SUMMARY TALK COVERING APPLICATION-ORIENTED SESSIONS*

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INTRODUCTION

We thank our hosts for their hospitality and the opportunities offered us here to share ideas, successes, and failures. The Conference and Program chairmen, at least, have devoted significant shares of their professional lives to allow us these opportunities. I believe we have taken good advantage of the interchanges afforded us.

I was to cover the application-oriented talks, but I am quite pleased to say that in many cases I found that a single interesting paper contributed to the three areas. In any case I cannot cover in detail the wealth of relevant papers, but a few are mentioned just as examples. We look forward to the proceedings and to the future papers that will allow full value to be gained from the research reported at this conference.

The work presented here, in talks and in the posters that surround us, reflects our drives for excellence and productivity that have brought the world the rich base of nuclear data it now possesses. It is rich in variety of types of information, in accuracy, in utility, and in its intrinsic value measured by the great efforts that have been required to wrest information from reluctant Nature.

Unfortunately, our data base is also sometimes too rich in the range of choice offered a user who must select among values spread too broadly across the canvas; yet we have much cause to be proud of our community and its founders on whose shoulders we stand.

THOSE AT OUR FRONTIER ARE NOT LOST

I just completed Lost at the Frontier, a new little book by Deborah Shapley and Rustum Roy.[1] Relative to United States science policy, they ask whether, as we have pushed back the "endless frontier" of science, we have assured that basic science does nurture applied science and thence technology. They think the expected coupling has become rare in the U.S. because

"undirected" basic research is given favored elite status relative to "purposive" basic research, applied science, and engineering. Shapley and Roy believe the balance is presently more favorable in some other countries.

I believe that our little field is extraordinarily well balanced and integrated in this respect. This characteristic has been evidenced at this conference in the topics, the contents of the papers, and in the attitudes of the scientists and engineers.

We may take satisfaction that the projects of our medical doctors (often our own bodies), nuclear engineers, and other users will have full advantage from advances in basic physics.

WE ARE CONNECTED

Even within a field that smoothly grades from rather undirected research through purposive research to applied science and engineering, another problem can arise. At the beginning of this conference Alvin Weinberg asked, without bias, whether there has been a disconnect between our amassing of beautiful data and the real needs of technology.

My own answer is that the ability of engineers to take advantage of correct and detailed data is ever improving, and that the costs of doubt are very large in high technology whether in well-logging, radiotherapy, or energy conversion facilities. In part through meetings such as this one, nuclear data providers become sensitized to needs and will strive to work on projects that are appropriately directed.

VICTORIES

Next let us celebrate some victories represented here and won during the years roughly since the 1979 nuclear data conference in Knoxville. Like other victories, these will require some "mopping up," and close active guard will be required over the territory won.

Nonfuel actinide cross sections. The energy-dependent cross sections of the actinides produced in fission reactors, other than ^{239}Pu, were very poorly known ten years ago. Spurred partly by investigations of the "actinide burning" concept, international workshops identified accuracy requirements for the handling of spent fuel and found that these goals were far from being met. In some cases there was inadequate accuracy for estimation of operating reactor performance. As a result of considerable international attention, that situation is now very much improved. Many of these cross sections have now been measured two or three times with an acceptable range of values. There are two or three integral experiments in fast reactors now underway

to test these cross sections. Though there are some differences among the data sets, I think we can take pride in this actinide cross section "victory."

Fusion charged particle reactions. In the last few years the cross sections for the charged particle reactions important for fusion programs have been much improved. We heard here about the large share of that work performed at our host Laboratory. I understand that those cross sections now seem to be well-enough known. We applaud the success in those difficult experiments.

Lithium-7 breakup reaction. At our Knoxville meeting there was a large discrepancy among cross sections for the important $^{7}Li(n,n't)^{4}He$ reaction. Since that time a body of information has been developed which is much more nearly adequate, though I understand from the review paper at this conference that the presently estimated overall uncertainty in fusion blanket breeding gain remains somewhat too large.

Neutrons per fission. For the number of neutrons emitted from fission, there is now reasonable assurance that the overall uncertainty averaged over a reactor neutron spectrum is no more than ~0.3% even for fast reactors. However, questions still remain about η as a function of the energy in the thermal energy region, as reported here from the French critical experiment program. In any case our knowledge of $\bar{\nu}$ as a function of E for the fissile isotopes has become quite good, thereby erasing the situation as the "scandal" it was termed at an earlier meeting in this series.

Decay heat from fission products. In recent years there has been a large volume of data gained, both integral and differential, related to decay heat following fission of the major reactor fuel nuclides. At this conference time dependent beta and gamma energy emission data were reported for ^{232}Th and ^{238}U. No such data had been available previously. In addition, nuclide-by-nuclide data for the important fission products has been refined and work has been done on the theories that can indicate the division of energy between beta and gamma rays for those short-lived nuclides for which decay schemes are not know. The primary decay heat data are now in reasonably satisfactory form. However, I believe there has not been a comprehensive combination of all available information in recent years that would make the latest decay heat data available to users.

The form of the fission spectrum. For many years the form of the fission spectrum for practical applications was taken to be either a Maxwellian spectrum or a Watt spectrum. As we heard at this conference, there are now available practical theories which allow one to include a little more physics into the form

of the spectrum. This form can be combined with experimental observations, or for less well-studied nuclides theory can now perhaps be trusted to give a reasonable approximation to fission spectra. Further strides are possible to include more physics knowledge in the projected fission spectra shapes, but one cannot doubt that important progress has been made.

Neutron scattering differential cross sections. As one listens to sessions here and looks at the posters that surround us, one must be impressed with the beautiful neutron scattering data that is now available to help determine appropriate optical model parameters. The data appear to be of a quality almost comparable to the similar data obtained in the past for charged particle scattering. These experiments are not easy. The fact that techniques have been developed and the energy expended to provide such data is remarkable and commendable.

WELCOME TRENDS

Next I want to welcome some favorable trends in our field. In these cases most of the work remains to be performed, but new ground has been broken and avenues paved that will lead to the victories for us to count at future meetings.

N(E,t) for delayed neutrons. At this meeting I discovered that there exist detailed neutron spectra as a function of time after fission and nuclide-by-nuclide for many specific delayed neutron emitters. As this data base is rounded out, estimates from first principles of effective delayed-neutron fractions, or their equivalent, will be possible. Reactor kinetics, whether based on a limited number of effective delayed neutron groups or not, will have achieved a higher plane of detailed understanding than has been possible up to now. We look forward to learning what improvements in reactor kinetics calculation this new level of knowledge will make possible.

Internationally focussed efforts to resolve outstanding problems. At this meeting we heard reports on the NEANDC Committee set up to study discrepancies in the parameters of the 1-keV resonance in ^{56}Fe and the resonance region in ^{238}U. While those problems have not yet been entirely resolved, it is apparent that with the help of the international cooperative committees it has been possible to focus effective efforts on these distressing situations. I hope that these efforts will be a paradigm for future international technical coordination.

Dosimetry cross sections and techniques. In the last few years, the field of neutron reaction rate dosimetry seems to have become integrated into the overall field of neutronics, nuclear

data, and nuclear techniques. I do not wish to imply that there was previously a total schism, but earlier there had been a tendency in applied neutron dosimetry to utilize cross sections and techniques somewhat different from those used elsewhere in work with the same reactions. This situation derived from our earlier inability to provide adequately accurate cross section data and reduced overall credibility. Change has been gradual, but I no longer sense such a schism. With improved cross section and dosimetry analysis techniques I believe results are improving. It is a difficult field and one that will always face questions of data and technique.

Fusion integral experiments. Integral experiments to test fusion-related cross sections, usually driven with neutron generators based on the heavy hydrogen reactions, were reported here in some detail. In the last few years these experiments have been designed, performed, and analyzed with a higher level of sophistication of technique than might have been expected at this stage of fusion energy development. We applaud this careful work. The trend bodes well for the future of this technology, and needs to be continued as designs for fusion systems evolve.

Data adjustment. Papers at this conference involving the adjustment of nuclear data seem to me to indicate an improved understanding of the strengths and weaknesses of this technique. On the one side, "adjusters" showed concern whether mere data fitting was being used that could not be extrapolated beyond the range of the integral experiment data base, and particular concern about the physical significance of any adjustments. On the other side, and I think because of the knowledgeable approach by adjusters, providers of differential cross sections have become more comfortable with those adjustments that are performed. Though there is marked progress in this area over the last several years, I believe the definitive paper on nuclear data adjustment, how one can best employ the consistency between differential and integral experiments and when one should do so, has yet to be written.

More rigorous analysis of differential data. Commensurate with the more careful use of integral data identified above, I note the use of improved data reduction and analysis techniques at several laboratories. This is important if full value is to be obtained from experiments and in particular if appropriate measures of experimental uncertainty are to be obtained. Rigorous analysis is now understood as a goal for experiments on cross sections of practical importance even though the techniques for performing proper uncertainty analysis in the case of data sets involving a large number of experimental points have just been presented at this conference.

Reconsideration of "completed" data areas. Some important cross sections received detailed attention 15 or 20 years ago when modern accelerators and detector equipment first became available. I refer to the cross sections of the standards, to the resonance regions of the principal thermally fissile nuclides, and to other such mainstay data. It became ingrained in our minds that these data areas had been completed. This image extended beyond the time that complacency was appropriate. Now I note general understanding that these data areas must receive new attention. At our Laboratory, for example, there is work again in the resonance region of ^{239}Pu. I believe there is interest elsewhere in similar projects. I hope this trend will lead to an upgrading of our most important data. Serious effort is required because the earlier work was indeed thorough and the best that could be done at the time.

Particle emission cross sections for fusion systems. Serious efforts have now been initiated at several laboratories to meet the long-stated requirements for neutron and for charged particle emission spectra for materials being considered for fusion reactors. In both areas the experiments are quite difficult and time-consuming even at ~14 MeV where D-T sources can be employed. The progress in these areas should be nurtured.

CHALLENGES

At this meeting many challenges were offered for us to meet in the future. Let me list a few that pertain to "data for applications."

Neutron kerma data for neutrons above 10 MeV. The kinetic energy release in tissue for neutrons has been relative poorly known once the incident energy is high enough that scattering on hydrogen does not dominate the release. Because of the use of fast neutrons in radiotherapy it is important that neutron charged-particle reactions, in the components of tissue and in carbon (a component of dosimeters), ought to be known quite well. There are serious starts on this problem as indicated in the papers from University of California Davis, but it is apparent that considerably more work is required to assure that the established accuracy needs have been met.

Helium production from neutrons on Boron-10. We heard at this conference a review of the long-standing discrepancy between the U. S. differential data evaluations and the observed production of helium in boron in various clean spectrum facilities. That discrepancy has been pointed out with some force previously, but as the integral data have been looked at with increasing care it

has become more and more difficult to be complacent about the discrepancy in the range of 10-15%. We think of boron as a standard for cross sections even though it is used in fluxes with neutron energies far higher than the region where its cross sections have ever been a standard. I think we now must take this discrepancy seriously and re-examine experimentally all the neutron cross sections with boron to strengthen the relevant data base that now contains many contradictions.

The resonance and thermal regions of fuel nuclides. As indicated above, we have too long left the status of resonance analysis for the important fissile nuclides in static condition. We heard at the meeting that there is consideration again for severely undermoderated light-water reactors in which neutron reactions in the resonance region would dominate. Even for the present commercial thermal reactors there have been longstanding indications that the resonance region data in use induce some discrepancies with integral data. Upcoming data in the thermal region from BCMN, the Euratom Laboratory in Geel, Belgium, may help resolve questions long raised there only by careful remeasurement and data analysis. There is now emerging a widespread acceptance that a concerted program of remeasurement and data analysis is required.

Tightening requested accuracies. We heard at this meeting requests for narrower tolerances for uncertainty in evaluated nuclear data. For example, Salvatores suggested that the selfshielding coefficient in ^{238}U should be known to 1%. Also, we heard indication that considerably increased precision will be needed in cross sections that affect fusion blanket breeding gain. We are alert to learn of such needs from persons close to the application areas.

I hope that we will accept and meet all these challenges in the next years. They can be met or closely approached with incrementally improved experimental techniques and analysis methods, but it must be done with seriousness and without hurry.

CONCLUSION

While meeting the "normal accuracy" needs of various applications, we must emphasize our commitment to excellence and pay particular attention to the more important and demanding challenges. Often we will find that problems associated with determining the cross sections of a particular important nucleus can best be understood through an international dialog.

Secure in our own knowledge that these efforts are justified, we must increase our work to obtain the necessary financial support.

REFERENCES

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[1]D. Shapley and R. Roy, Lost at the Frontier, ISI press, 3501 Market St., Univ. Citay Science Center, Philadelphia, PA 19104.