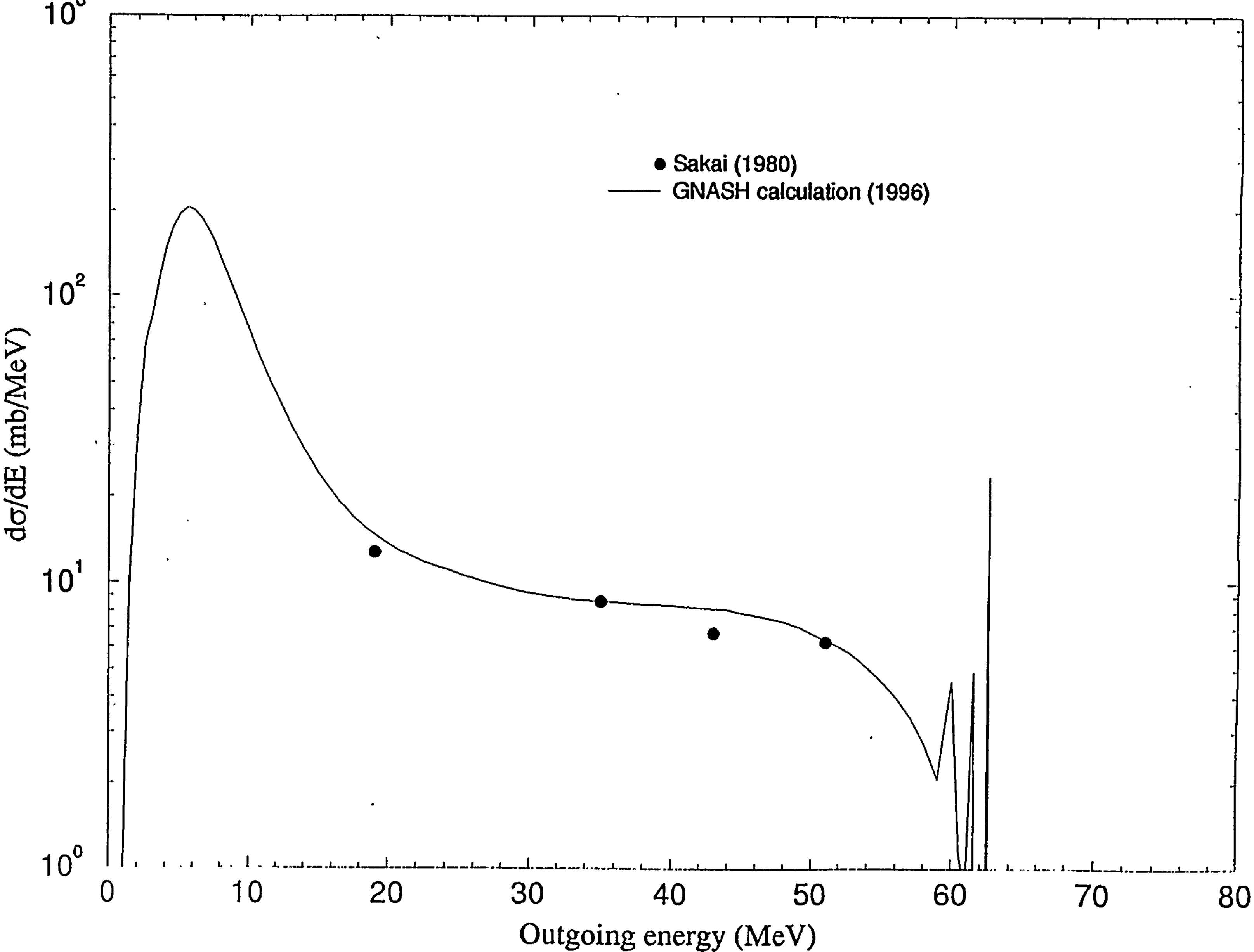


Fig 12

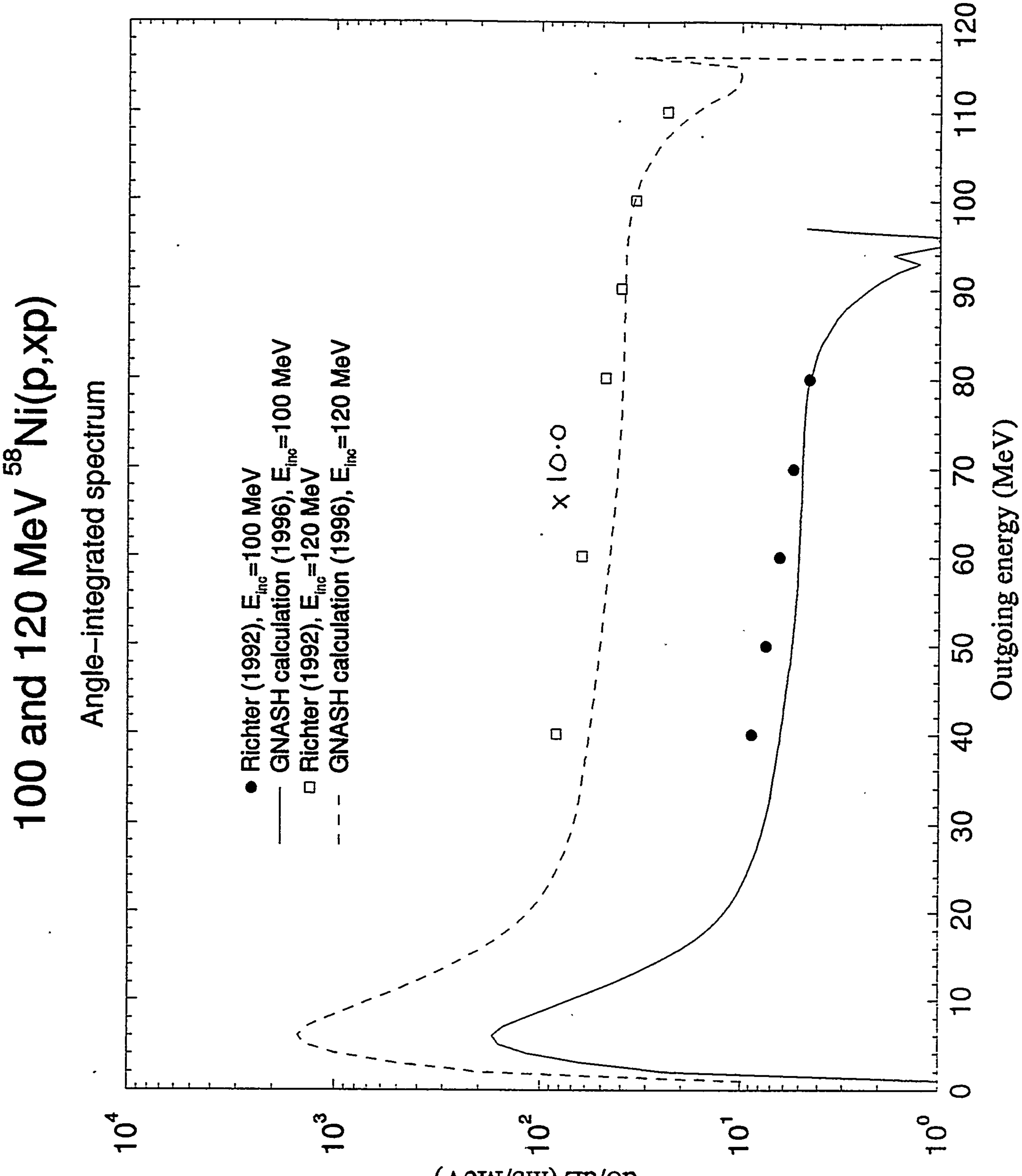

100 and 120 MeV ⁵⁸Ni(p,xp)
Angle-integrated spectrum
Richter (1992), E_inc=100 MeV
GNASH calculation (1996), E_inc=100 MeV
Richter (1992), E_inc=120 MeV
GNASH calculation (1996), E_inc=120 MeV
× 10.0
dσ/dE (mb/MeV)
Outgoing energy (MeV)

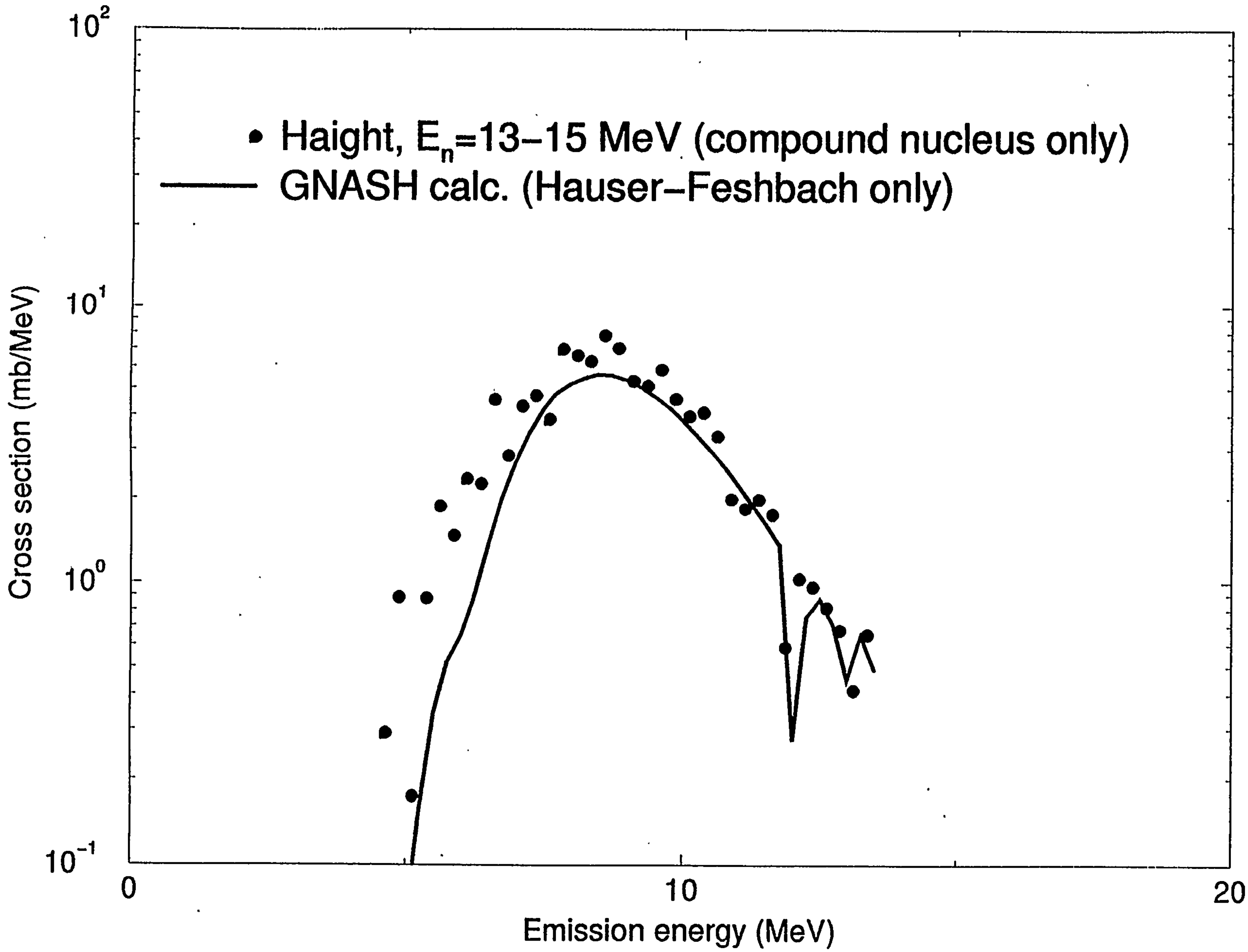
Fig 13

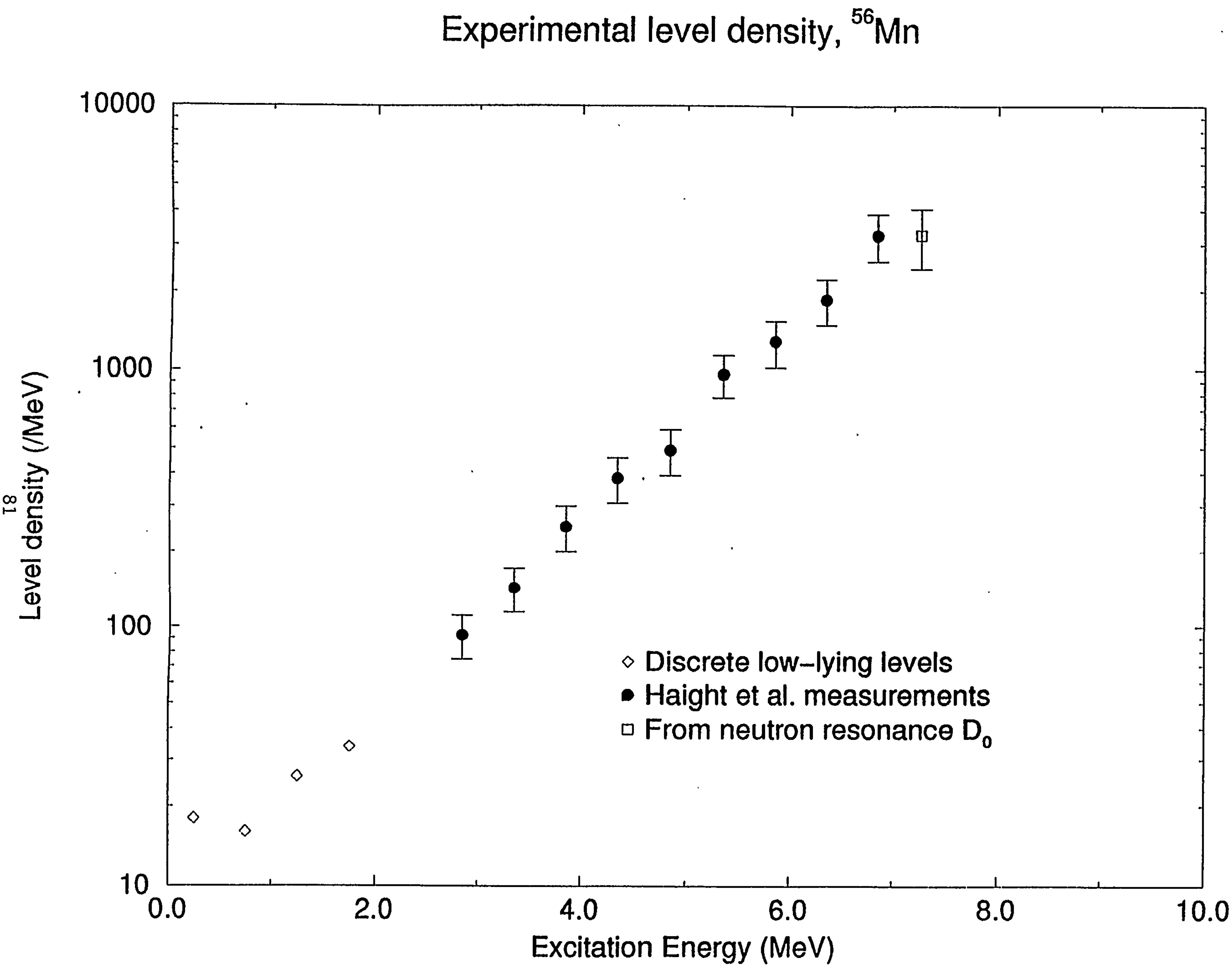
Level density studies

Method for extracting level densities using Haight (n, z) measurements from LANSCE:

- Enables level density in target nucleus and alpha decay channel to be determined. Many uncertainties from model calculations minimized by methodology used
- Model calculations modified, by adjusting level density in target nucleus, so that (n, α) data are fitted in discrete level region *where level density is known*
- Level density in (n, α) nucleus inferred by modifying calculated density by ratio of *exp/theory*
- Uncertainties are due to uncertainties in neutron and alpha optical potentials, and preequilibrium processes

14 MeV $^{59}Co(n,xa)$ emission spectrum




Experimental level density, ^{56}Mn
10000
1000
100
10
Level density (/MeV)
0.0
2.0
4.0
6.0
8.0
10.0
Excitation Energy (MeV)
Discrete low–lying levels
Haight et al. measurements
From neutron resonance D_0

Review of Experimental Activities for the U.S. Nuclear Reaction Data Network

July 1995 - February 1996

Donald L. Smith
Technology Development Division
Argonne National Laboratory

Second Coordination Meeting for the U.S. Nuclear Reaction Data Network

Golden, Colorado
13-14 March 1996

Introductory Comments

- 8 individuals from the current directory of NRDN participants are identified as being involved in experimental work.

- 6 reports have been received dealing with experimental work under the auspices of the NRDN.

- 7 of the 8 individuals involved in experimental work (88%) have contributed to these reports.

- 2 of the 8 individuals who have participated in this experimental work (25%) have indicated that they are either no longer involved in such activities or soon will leave the field (probably irrevocably).

- The contributions of many additional individuals, both inside and outside the network (in the U.S. and abroad), are also reflected in these reports.

- The reported work spans diverse aspects of low- and medium-energy nuclear physics, and is relevant to both basic and applied nuclear data needs as well as to the development of nuclear methodologies.

- Details on some of this work can also be found in the CSEWG Measurement Committee 1995 Annual Report (available from Brookhaven National Laboratory in hard copy form or at the BNL World-Wide Web site).

Contributors

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Colorado School of Mines
(F. Edward Cecil et al.)

Los Alamos National Laboratory
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Massachusetts (University of -Lowell)
(G.H.R. Kegel et al.)

National Institute of Standards and Technology (NIST)
(Allan D. Carlson et al.)

Ohio University
(Steve Grimes et al.)

Argonne National Laboratory

- Activation cross-section measurements < 15 MeV for reactions with medium- to long-lived products [$^{109}Ag(n,2n)^{108m}Ag$, $^{151}Eu(n,2n)^{150g}Eu$, $^{159}Tb(n,2n)^{158g+m}Tb$, $^{179}Hf(n,2n)^{178m2}Hf$, $^{107}Ag(n,2n)^{106m}Ag$, $^{176}Hf(n,2n)^{175}Hf$, $^{180}Hf(n,2n)^{179m2}Hf$, $^{46}Ti(n,p)^{46g+m}Sc$, $^{54}Fe(n,p)^{54}Mn$, $^{54}Fe(n,\alpha)^{51}Cr$, $^{60}Ni(n,p)^{60g+m}Co$, $^{63}Cu(n,\alpha)^{60g+m}Co$].

Status: Completed. Journal paper accepted for publication.
Basic Science: Nuclear reaction mechanisms. Level densities.
Applications: Fusion (nuclear waste disposal).
Collaborators: JAERI and LANL.

- Observation of photofission from ^{16}N decay gamma rays.

Status: Measurements completed. Data analysis in progress.
Applications: Anti-proliferation technologies.
Collaborators: JAERI.

- New radiography technique using ^{16}N decay gamma rays.

Status: Completed. Journal paper accepted for publication.
Applications: Contraband detection. Industrial and defense radiography. Nuclear waste management.

- Activation cross-section measurements from 5-14 MeV [$^{51}V(n,p)^{51}Ti$, $^{51}V(n,\alpha)^{48}Sc$, $^{52}Cr(n,p)^{52}V$ and $^{52}Cr(n,2n)^{51}Cr$].

Status: Measurements completed. Data analysis in progress.
Basic Science: Nuclear model development.
Applications: Fusion energy.
Collaborators: PTB-Braunschweig.

Colorado School of Mines

- Determination of an upper limit on contribution of $D(\alpha,\gamma)^6Li$ reaction to observed abundance of ^6Li in the universe.

Status: Work completed. Accepted for publication.
Basic Science: C.P. reaction mechanisms in light nuclei at stellar temperatures.
Applications: Astrophysics (nucleosynthesis).
Collaborators: Various mentioned.

- Measurements on deuteron reactions for ^9Be, $^{10,11}B$.

Status: Work in progress.
Basic Science: C.P. reaction mechanisms in light nuclei at stellar temperatures.
Applications: Astrophysics (nucleosynthesis).
Collaborators: Various mentioned.

- Measurements on $^7Li(d,\alpha)$ and $(^3He,p)$ reactions.

Status: Work completed. Accepted for publication.
Basic Science: C.P. reaction mechanisms in light nuclei at stellar temperatures.
Applications: Astrophysics (nucleosynthesis).
Collaborators: Various mentioned.

- Development of a high-flux C.P. spectrometer.

Status: Tests have been performed in a fusion plasma (JET).
Applications: Fusion reactor first-wall monitor. Diagnostic measurements at plasma and accelerator facilities.
Collaborators: Various mentioned.

Los Alamos National Laboratory

- (n,Z) reaction studies at WNR to ≥ 50 MeV. Measured (n,Xp) and/or (n,Xα) cross sections [Si, SiO_2, ^{51}V, ^{59}Co, $^{58,60}Ni$, ^{89}Y, ^{93}Nb, ^{181}Ta]. Studied of feasibility of measuring non-elastic cross sections with spallation neutron source.

Status: Data acquired. Analysis in progress.
Basic Science: Reaction mechanisms. Level densities.
Applications: Fusion energy. Design of spallation neutron source for tritium production and actinide waste burning.
Collaborators: U. of Vienna, TU-Munich and various others.

- Measured gamma-ray production from $^{208}Pb(n,Xn'\gamma)$.

Status: Preliminary measurements have been performed.
Basic Science: Level densities vs. angular momentum.
Applications: Data for shielding calculations.
Collaborators: U. of Saskatchewan.

- Measurements on the $^{17}O(n,\alpha)$ reaction.

Status: Experiment in progress.
Basic Science: Mechanisms for light-nuclei reactions.
Applications: Astrophysics (nucleosynthesis).

- 10-MeV n-p scattering measurements to resolve discrepancy in hydrogen standard.

Status: Measurements and analysis in progress.
Basic Science: Study of nucleon-nucleon interaction.
Applications: Standard for cross-section measurements.
Collaborators: NIST and Ohio University.

University of Massachusetts (Lowell)

- Neutron scattering studies for ^{169}Tm, ^{197}Au ^{235}U and ^{239}Pu at various neutron energies in the several-hundred keV to few-MeV range.

Status: Work on ^{239}Pu completed and accepted for publication. Measurements and data analysis in progress for the other nuclei.

Basic Science: Develop understanding of competition between direct and compound mechanisms for neutron interactions with heavy nuclei.

Applications: Fission energy.

Collaborators: None mentioned.

- Measurements of fission neutron spectra for fast neutrons on ^{235}U and ^{239}Pu. Developed "tagging" technique for distinguishing events due to nuclear fission from those due to inelastic scattering of neutrons (based on coincident detection of fission gamma rays with BaF_2 scintillation detectors).

Status: Work in progress.

Basic Science: Provides data to validate models of nuclear fission processes.

Applications: Fission-spectrum standards. Fission energy.

Collaborators: None mentioned.

National Institute of Standards and Technology (NIST)

- Measurements, analysis and evaluation activities for the $^{10}B(n,\alpha_{tot})$ and $(n,\alpha_1\gamma)$ standard reactions.

Status: An international collaborative effort is underway to perform neutron and gamma-ray measurements (by various techniques) from the keV energy range to > 10 MeV, and to analyze these data using the R-matrix formalism in order to generate a reliable evaluation for these important standard reactions over a wide energy range. Work is still in progress, although some of the earlier results have been published.

Basic Science: Neutron reaction mechanisms on light nuclei.

Applications: Development of a convenient neutron fluence standard to complement neutron scattering from hydrogen.

Collaborators: ORNL, Ohio University, LANL and IRMM.

- 10-MeV n-p scattering measurements to resolve discrepancy in hydrogen standard. [See report for LANL].

Status: Measurements and analysis in progress.

Basic Science: Study of nucleon-nucleon interaction.

Applications: Standard for cross-section measurements.

Collaborators: Ohio University and LANL.

Ohio University

- Neutron spectrum measurements at various emission angles for deuterons and protons incident on thick ^{9}Be targets. Required development of techniques to measure low-energy neutrons using Li-glass scintillators and a fission chamber.

Status: Measurements are being carried out in the 2-7 MeV energy range for incident C.P.s and the 0.2-15 MeV energy range for neutrons. A number of measurements have been performed and the data are being analyzed.

Basic Science: Study of light-nuclei reaction mechanisms.

Applications: Spectral data on reactions used for neutron interrogation, for neutron radiography and for medical radio-therapy using neutrons (BNCT).

Collaborators: ANL and MIT.

- Measurements of $^{27}Al(d,n)$ thick-target neutron spectra.

Status: Measurements and data analysis in progress. Detector development work involved in this study.

Applications: Development of standard spectra for neutron detector calibration purposes.

Collaborators: PTB-Braunschweig and ANL.

- Studies of the deuteron optical-model potential at energies near the Coulomb barrier for ^{27}Al and ^{56}Fe.

Status: Initial measurements completed for neutron, proton, deuteron and alpha channels from 2.5-7 MeV.

Basic Science: Development of the optical model.

Collaborators: None mentioned.

Summary Comments

- The measurement activities can hardly be characterized as "well co-ordinated". For understandable reasons, most of the experimental work tends to be motivated mainly by:
  --- Traditional interests and expertise of the researchers.
  --- Facilities and other resources that are available to the researchers.
  --- Convenient opportunities for collaboration (both in the U.S. and abroad).

- Nevertheless, the current activities are often very relevant to important issues in basic science as well as in the more applied areas, including:
  --- Acquiring a better understanding of nuclear reaction mechanisms and developing superior nuclear models.
  --- Satisfying some of the data needs for astrophysics.
  --- Developing new nuclear methodologies to address a variety of industrial, social and defense requirements.

- Communication between researchers can be enhanced by the efforts of the NRDN, but the formation of research collaborations is best left to individual initiatives.

- There is extensive foreign collaboration. Without that the U.S. experimental program would probably not be viable. Every effort should be made to continue to nurture these relationships. They benefit all the participating nations and are very cost effective.

Summary of the Astrophysics Task Force Meeting

M.S. Smith, ORNL
Golden, Colorado, March 13-14, 1996

A summary of nuclear data projects relevant for nuclear astrophysics that are in progress or planned by USNRDN members was presented by M.S. Smith (ORNL) at the USNRDN Meeting in Golden, Colorado on March 13-14, 1996. These activities include projects in measurements, compilations, modeling, evaluations, (reaction rate) calculations, and data dissemination. These projects, as well as issues concerning the evaluation of nuclear reactions and dissemination of data for nuclear astrophysics, were discussed at a meeting of the Astrophysics Task Force. Members of the Task Force present included M.S. Smith (Chair), F.E. Cecil, G.M. Hale, and D.A. Resler; other USNRDN members also participated in the discussion. The Task Force made the following four recommendations:

1. Evaluation Procedures: A group of nuclear astrophysicists and nuclear data scientists should evaluate a few (2-3) nuclear reactions of astrophysical importance, and provide extremely detailed documentation of the evaluation procedures and problems. This documentation, along with a hands-on demonstration (the details of which will be determined at a later date), should assist prospective evaluators of these reactions in learning modern evaluation procedures by example.

2. Upon consultation with colleagues, the Task Force chairman will determine the reactions to be evaluated.

3. The future roles of the Task Force include the following:

    a. Contribute to the nuclear data evaluations and expertise of the Nuclear Astrophysics Data Evaluation Steering Committee.

    b. Initiate, encourage, and publicize astrophysics data activities by USNRDN members.

    c. Recruit evaluators for nuclear astrophysics data evaluations.

    d. Interface with the Steering Committee and with other nuclear data organizations.

4. The Task Force should help determine the data dissemination needs of the nuclear astrophysics community, and should encourage and publicize ongoing data dissemination efforts.

Part of the discussion at the Task Force meeting focused on a proposal by David Resler (LLNL) and Roger White (LLNL) to expand their Thermonuclear Data File (TDF) into an Astrophysics Data File

(ADF). TDF, developed by White and Resler for fusion energy applications, presents users with fast, standardized, easily-updated, numerically-accurate access to the rates of the 5 plasma-burn reactions [such as t(d,n)alpha] as a function of temperature. These rates are generated from (user-selected) files of evaluated cross sections (stored at LLNL) on a minimal temperature grid and downloaded to the users' computer along with access subroutines -- including a four-point, cubic Lagrange interpolator to generate rates at any required temperature. This method is equal in speed to analytical parameterizations of rates as functions of temperatures, and has an intrinsic uncertainty of only 0.1%; better than analytic expressions. Modifications planned for this system include providing temperature-derivatives of reaction rates, useful for coupling nuclear reactions with stellar hydrodynamics, and the incorporation of analytic reaction rate formulae (from existing rate compilations) into ADF to enable the calculation of rates before large sets of evaluated cross sections are available. It was generally felt that ADF was an excellent proposed application of nuclear data expertise to problems of astrophysical importance. More information on ADF can be obtained from David Resler (daresler@llnl.gov) or Roger White (rmwhite@llnl.gov).

For more information on the Task Force or the status of its work, please contact Michael S. Smith at msmith@orph01.phy.ornl.gov.

Proposed new formalism for using Maxwellian-averaged reaction rates in astrophysics applications

D. A. Resler and R. M. White

Nuclear Data Group
Lawrence Livermore National Laboratory
March 1996

ABSTRACT: We propose to use our experience with the LLNL-developed thermonuclear data file (TDF) system to build and update a standard reaction rate file, the astrophysics data file (ADF), for use by the astrophysics community.

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Summary of some points of the February 3rd Organizing Committee at Caltech

- numerous efforts involved in reaction rates: Caughlan and Fowler, Woosley, EuroNet, etc.
- help needed in reaction evaluation, perhaps including methods
- reaction rates in one parameterized form very beneficial
- difficulties in extrapolation to unmeasured regions
- questions of formats, archival problems including control and updating information

In most of these issues, we believe the Nuclear Reaction Data Network can provide considerable assistance to the astrophysics community, based upon the experience/resources, e.g., NNDC, CSEWG, etc., in producing the U.S. evaluated nuclear data system, ENDF/B.

We believe the adaptation of the LLNL-developed thermonuclear data file (TDF) system for astrophysics applications could help to solve a number of issues relevant to astrophysics calculations.

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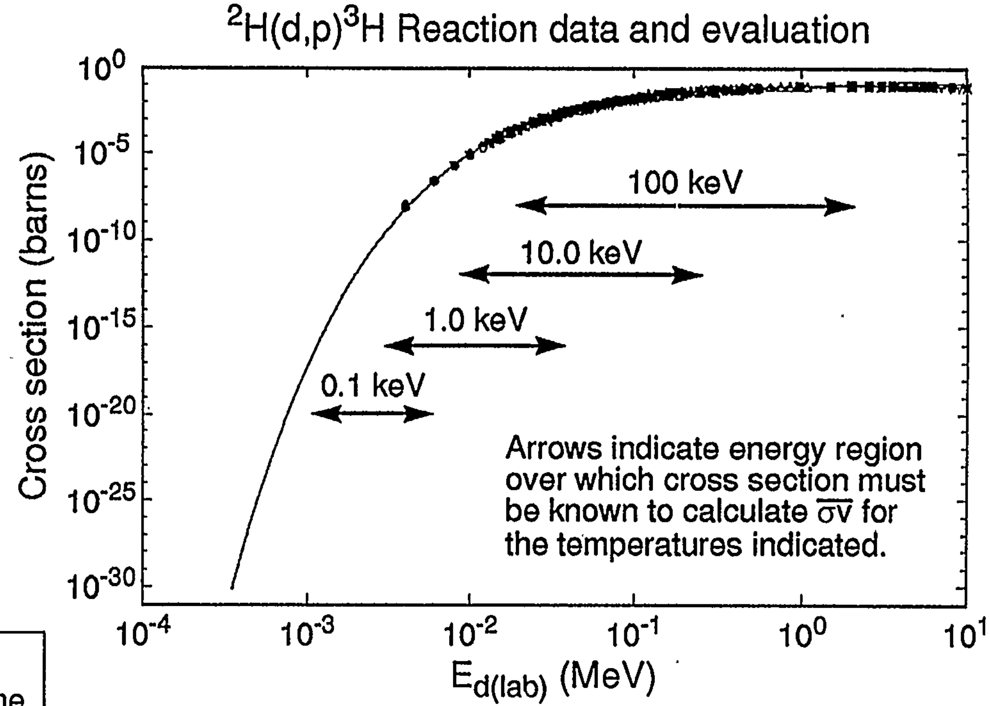
Proposed Astrophysics Data File, ADF, and access routine, ADFLIB

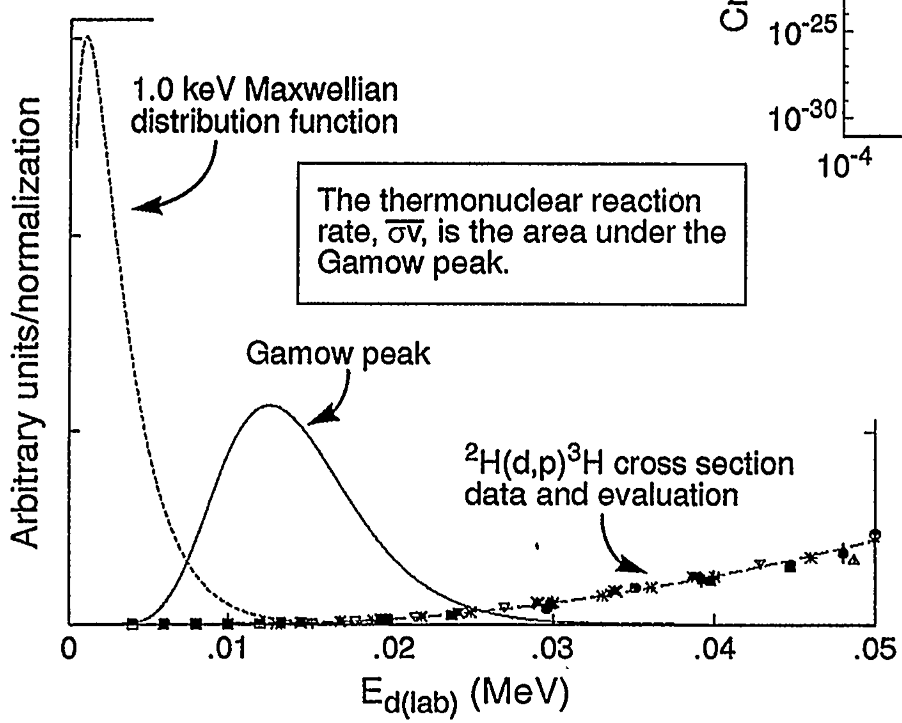
Advantages to astrophysics community:

- ✔ provides access to standardized astrophysics reaction rates and derivatives
- ✔ based on experience gained with TDF and TDFLIB system — LLNL UCRL-JC-109082 and -107158
- ✔ system as accurate as original reaction cross section from which reaction rate is calculated
- ✔ approach is accurate over temperature range from 100 eV to 1 MeV — can be extended
- ✔ simplicity and consistency — method is the same for all reactions
- ✔ no worry about whether a physical or mathematical approach is used
- ✔ data format issues become irrelevant with the ADF-ADFLIB approach
- ✔ easy to maintain and update
- ✔ speed is as fast or faster than current analytic calculations
- ✔ machine-independent (TDF system runs on MSDOS, Apple, Unix and Cray operating systems)
- ✔ accessed from Nuclear Astrophysics Web pages, e.g., LBNL/UCSC, LANL and NNDC
- ✔ upgrades facilitated by astrophysics steering committee adopting a CSEWG-like approach

Connection between the reaction cross section and the Maxwellian-averaged reaction rate

- Reaction cross sections are evaluated from measured data or calculated from nuclear theory.
- Maxwellian-averaged reaction rates, $\overline{\sigma v}$, and their derivatives are needed in astrophysics codes.
- For a given temperature, the product of a Maxwellian distribution and a reaction cross section is a "Gamow peak" shown below.





- Integration of the Gamow peak is required to produce the reaction rate from the reaction cross section.
- The reaction rate, typically in units of cm^3/sec, is a function of temperature, usually given in keV or Kelvin.

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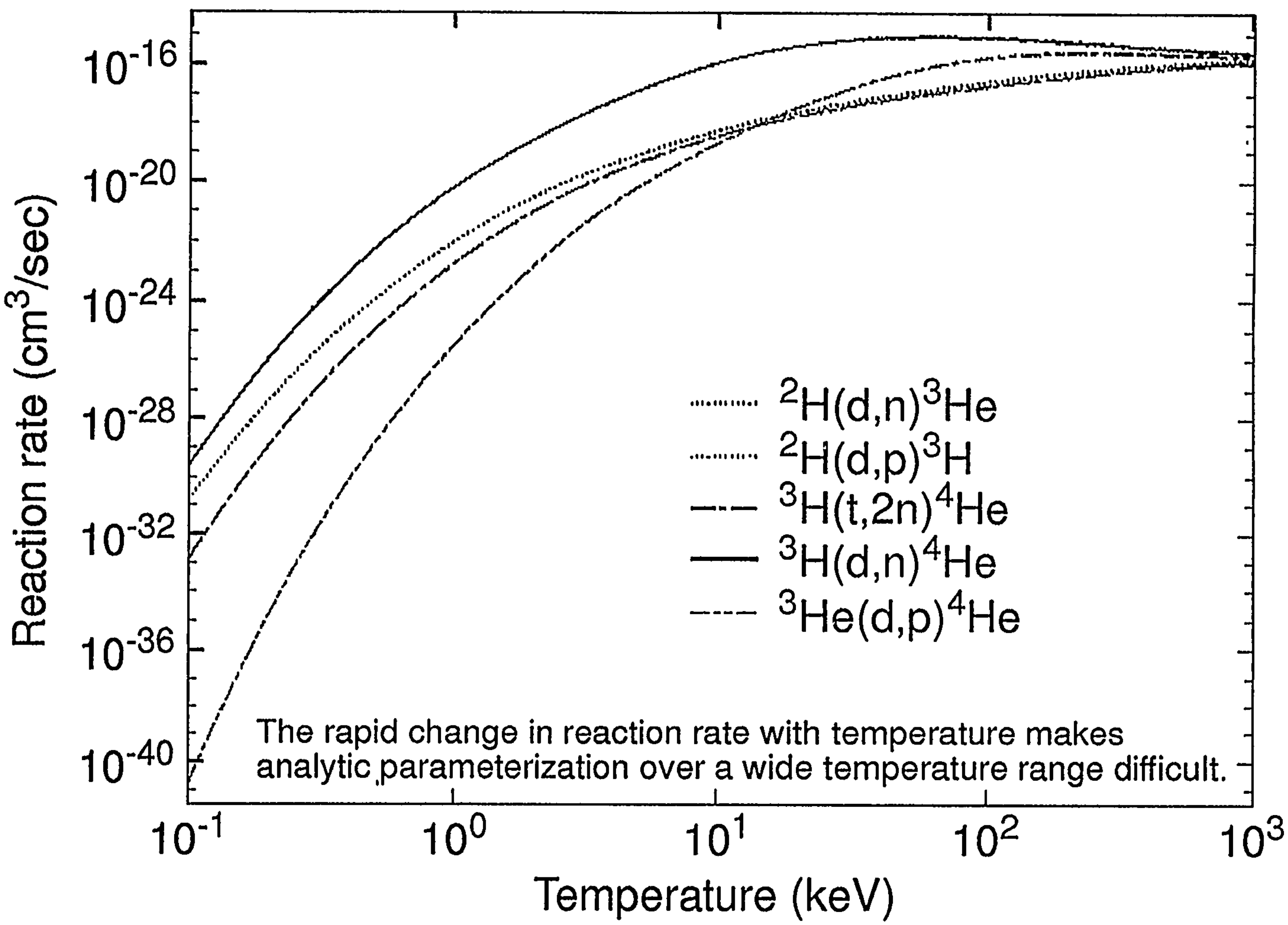
Reaction rates change by more than 25 orders of magnitude for temperatures from 100 eV to 1 MeV

Examples of Maxwellian-averaged reaction rates



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Reaction rate formalisms used in astrophysics simulation codes

Caughlan and Fowler, Atomic & Nuclear Data Tables, Vol. 40, No. 2, Nov. 1988

H2(D,P)H3

```
T913 = T9**(1/3), etc.
RATE = 4.13E+08/T923*EXP(-4.258/T913)*(1.+0.098*T913+4.39E-02*T923
      +3.01E-02*T9+0.543*T943+0.946*T953)
```

Parameterizations tailored for each reaction

Table 5. of Woosley's re-parameterization — from LBNL Web Page

d + d -> p + t

```
A1 = 0.116493E+02, A2 = 0.150095E-01, etc.
RATE = EXP(A1+A2/T9+A3/T913+A4*T913+A5*T9+A6*T953+A7*LOG(T9))
```

Thousands of reactions parameterized by same form

Reaction rates are parameterized in various analytic forms to facilitate calculations

Our proposal:

White, et at., Nuclear Data for Science and Technology, Proc. of the Int. Conf., May 1991; (Springer-Verlag, Berlin, 1992) p. 832.

$^{2}H(d,p)^{3}H$ is reaction no. 2

```
RATE = SVBLU(2,T)
```

Uses a four-point, cubic Lagrange interpolation of reaction rates pre-calculated on a minimum size, variable, logarithmic temperature grid. This approach maximized the accuracy (processing error including integration and look-up less than 0.1%) and minimizes both the data file size and access time.

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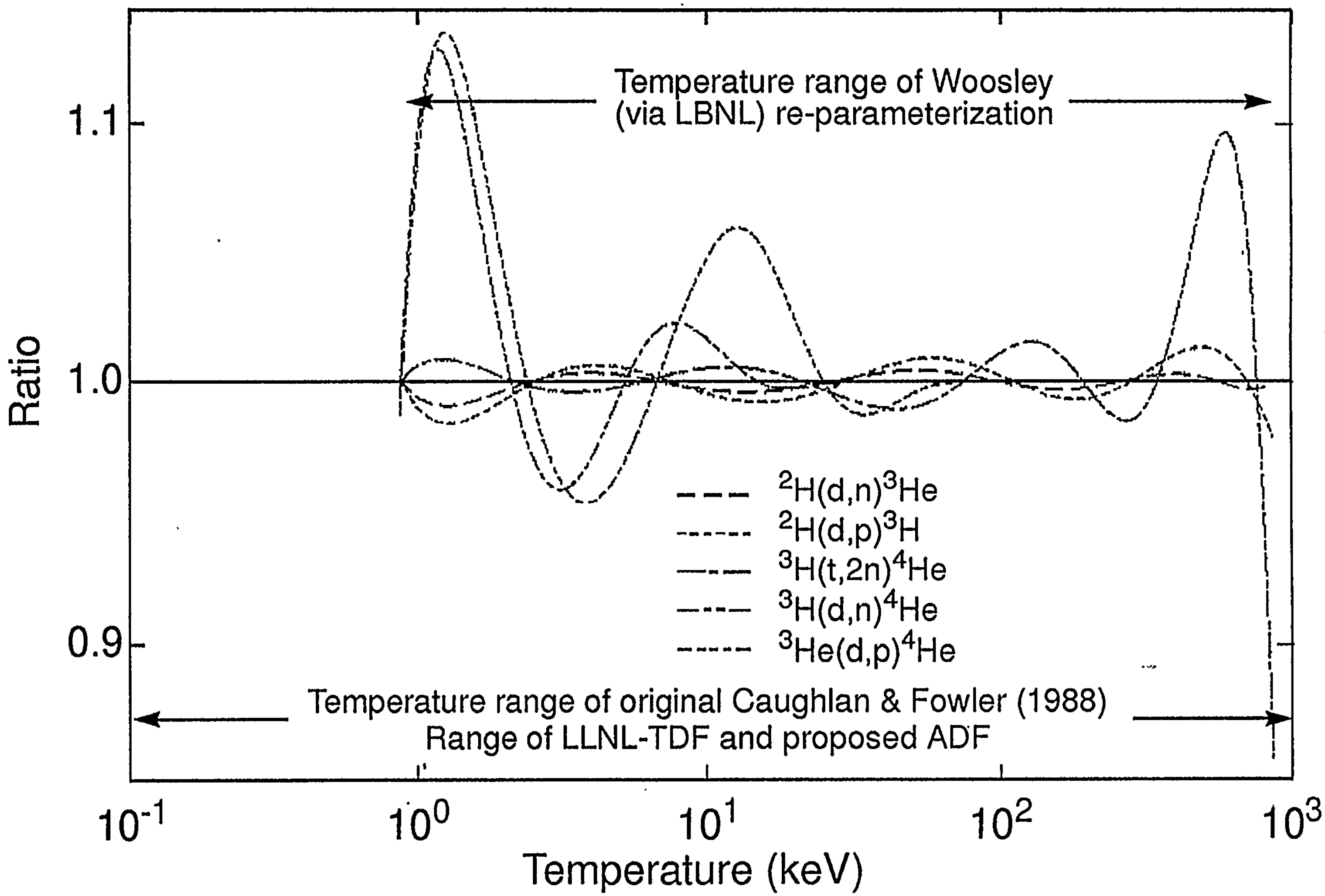
Ratio of Woosley's re-parameterization from LBNL's Web Page to Caughlan & Fowler (1988)



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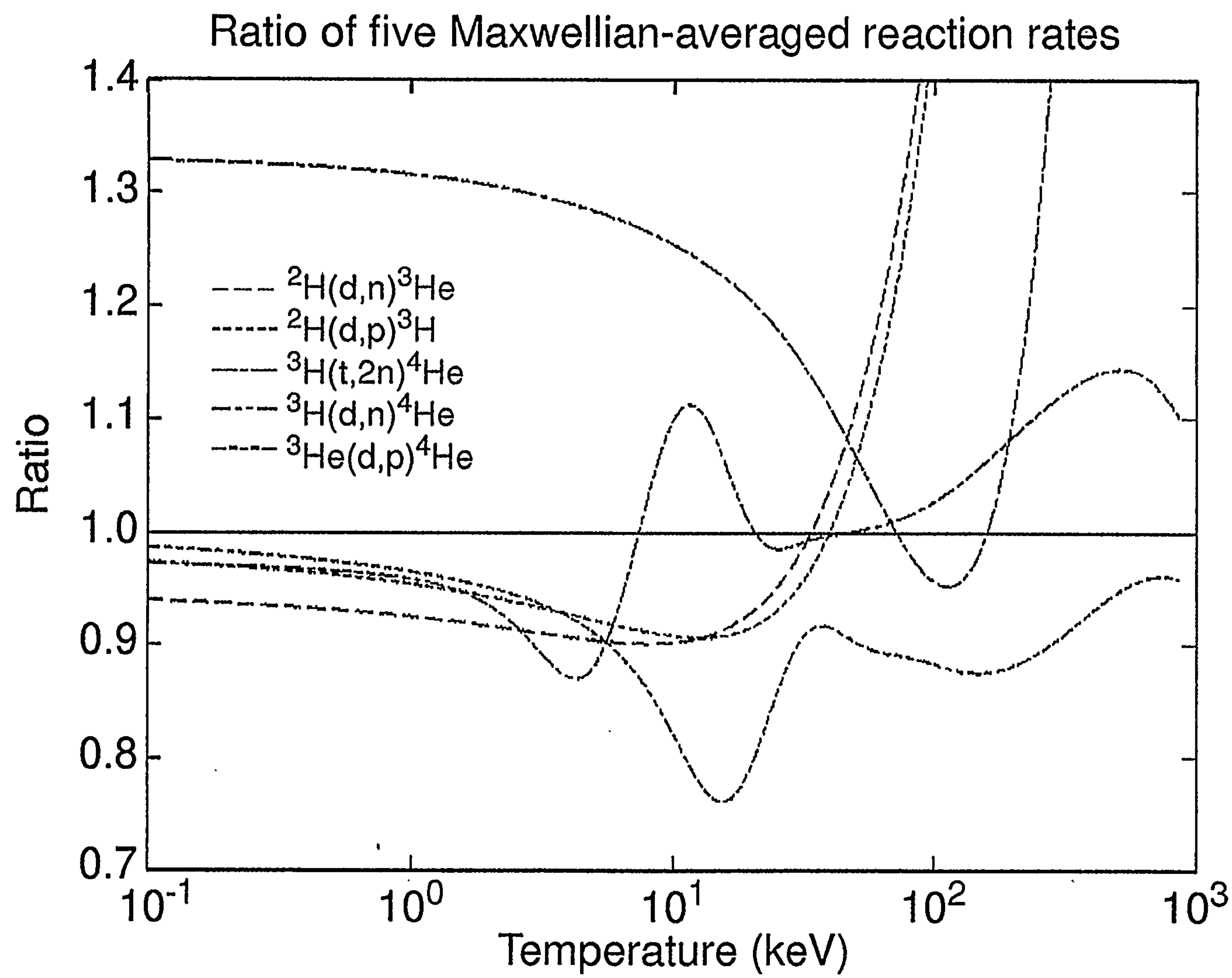
Ratio of Caughlan & Fowler (1988) to White, *et al.* (1991) — LLNL



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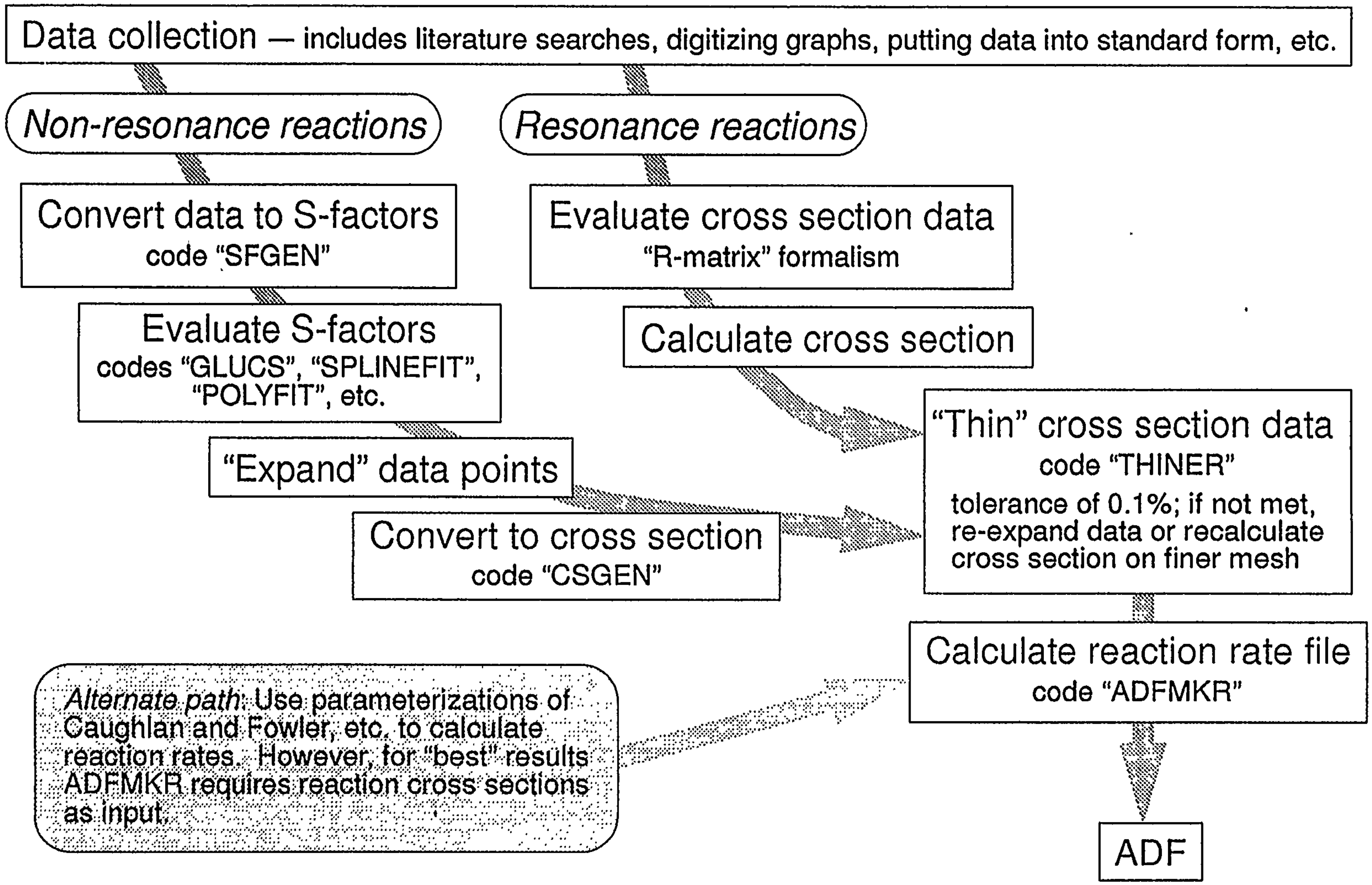
Recommended evaluation method for producing ADF file



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SOME GUIDELINES FOR THE EVALUATION OF NUCLEAR DATA

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March 20, 1996

Introduction

Modern data evaluation methodology draws upon basic principles from statistics. It differs from earlier *ad hoc* approaches which are completely subjective (e.g., eye guides to data) or are objective in a limited sense (e.g., combinations of reported data by a simple least-squares procedure without regard to correlations in the data errors or a careful scrutiny of the data included in the evaluation). In addition to utilizing more rigorous mathematical procedures, modern evaluation methodology involves taking great care to insure that the data which are being evaluated are equivalent to what has been assumed in the evaluation model and that the values are consistent with respect to the use of standards and other fundamental physical parameters. This short memorandum cannot substitute for more comprehensive treatments of the subject such as can be found in the listed references. The intent here is to provide an overview of the topic and to impress upon the reader that the evaluation of data of any sort is not a straightforward enterprise. Certainly evaluations cannot be carried out automatically with computer codes without considerable intervention on the part of the evaluator.

There are two types of information (data). One is objective data based on experimental measurements. The other is subjective data which, in the case of basic nuclear quantities, often emerge from nuclear model calculations. It is rare that there is sufficient experimental information upon which to base a comprehensive evaluation. Usually it is necessary to merge the complementary processes of measurement and modeling in order to generate such an evaluation. Furthermore, various nuclear quantities are not independent. For example, an evaluated file for a particular isotope or element, as it appears in ENDF/B or any other national or international file, consists of many interrelated components (e.g., partial cross sections) corresponding to various reaction channels. Partial cross sections must add up to the total cross section. Unitarity of the S-matrix appearing in theoretical calculations generally insures that this will be the case when these quantities are derived from nuclear models. However, this will not happen for experimentally derived quantities. Completely different experiments and techniques are involved in measuring individual partial cross sections (or combinations thereof), often leading to a rather messy state of affairs for the evaluator to sort out in carrying out an evaluation. What is measured is rarely equivalent to what one seeks to obtain. The relationship between what is measured (or calculated) and what is sought must be specified in order to carry out a proper evaluation. The experimenter or model calculator ought to be aware of this, but frequently this is not the case so it is left to the evaluator to bridge the gap in understanding. Ideally an evaluator ought to be well versed in all aspects of nuclear model calculations, nuclear data measurements and the analysis of measured data so that all the features of the raw materials which must be employed in his evaluation are well understood. Realistically this happens rarely, so comprehensive evaluations such as those appearing in ENDF are often the result of collaborations involving individuals with various complementary skills. This used to be feasible in-house at many of the individual laboratories in the U.S. doing nuclear data research, since in earlier times the resources available were far more extensive than they are now. Due to staff reductions, retirements, laboratory closings, etc., it is far less common now to find under one roof all the necessary skills needed to perform a comprehensive evaluation properly. Today inter-laboratory collaboration is essential. Adequate funding is also required to support the personnel involved in this labor-intensive activity.

Modern Theory of Data Evaluation

In rather abstract terms, the process of data evaluation reduces to the following: Given a data set $\mathcal{D}$ (which may include both objective and subjective information), determine what is the most likely (best) set of values for the evaluated quantities represented by a vector $\mathbf{p} = (p_1, p_2, \ldots, p_k, \ldots, p_K)$. The methodology described here is based on the application of three fundamental principles: i) Bayes' Theorem, ii) the Principle of Maximum Entropy, iii) the Generalized Least-squares Method. These principles are somewhat interrelated, as discussed in the references below. The following formalism is a fully probabilistic one in the sense that it offers a prescription for generating a probability distribution function $p(\mathbf{p})$ that embodies all the information available concerning the parameters $\mathbf{p}$.

Bayes' Theorem and the Principle of Maximum Entropy

In the present context, Bayes' Theorem assumes the form

$$p(\mathbf{p}|\mathcal{D}) = C\mathcal{L}(\mathcal{D}|\mathbf{p})p_a(\mathbf{p}), \tag{1}$$

where $p_a(\mathbf{p})$ is the *a priori* probability distribution that describes the knowledge of $\mathbf{p}$ before any new information is acquired, $\mathcal{D}$ represents the newly obtained information, $\mathcal{L}(\mathcal{D}|\mathbf{p})$ is the likelihood that the parameters $\mathbf{p}$ could have led to the data set $\mathcal{D}$, $p(\mathbf{p}|\mathcal{D})$ is the *a posteriori* probability distribution for $\mathbf{p}$ (after the new information became available) and C is a positive constant which insures that the *a posteriori* distribution is normalized, i.e., that the requirement $\int p(\mathbf{p}|\mathcal{D})d\mathbf{p} = 1$ is satisfied when integration is carried out over the entire space of physically reasonable parameters $\mathbf{p}$.

Suppose that the experiments and/or calculations which generated the data set $\mathcal{D}$ involve a collection of J physical quantities denoted collectively as $\mathbf{y} = (y_1, y_2, \ldots, y_j, \ldots, y_J)$. The generation of data entails uncertainties, therefore let $\mathbf{V}_y$ represent the covariance matrix (error matrix) for these data. Thus, $\mathcal{D}$ is represented by the values $\{\mathbf{y}, \mathbf{V}_y\}$. It is assumed that given parameter set $\mathbf{p}$ it is possible to calculate a set of J quantities $\mathbf{f}(\mathbf{p}) = [f_1(\mathbf{p}), f_2(\mathbf{p}), \ldots, f_j(\mathbf{p}), \ldots, f_J(\mathbf{p})]$ which are equivalent to the data values $\mathbf{y}$ (one-to-one). The Principle of Maximum Entropy enables a relatively simple expression for $\mathcal{L}(\mathcal{D}|\mathbf{p})$ to be written down directly, namely,

$$\mathcal{L}(\mathcal{D}|\mathbf{p}) \propto \exp\{(-1/2)[\mathbf{y}-\mathbf{f}(\mathbf{p})]^+\mathbf{V}_y^{-1}[\mathbf{y}-\mathbf{f}(\mathbf{p})]\}, \tag{2}$$

where "+" signifies matrix transposition and "-1" signifies matrix inversion. $\mathbf{V}_y$ is required to be positive definite. If the *a priori* knowledge includes a parameter set $\mathbf{p}_a$ and corresponding positive definite covariance matrix $\mathbf{V}_a$, then the Principles of Maximum Entropy states that

$$p_a(\mathbf{p}) \propto \exp\{(-1/2)[\mathbf{p}-\mathbf{p}_a]^+\mathbf{V}_a^{-1}[\mathbf{p}-\mathbf{p}_a]\}, \quad (3)$$

which is a multivariate normal distribution.

The Generalized Least-squares Method

The Generalized Least-squares Method (GLSM) follows from imposing a maximum-likelihood condition on Eq. (1), namely, that the GLSM solution for **p** is the one for which the *a posteriori* probability distribution achieves its maximum value. Because of the nature of the exponential function, combining Eqs. (1)-(3) leads to the requirement

$$[\mathbf{y}-\mathbf{f}(\mathbf{p})]^+\mathbf{V}_y^{-1}[\mathbf{y}-\mathbf{f}(\mathbf{p})] + [\mathbf{p}-\mathbf{p}_a]^+\mathbf{V}_a^{-1}[\mathbf{p}-\mathbf{p}_a] = \text{minimum}, \quad (4)$$

provided that the new and prior knowledge are essentially independent (a point which an evaluator must always keep in mind when collecting input data and prior information for a GLSM evaluation). If the relationship between **p** and **f(p)** is non-linear, in general it can be quite difficult to find a solution which satisfies Eq. (4). There are ways to do this based on numerical integration involving the probability distribution but this will not be discussed here. However, if the model is linear, i.e., if **f(p)** = **Ap**, then the *a posteriori* probability distribution $p(\mathbf{p}|\mathcal{D})$ is a multivariate normal distribution. The matrix **A** is often referred to as the design (or sensitivity) matrix. A complete description of the relationship between the acquired data and the parameters to be derived from the evaluation process is contained in **A**. Even if the relationship between **p** and **f(p)** is non-linear it may still be possible to linearize the problem via the approximate relationship

$$\mathbf{f}(\mathbf{p}) - \mathbf{f}(\mathbf{p}_a) \approx \mathbf{A}(\mathbf{p}-\mathbf{p}_a), \quad (5)$$

where the elements of matrix **A** are given by the expression $a_{jk} = [\partial f_j/\partial p_k]$ evaluated at $\mathbf{p} = \mathbf{p}_a$. The approximation in Eq. (5) is valid as long as the solution **p** does not differ too much from the prior estimate $\mathbf{p}_a$. In practice, most evaluations rely on being able to use this approximation, and therefore experienced evaluators try to set up an evaluation process so that this condition is reasonably well satisfied.

For the linear (or "linearized") model, the solution to Eq. (4) is contained in the following four equations which form the basis of data evaluation by GLSM:

$$\mathbf{p} = \mathbf{p}_a + \mathbf{V}_a\mathbf{A}^+(\mathbf{Q}+\mathbf{V}_y)^{-1}[\mathbf{y}-\mathbf{f}(\mathbf{p}_a)], \quad (6)$$

$$\mathbf{Q} = \mathbf{A}\mathbf{V}_a\mathbf{A}^+, \quad (7)$$

$$\mathbf{V}_p = \mathbf{V}_a - \mathbf{V}_a\mathbf{A}^+(\mathbf{Q}+\mathbf{V}_y)^{-1}\mathbf{A}\mathbf{V}_a, \quad (8)$$

$$(\chi^2)_{min} = [\mathbf{y}-\mathbf{f}(\mathbf{p}_a)]^+(\mathbf{Q}+\mathbf{V}_y)^{-1}[\mathbf{y}-\mathbf{f}(\mathbf{p}_a)]. \quad (9)$$

Two features of this solution are worth pointing out here. First, the solution yields not only a parameter vector **p** (the evaluation itself) but also a corresponding covariance matrix $\mathbf{V}_p$ representing the uncertainties in the evaluated quantities. Second, there is a statistical test provided *gratis* in the form of the quantity $(\chi^2)_{min}$. This quantity obeys a chi-squared distribution with J degrees of freedom. A comparison with standard tables of the chi-square distribution enables the evaluator to determine whether the input data and/or evaluation model are consistent. If inconsistencies are found then the input information and evaluation model must be examined to try to discover the source of the problem.

Practical Considerations in Data Evaluation

The procedure sketched out above is deceptively simple. In order to emphasize this point it is worthwhile examining each of the quantities appearing in Eqs. (6)-(9).

p (parameters to be evaluated):

It may seem obvious what it is that one wishes to evaluate but this is not always the case. For example, if an evaluated reaction cross section is desired vs. incident energy, this is really a continuous function. How should it be represented? One approach is to give "point" cross sections, namely, a set of energies and corresponding cross section values such that one can reconstruct the desired curve through interpolation. Another approach is to give group cross sections, namely, interval-average cross sections for well-defined energy intervals. If the desired quantity is a derived value, e.g., a Maxwellian-spectrum-average capture neutron capture cross section then this needs to be well defined before the evaluation process begins.

$\mathbf{p}_a$ and $\mathbf{V}_a$ (prior parameter values and their uncertainties):

In the GLSM method it is necessary to start from somewhere, even if it is only a guess. The prior parameters $\mathbf{p}_a$ might be values from an earlier evaluation (in which case the new evaluation should include only information not reflected in the earlier evaluation) or they may result from model calculations which are to be "adjusted" by the inclusion of new experimental data via the GLSM method (data merging). The associated covariance matrix $\mathbf{V}_a$ needs to be generated in a consistent way (e.g., it must be positive definite). This is not easy to do if the prior values are merely estimates, or if they are based on calculations using models that are very sensitive to fundamental nuclear interaction constants and that are not well validated to begin with. It seems rather intimidating to be forced to provide something as input to the codes which implement GLSM in the face of such sketchy knowledge. However, it should be comforting to know that assumed prior parameters with large errors generally carry very little weight in the GLSM process, and the solution tends to be heavily dominated by the new information if that is both extensive and relatively accurate. Still, this happy state of affairs can be thwarted if the correlations existing in the covariance matrices $\mathbf{V}_a$ and $\mathbf{V}_y$ are too strong, posing yet another potential pitfall for the wary evaluator!

y and $\mathbf{V}_y$ (new data and their uncertainties):

The most important thing to know here is what the data actually represent. Are the energies well established? What was the neutron spectrum in which they were measured? What standards were used? Are the various data collected from the literature truly independent or are there common sources of uncertainty? These and many other questions force the evaluator to examine the data and their documentation very carefully, and it is often necessary to adjust these data for changes in standards, to transform to new energy grid points, etc. This process of adjusting data prior to their evaluation is the most time consuming part of evaluation work, and often it is the most arbitrary one since poor documentation of published data is a notorious problem. Only when the input data are properly prepared can one hope to get reasonable results from an evaluation, regardless of the procedure used. This simply cannot be done by a "machine approach" without the aid of human scrutiny.

f(p) or **A** (the model which relates the data to the evaluated parameters):

This is a test of the evaluator's skill. The elements of matrix **A** can be generated easily enough from the selected model, either analytically or via numerical procedures. What is taxing is knowing just how a given piece of data relates to the parameters to be evaluated when the data in question are either undocumented or relatively poorly documented. Often it is necessary to reject certain data points because crucial information is lacking. For example, if a cross-section published in 1957 indicates an energy "14 MeV" could this mean 13.9 MeV or 14.1 MeV? If the physical quantity is known to vary rapidly with energy this is a crucial matter. Often the evaluator has to look at the original paper and, from a description of the experimental setup, try to answer the question. Early works frequently fail to indicate which standards were used or to give actual values for these standards when they are mentioned. Based on the date of the work and clues in the documentation it may be possible for an evaluator to estimate what was used in the original data analysis with reasonable reliability. Frequently that is not possible. If care is not taken to relate what was measured to what is sought then the evaluation process reduces to an exercise not unlike that of comparing apples and oranges.

$(\chi^2)_{min}$ parameter (test for confidence in the GLSM evaluation):

If all the data are reasonably consistent with the assumed uncertainties, and if the evaluation model is consistent with the input data, then $(\chi^2)_{min} \approx J$ (number of degrees of freedom) should result from the analysis embodied in Eqs. (6)-(9). If $(\chi^2)_{min} >> J$, then there are inconsistencies which need to be resolved by the evaluator. This may entail looking at all the data sets to see if they are discrepant or if the assumed errors are too small. It may also entail looking at the evaluation model which relates the data and parameters to see if it is somehow faulty. In any case, the evaluator must do something! An evaluation with a low degree of confidence (large chi-square value) is simply unacceptable.

Finally, it should be mentioned that computational round-off errors associated with the adjustment of data or with the GLSM evaluation process (which often involves the inversion of large matrices) can lead to inferior evaluated results. Evaluators need to insure that their analyses are carried out using adequate numerical precision.

Summary

Data evaluation, like making good wine or cheese, involves not only good quality ingredients but also depends critically on the "art of the evaluator". Combing the literature and experimental data files for the raw materials needed in evaluations has been likened to archaeology. A good evaluator must be a very patient individual. Modern data evaluation concepts, as embodied in GLSM, provide an unbiased approach to the merging of all types of data which become known to an evaluator, once it has been assembled, examined critically and put into a unified format for analysis. There are various codes that can do the actual GLSM calculations, depending upon the nature of the data (e.g., SAMMY, GLUCS, GMA, GLSMOD, UNFOLD, BAYES, etc.). The particular software which is used is generally of less importance than understanding the nature of the data employed and verifying its fidelity.

References

This list gives a good starting point for a more extensive study of the literature on this subject.

1. Donald L. Smith, "Covariance Matrices and Applications to the Field of Nuclear Data", Report ANL/NDM-62, Argonne National Laboratory (1981).

   [A basic primer on the concepts of modern data evaluation. Formulas are derived and some simple examples are worked through in detail].

2. Donald L. Smith, "Non-evaluation Applications for Covariance Matrices", Report ANL/NDM-62, Argonne National Laboratory (1981).

   [Extends the material presented in Report ANL/NDM-62 by giving numerous simple examples from everyday nuclear applications including detector calibrations, etc. Note that the methods used in analyzing experimental nuclear data are identical to those employed in nuclear data evaluation].

3. Donald L. Smith, Probability, Statistics, and Data Uncertainties in Nuclear Science and Technology, American Nuclear Society, LaGrange Park, Illinois (1991).

   [A comprehensive treatment of basic probability theory and the development of modern nuclear data analysis and evaluation methodology. Numerous simple examples are given and a detail search of the literature on nuclear data evaluation methodology up to 1990 is documented in the reference list. Available in hardback (269 pages) from the American Nuclear Society Press, LaGrange Park, Illinois 60525, USA. Price is $25 with a 10% discount available for ANS members (credit card orders accepted).]

4. Nuclear Data Evaluation Methodology, ed. Charles L. Dunford, World Scientific Press, Singapore (1993).

   [An extensive collection of papers on nuclear data evaluation reflecting the status of development up to 1992. Contributions to a conference on data evaluation held at Brookhaven National Laboratory.]

5. Donald L. Smith, "A Least-squares Computational 'Tool Kit'", Report ANL/NDM-128, Argonne National Laboratory (1993).

   [A handy reference on the basic principles of data evaluation by the least-squares method (both simple and generalized). Examples are given and computer codes that are useful for data analysis and evaluation are described.]

6. A. Pavlik, M.M.H. Miah, B. Strohmaier and H. Vonach, "Update of the Evaluation of the Cross Section of the Neutron Dosimetry Reaction ^{103}Rh(n,n')^{103m}Rh", Report INDC(AUS)-015, IAEA Nuclear Data Section, International Atomic Energy Agency, Vienna (1995).

   [Well-documented description of a recent evaluation effort at the University of Vienna. The procedures associated with collecting data from the literature and reviewing and adjusting it in preparation for evaluation by the least-squares method are discussed very well in this report.]

Summary of the Radioactive Ion Beam Task Force Meeting

M.B. Chadwick, LANL
Golden, Colorado, March 13-14, 1996

The Radioactive Ion Beam Task force met during the Nuclear Reaction Data Network Meeting in Golden, Colorado. Members of the Task Force present were: M.B. Chadwick (chair), S.M. Grimes, C. Kalbach, P.G. Young, along with other members of the USNRDN present who participated in the discussion (T. Massey, R.C. Haight, R.E. MacFarlane, R.M. White). At this meeting, research work by members of the Nuclear Reaction Data Network supporting U.S. efforts in Radioactive Ion Beam research was discussed, and we planned future activities in this area.

Excitation Function Calculations

M.B. Chadwick and P.G. Young discussed recent GNASH results from Los Alamos on the calculation of (p,xn) excitation functions producing proton-rich nuclides. Reactions on 58Ni have been completed, and the results have been communicated to Oak Ridge. Similar calculations for proton reactions on 64Zn and 70Ge are in progress, as are calculations of induced radioactivity in proton reactions on a 238U target.

Level Densities and Code Development

R.C. Haight, S.M. Grimes, and T. Massey discussed measurements of (n,z) reactions (where z represents alphas and protons), and their use in inferring nuclear level densities. Recent analyses by Group T2 in Los Alamos give preliminary results for the level densities in 59Co and 56Mn (showing consistency with the neutron-resonance result for 56Mn). An improved knowledge of nuclear level densities will significantly improve the accuracy of statistical model calculations used in RIB applications. Recent developments in modeling preequilibrium spectra were described by C. Kalbach. These developments are important for accurately predicting RIB (p,n) excitation functions, as preequilibrium mechanisms are the dominant contributor when the incident proton energy exceeds a few tens of MeV. R.M. White summarized recent work performed by M. Blann in extending the applicability of the ALICE code to higher energies. Finally, R.E. MacFarlane described the addition of a new RIB WWW site on the T2 Nuclear Information Service at Los Alamos.

Recommendations

1. High priority tasks supporting the experimental efforts at Oak Ridge are the calculation of (p,xn) excitation functions, to guide the choice of suitable RIB candidates, and calculations of induced radioactivity when a uranium target is used.

2. A new theoretical effort in the calculation of fission-fragment distributions is needed to guide the experimental efforts in producing neutron-rich products far from stability. The Los Alamos T2 group is well-placed to initiate such an effort.

3. The HERA gamma-ray detector, recently moved to LANSCE at Los Alamos, provides a new measurement tool which will significantly advance our understanding of fission processes and nuclear structure. It is important to closely collaborate with experimentalists working with HERA, particularly J. Becker, R.C. Haight, and R. Nelson, to improve our understanding of nuclear structure and reactions relevant to RIBs.

4. The experimental level density studies undertaken at Los Alamos and Ohio University are very useful in nuclear reaction calculations of RIB production. Theoretical support for these analyses by Group T2 should continue.

5. The Los Alamos WWW T2 Nuclear Information Service should be used as an interim area for posting RIB calculation results. Ultimately, some of these results should be stored in ENDF format at the Brookhaven NNDC. An option should be included on the WWW site so that visitors can request calculations for high-priority reactions.

6. Further research into isospin-dependent optical models, and nuclear masses, far from stability is needed for improved RIB model calculations.

7. The RIB Task Force should contact the North American Steering Committee for the Isospin Laboratory, to inform them of our activities, and to solicit their input on research areas where we can contribute.

8. The RIB Task Force should contact researchers working on RIB physics at Argonne National Laboratory, to explore areas of common interest.

For more information on the status of work in progress, please contact Mark B. Chadwick at: mbchadwick@lanl.gov.

MEASUREMENTS GROUP REPORT

Colorado School of Mines
Golden, Colorado, March 13, 1996

Participants: D.L. Smith (Discussion Leader), R.C. Haight, A.D. Carlson, T. Massey* and F.E. Cecil*

It was agreed that the report of the Measurements Working Group meeting held in Del Mar, California, during August 7-9, 1995, documented the underlying justification for a measurements activity within the U.S. Nuclear Reaction Data Network (USNRDN) and also described the basic strengths and capabilities of the U.S. infrastructure for low-energy nuclear physics measurements in general terms. The objective of the present discussions was to examine what specific resources appeared to be in place for measurements during the next 1-3 years, and to indicate what types of measurements are likely to be performed. Unfortunately, two other discussion groups (on astrophysics and radioactive ion beams) were held in parallel sessions and these attracted several individuals who might otherwise have attended the present meeting.

It appeared to the participants that the USNRDN measurement efforts could be examined in the context of addressing needs for the following five areas: astrophysics (Astro), radioactive ion beams (RIB), Relativistic Heavy-ion Collider (RHIC), electron beam physics (CEBAF/Bates) and basic physics (BP). The ongoing work, as well as that projected for the near-term (1-3 years), is likely to have only a relatively modest impact on the RHIC or CEBAF/Bates programs, but it is often difficult to foresee the longer-term impact of any measurement activity. Due to the limited time available for this meeting, it was decided to review the existing resources at the participating laboratories, to indicate some measurement activities which are likely to produce results during the next 1-3 years, and to speculate on where these data may have a beneficial impact.

The LANSCE (Los Alamos Nuclear Science Center) facilities are active and providing data relative to the USNRDN effort. These include the WNR fast-neutron white source and, to a lesser extent, the MLNSC moderated neutron facility. Unfortunately, the Los Alamos Tandem accelerator (with its unique triton beam capability) and the OMEGA-West reactor are now being decommissioned. At WNR there are two experimental setups which provide data for the USNRDN. A multi-angle spectrometer for (n;X,c.p) reaction studies is used in measurements over a broad range of mass number at neutron energies < 50 MeV. Emitted charged particles (c.p.) are observed over a broad range of energies (e.g., 1.5-50 MeV for protons). Targets under consideration are carbon, nitrogen, oxygen, silicon and various structural materials up to a mass equivalent of Ta. These experiments are providing data that often can be acquired by no other means. The HERA setup at WNR is used for (n;X,gamma) experiments which tend to complement the c.p. studies. The Los Alamos program impacts on Astro, RIB and BP (level density information) concerns. In principle, (n,gamma) measurements of interest for Astro could be carried out at MLNSC, but there is no

*Not present for these discussions, but shortly afterwards provided input which is included here.

activity at present because of limited manpower. Los Alamos is also involved in collaborations in the U.S. and abroad which support the interests of the USNRDN, including NIST and Ohio University for the standards experiments.

The National Institute of Standards and Technology (NIST) has a research reactor with a capability for measurements at very low neutron energies. However, current experimental activity in support of the USNRDN is being carried out exclusively at other facilities. The main emphasis now is on the B-10(n,alpha) and H(n,n) standard reactions. For boron, the goal is to establish this standard over a broad energy range extending continuously from very low energies up to several MeV so that a good overlap with the hydrogen standard can be achieved. Over the next 1-3 years the plan for boron is to complete analysis of existing data on the alpha-0 and alpha-1 branches (or alpha-tot depending on the nature of the experiment). There may be some cold neutron measurements at the NIST reactor, and possibly a new collaboration with IRMM-Geel, Belgium. The work on hydrogen aims to resolve a significant discrepancy (of several percent) between existing evaluations around 10 MeV, but there is also a plan to perform measurements at 14 MeV. The NIST effort involves collaborations with other USNRDN participants as well as foreign laboratories. The results of this standards measurement effort is likely to impact on all areas of interest to the U.S. nuclear physics program.

There are no facilities for low-energy nuclear physics experiments at Argonne so all current and projected activity involves work at other laboratories in the U.S. and abroad. Laboratories in Germany, Belgium and Japan are valuable collaborators in this program. Neutron activation measurements are being carried out at energies < 15 MeV to provide information pertinent to Astro and BP (model development). Potential uses for the energetic decay radiations from N-16 are also being explored (for Astro as well as industrial and defense interests). Argonne is collaborating with Ohio University in a study of neutron production from light nuclei, an area of interest for Astro as well as medical, industrial and defense concerns.

No one was present during the present discussions to speak for the program at Oak Ridge, but the ORELA white-source neutron facility is available and well suited for (n,gamma) measurements of direct interest to Astro. In fact, this is a designated national facility for such work.

Ohio University, in addition to being involved in the B-10(n,alpha) and H(n,n) standards work with NIST and Los Alamos, has an extensive program of measurements on light- to medium-mass nuclei. The 8 MV electrostatic accelerator at the laboratory, coupled with a new ion source capable of producing a wide range of relatively intense ion beams, represents a very important resource for the USNRDN experimental program. During the next 1-3 years, experiments will continue to examine neutron production by c.p. bombardment of light nuclei using both thick and thin targets. Thick-target measurements on Al-27(d,n) aim to develop a secondary-standard neutron source for detector calibration. This study involves collaboration with a standards laboratory in Germany. Measurements of (d,n) and (p,n) processes with both light- and medium-mass targets will provide unambiguous information on nuclear level densities for BP. Measurements on all deuteron-initiated reaction channels is providing valuable information on the deuteron optical model (OM). A whole new area of work to be explored involves reactions initiated by ions heavier than He-4 in the few-MeV energy range. This work should benefit both Astro and BP.

Colorado School of Mines (CSM) has been actively involved in measurements on c.p.-induced reactions for light-nuclei leading to c.p., neutron and gamma-ray emission. These measurements are carried out mainly at energies < 0.18 MeV, a domain of direct interest for Astro. This work is carried out at a Cockcroft-Walton (CW) accelerator facility which includes a flexible ion source and beam mass analyzer as well as a c.p. scattering chamber and various gamma-ray detectors. There are collaborations with other laboratories in work at higher energies and with the nuclear fusion community. During the next 1-3 years, it is planned to continue an ongoing investigation of (d,p), (d,alpha) and (d,n) reaction studies involving targets of Be-9 and B-10,11. This experimental work will be coupled with DWBA model calculations in an attempt to understand the reaction mechanisms of interest for BP. In addition, work will continue on the Li-7(t,p) and Li-7(He-3,p) processes. These data are very important for understanding primordial nucleosynthesis for Astro.

No one was present to discuss the measurements program at the University of Massachusetts - Lowell. This laboratory has a well-equipped 5.5 MV electrostatic accelerator facility. The present program is directed mainly toward neutron scattering from heavy nuclei, including the actinides, and toward examining the neutron fission process near the fission barrier in support of BP. However, work related to detector calibrations for RHIC was reported by this group at the earlier Del Mar meeting of the USNRDN.

INTERNATIONAL COLLABORATIONS IN THE AREAS OF APPLIED NUCLEAR THEORY AND DATA EVALUATION: NEA AND IAEA

P. G. Young and M. B. Chadwick
Los Alamos National Laboratory

* Presentation at Nuclear Reaction Data Network coordination meeting, Golden, Colorado, 13-14 March 1996.

IAEA COORDINATED RESEARCH PROGRAMS WITH STRONG NUCLEAR THEORY COMPONENTS

JUST CONCLUDED

- **Isomer Cross Sections for Fusion Technology (CRP ended June 1995).**
  This CRP included both theoretical and experimental efforts to determine high-priority activation cross sections in (n,2n) and (n,p) reactions. Nuclear model improvements were made including spin-effects in preequilibrium reactions, appropriate optical potentials, and gamma-ray cascades in discrete and continuum level regimes. Theoretical aspects of this project involved collaborations between Los Alamos, Livermore, Argonne, JAERI, and Obninsk.

IN PROGRESS

- **Gamma-Ray Production in Nuclear Reactions.**
  Theories of gamma-ray emission mechanisms are being studied. F. Dietrich (Livermore) and M. Chadwick are contributing to theories of direct-semi-direct, and statistical, gamma-ray emission. Recent research in measurement and theory of (n,x gamma) cross sections at LANSCE is also included.

- **Reference Input Parameter Library for Nuclear Model Caculations (Phase I: Starter File).**
  Purpose is to develop a Reference Input Parameter Library (RIPL) that will contain reliable, state-of-the-art parameterizations for modern nuclear model codes used in calculations of nuclear data for applications. Areas are (1) atomic masses, shell corrections, deformations (Chadwick); (2) discrete level schemes (Molnár); (3) neutron resonance parameters (Reffo): (4) optical model parameters (Young); (5) level densities (Ignatyuk); (6) photon strength functions (Kopecky); (7) continuum angular distributions (Chadwick).

- **Measurement and Evaluation of Helium-Production Data.**
  Purpose is to improve knowledge of helium-production cross sections. Haight, Baba, Vonach, Fu and others are involved.

<u>FUTURE</u>

- The IAEA is initiating a new CRP on photonuclear reactions and has asked T2 to help define. Plans include theories for modeling photonuclear reactions to 150 MeV, including quasideuteron mechanisms and angular distributions.

- Phase 2 of RIPL CRP. Purpose is to finalize parameter libraries, perform detailed testing, validation, and to develop processing codes.

AREAS OF STUDY IN RIPL CRP

1. Atomic Masses, Shell Corrections, and Deformations (Coordinator: M. B. Chadwick)

The latest Möller-Nix table of masses, shell corrections, and ground-state deformation parameters has been adopted and is available from Vienna (as well as from Los Alamos). Chadwick will supplement the table for nuclides lighter than oxygen with experimental values from the work of Audi et al.

2. Discrete Level Schemes (G. Molnár)

A master file suitable for nuclear model calculations is being developed from the more general ENSDF nuclear structure file. The Bologna format has been adopted for the final starter file. Three quantities that are directly useful to users will be derived and included for each nuclide in the file: U_c, the excitation energy limit below which the level scheme is thought to be complete, and N and U_{max}, the total number of levels and corresponding excitation below which the total count of levels (without necessarily knowing spins, parities, etc.) is thought to be complete. The quantities N and U_{max} will be determined from staircase plots which will be made available in the starter file.

3. Average Neutron Resonance Parameters (G. Reffo)

Efforts are underway to compare three different files (Bologna, Beijing, Obninsk) of average neutron resonance parameters and a procedure for selecting a final set has been outlined. The goal is to assess the three sets taking into account the different evaluation methodologies used and to arrive at a single recommended set.

4. Optical Model Parameters (P. G. Young)

Over the past year Young and Garg developed a trial format for compiling optical model parameterizations and have converted a collection of potentials to the format. Over the next year additional parameterizations will be included in the optical model library, and an effort to assess the best parameterizations for reaction theory calculations will begin. For the latter activity, it is planned to perform systematic comparisons of different optical model parameterizations with experimental data. One possibility for performing this task is for Dr. Kumar to spend several weeks at Los Alamos National Laboratory developing the necessary software and begin the necessary calculations. The ultimate goal is to determine a recommended set of optical parameters for reaction theory calculations, but this final result might have to await a follow-on CRP. By the end of this CRP we expect to have in place a substantial library of optical model parameterizations, with the possibility to retrieve parameters for particular nuclides for a selection of well-defined evaluated data sets, e. g., JAERI, China, Los Alamos, etc.

5. Level Density Parameters

A. Total Level Densities (A. V. Ignatyuk)

A plan is in place to derive total level density parameters (Obninsk) for three different level-density formulations from the recommended average neutron resonance parameters (Chinese and Obninsk groups) and the recommended cumulative number of low-lying levels (Budapest group).

B. Fission Level Densities (A. V. Ignatyuk)

A starter file of fission barriers and level densities will be prepared in a collaboration between the Minsk and Obninsk groups.

C. Partial Level Densities (M. B. Chadwick)

Chadwick is developing a text file that will review the various approaches for determining partial level densities. He will provide Fortran subroutines for computation with several of the approaches.

6. Gamma-Ray Strength Functions (J. Kopecky)

The Kopecky/Uhl enhanced generalized Lorentzian formulation has been accepted for obtaining gamma-ray strength functions. Kopecky will supply formulas for calculating giant resonance Lorentzian parameters, the models, and systematics.

7. Continuum Angular Distributions (M. B. Chadwick)

The Kalbach systematics have been recommended for determining continuum angular distributions for particle-induced reactions. Similarly, a model developed by Chadwick for calculating neutron and proton angular distributions for photonuclear reactions is recommended. Additionally, the Chadwick/Oblozinsky model is recommended for physics-based calculations. The various approaches will be described in the RIPL file, including subroutines for calculating the angular distributions.

NUCLEAR ENERGY AGENCY NUCLEAR SCIENCE COMMITTEE
Working Party on International Evaluation Cooperation
(last meeting: 17-18 May 1995)

SUBGROUP STATUS

No	Topic	Co-ordinator	Status
4.	^{238}U inelastic scattering cross sections	Y. Kanda, Japan	Final report before next WPEC meeting
6.	Delayed Neutron Data	A. Filip, France	Differential and integral measurements under way.
8.	Minor Actinide Data	T. Nakagawa and H.Takano, Japan	Benchmark phase on-going.
10.	Fission Product Inelastic Scattering	M. Kawai, Japan	Final report before next WPEC meeting.
11.	Resonance Region of ^{52}Cr, ^{56}Fe, and ^{58}Ni	C.Y. Fu, USA	Recommendations for Fe and Ni isotopes before next WPEC meeting. Cr analysis on-going.
12.	Nuclear Model Validation	G. Reffo, Italy	Work in different sub-sections under way
13.	Intermediate Energy Nuclear Data Evaluation	A. Koning, Holland T.Fukahori, Japan	On-going
14.	Kerma and Radiation Damage	R. MacFarlane, USA	Clairfication of progress needed
15.	Self-shielding in the unresolved resonance region	F. Fröhner, Germany	Investigation of streaming effects. Final report before next WPEC meeting
16.	Nuclear Level Densities for ^{52}Cr, ^{56}Fe and ^{58}Ni	C.Y. Fu, USA	On-going
17.	Fission Product Cross Sections	H. Gruppelaar, Holland	Newly started. Benchmark input data distributed.
18.	Epithermal capture of ^{235}U	C. Lubitz, USA	Analysis work on-going
B.	Formats and Processing for Application Libraries	R. Roussin, USA	On-going
C.	High Priority Request List	J. Rowlands, France	First version to be published by the end of 1995

MEETINGS

- Next International Nuclear Data Conference being organized by G. Reffo and will be held in Trieste, Italy, early June, 1997.
- NEANSC Working on International Evaluation Cooperation, Argonne National Laboratory, June, 1996.
- NEANSC Specialists' Meeting on the Nucleon Optical Model up to 200 MeV, Bruyères-le-Châtel, France, 13-15 November 1996.

International Collaborations in Measurements

Donald L. Smith
Meeting of the USNRDN
Golden, Colorado
13-14 March 1996

General Comments

It is likely that just about everyone associated with the USNRDN is involved in collaborative arrangement with one or more foreign scientists or laboratories. Certainly there are both explicit and implicit commitments in these arrangements.

Most of the European and Japanese programs involved in collaborations with members of the NRDN have nuclear energy development as their main objective. Of course, there are some notable exceptions (KfK astrophysics program). If the U.S. explicitly pulls away from supporting scientists to work in these areas, then this will definitely have a negative effect on relationships between U.S. and foreign scientists.

The problem is not so great in the area of basic science, i.e., nuclear data work to support the development of nuclear models, to improve standards, etc. Work in this area tend to be supportive of programs in traditional applied areas as well as more intellectual pursuits (e.g., astrophysics). The important factor is PACKAGING! It seems possible to package work in almost all aspects of low- to medium-energy physics in a way that is palatable to the sponsors of individual scientists. Collaborators A(U.S.) and B(foreign) can forge a relationship to investigate Topic C even though their motivations may be different. A study of neutron capture cross sections might be beneficial to both fission reactor development and astrophysics. There is always room for compromise in the selection of materials to study since all data tend to improve our understanding of the fundamental processes, and can enrich the development of modeling techniques which everyone favors.

Here are the origins of most foreign commitments: (i) participation in IAEA projects (CRPs, etc.), (ii) participation in NEA projects, (iii) non-formal individual arrangements (scientist-to-scientist), and (iv) participation in projects based on bi-lateral national agreements (Japan, etc.).

The following list is probably incomplete but it reflects my current knowledge of the worldwide situation.

Commitments Associated with the International Atomic Energy Agency (IAEA) Programs

- R. Haight (LANL) is a participant in a CRP on neutron-induced alpha-production reactions.
- D.L. Smith (ANL) has agreed to participate in a CRP (if formed) that would be dedicated to a continuation of studies associated with fusion-reactor radioactive waste, including an investigation of short-lived activation reactions.

Commitments Associated with the Nuclear Energy Agency (NEA) Programs

The following items are derived from the proceedings of the May 1995 meeting in Paris.

- D.L. Smith (ANL) has agreed to serve as co-chairman of the WPMA.

- D.L. Smith (ANL) and A.D. Carlson (NIST) are serving as leaders of Interlaboratory Collaboration projects (activation and boron n-alpha standards, respectively).

- A.D. Carlson (NIST) has discussed plans for further measurements on the boron n-alpha standard at IRMM. He visited IRMM and may possibly work with them on these measurements during 1996-97.

- It was suggested by D.L. Smith (ANL) that there be an NEA Specialists' meeting on activation cross sections to follow up on the 1989 Argonne meeting. NEA is willing to sponsor it, but no firm plans have been made.

- G. Kegel (UM-Lowell) is participating in the U-238 ILC headed by H. Weigmann (IRMM). New results on inelastic scattering from the first excited state have been promised.

- The U.S. has an implicit commitment to contribute to the NEA high-priority request list (with the demise of WRENDA) that is being maintained by J. Rowlands (Cadarache). A mechanism for gathering input to provide to Rowlands has not yet been discussed. Perhaps this is a responsibility of both NRDN and CSEWG? As long as the U.S. continues to submit requests to the international community for work to be done, there is an implicit responsibility to help in satisfying these needs.

- G. Kegel (UM-Lowell) indicated that his lab would measure neutron inelastic scattering cross sections for Pu-239 using a larger sample and Am-241, if a license for possession of the sample is obtained.

Arrangements Between Individual Scientists

- R. Haight (LANL) has several foreign commitments: IRK (Austria), Univ. of Saskatchewan (Canada), New Zealand,TU-Munich (Germany) etc.

- S. Grimes and T. Massey (Ohio University) are planning a collaboration with PTB-Braunschweig to develop the Al-27(d,n) thick-target reaction as a secondary standard neutron source for detector calibrations.

- D.L. Smith (ANL) has agreed to collaborate with A. Filatenkov (Khlopin Radium Institute, St. Petersburg, Russia) as an ISTC partner in a project to investigate various short-lived activation cross sections. Y. Ikeda (JAERI) is also participating in this collaboration.

- E. Cecil (CSM) has proposed to collaborate with scientists in Europe and Japan on charged-particle reaction studies of interest for astrophysics (at low energy).

Collaborations Based on Bi-lateral National Agreements

- D.L. Smith (ANL) is commited a program with JAERI on wide range of activation cross section measurements and investigations of potential new applications for activation processes. There is a similar commitment to IRMM (Belgium). Visits have been paid and experiments have been either carried our or are planned. Major part of the Argonne experimental program is based on foreign collaborations and use of foreign facilities.

- Yujiro Ikeda (JAERI) has indicated that his laboratory is looking for proposals on new subjects for scientific cooperation between JAERI and U.S. scientists. It is important to have a "framework" for such collaborative undertakings. Convenient frameworks are the NEA and IAEA programs, though bi-lateral cooperative arrangements with individual laboratories is also possible (Argonne has such an arrangement). Contact Don Smith (ANL) or Ed Cheng (TSI Research) for more information. This is an example of a foreign organization reaching out for collaborative ventures and offering to open its resources to U.S. scientists.