SOME PERSONAL REFLECTIONS

by

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Introduction

As the final player in this scene, I would like to convey some personal reflections on this Conference. I believe that this is fitting and proper, as the two previous speakers have given a comprehensive technical overview. My reflections will mirror my personal interests: microscopic experiments. I shall not attempt to "touch all bases" (my Japanese friends will understand that terminology, as they play a good game of baseball); rather, I shall only cite selected areas. The views may be right or wrong, but hopefully substantive. I may well be criticized for the opinions, but I am too old a fox to worry.

Some General Trends

I sense a trend, from the strong focus on engineering fission-reactor data of the previous Conference, to a diversity of applications of nuclear data, particularly to fusion-system data. This trend is healthy and should be encouraged if the field is not to stagnate.

In the beginning, the keynote speaker stressed the importance of international cooperation. This theme emerged elsewhere throughout the Conference. Cooperation is increasingly important as resources become more limited throughout the OECD area, and the technical issues are more quantitative and demanding. Cooperation has been essential to the successful solution of some of the most troubling problems, as demonstrated by the results of the 56-Fe and 238-U task forces we have just heard described. Similar successes were evident in a much wider scope (e.g., the JUPITER program and the cooperative fusion-blanket programs). It seems to me that, in this context, the future is clear: there should be increased international cooperation, extending from the initial concept to the final evaluation, and beyond.

At the 1978 Harwell Conference, William Hammon pointed out that emergency engineering needs for nuclear data were relaxed, and thus there was an opportunity to enhance the underlying physical understanding. This concept was extended at the 1985 Santa Fe Conference by Michaudon to include the most fundamental investigations of the neutron-nuclear interaction. In my view, the results of these suggestions have been mixed. Some very impressive fundamental studies have been described (e.g., astrophysical investigations; a deeper understanding of the fission process; and the potential for fundamental studies of the nucleus, such as the search for parity violation). However, the Conference emphasis remained on applied engineering issues.

Some data problems are of a statistical nature and are very specific (e.g., detailed resonance properties), and there appears no alternative to explicit, point-by-point experimental investigation. Other classes of problems lend themselves to model interpolation, coordinating experimental measurements and calculated interpolation for optimum efficiency. The latter approach was not much in evidence. In the future, selected measurements could be guided by the objective of validating calculations that subsequently provide the desired information, possibly even extending to the substitution of model parameterizations for lengthy listings of redundant numerical quantities. For example, why do we measure a multitude of energy-averaged total cross sections when a far more limited but precise data base can be well interpolated with the conventional optical model? The implementation of such a correlated measurement and calculation approach would mark a fundamental and valuable change in measurement philosophy.

Data for Fission Energy Development

There was a wealth of new fast neutron fission cross section data, extending from several hundred keV to > 14 MeV, and, in one instance in a preliminary manner, to ~ 400 MeV. Below ~ 20 MeV the consistency of the results is very good. The values are generally ratios (to 235U), with accuracies in the ± 1.5-3% range. A careful horizontal evaluation is needed to determine the exact situation, but I estimate $\sigma_2 = 1.15\%$ from 0.2-20 MeV for the prominent actinides. Any future $\sigma_2$ ratio measurements must be very precise ($\sigma_2 < 0.5\%$) if they are to make appreciable impact. Such precise measurements will not be easy as they must address the mass scale and the 235U standard, in addition to the ratio determinations themselves, to new and historically untamable accuracies. In view of the magnitude of such an endeavor and the present status, I doubt that the fast-fission cross sections of the common actinides will be much improved in the foreseeable future.

The low-energy fission and capture cross sections of 235,238U and 239Pu have long been a matter of concern as macroscopic thermal reactor characteristics appear inconsistent with microscopic cross section values. This "discrepancy" is a safety concern, highlighted by the Chernobyl accident, and it was recently studied by the NEACRP. Perhaps that accident motivated an extensive set of experimental measurements. In any case, some remarkably accurate low-energy actinide cross sections were reported at this Conference. These results show major differences in normalization and structure from widely used evaluations, but generally there were no surprises. Thus, I feel that the "discrepancy" lies with the integral measurements and/or their interpretation, rather than with the microscopic data. It should be noted that the techniques employed in these precise measurements have a wider and more fundamental applicability, extending to the study of the basic properties of the neutron.

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At this Conference we have seen a unique convergence of: 1) the results of a decade of precise measurements of 235, 238, and 239 Pu resonance properties; 2) interpretations by outstanding specialists at the peak of their professional capability; and 3) the application of the best physical models and fitting procedures. I doubt that this combination will occur again in my lifetime. The results, now nearing completion, are of a unique quality, and probably will meet the majority of fission-reactor needs for actinide resonance data into the foreseeable future. Improvements may very well be impossible with contemporary understanding of physical mechanisms and measurement technologies. This achievement in the area of actinide resonance properties is not an outstanding aspect of this Conference. There was some additional high-quality resonance information of relevance to fusion energy development, notably in the structural-material region, but otherwise new resonance information was limited.

Fast-neutron capture (primarily in 238 U) remains a concern, and I found no new information at this Conference. Perhaps that is to be expected, as the fast capture in 238 U was a part of the unified evaluation for ENDF/B VI standards, and the results, with uncertainties, are not yet available. I very much look forward to seeing them.

Actinide neutron scattering (or any scattering of fission-reactor relevance) was notable for its absence at this Conference. There was a single paper, dealing only with the excitation of vibrational levels in 232 Th. The general lack of new scattering information is disturbing, particularly in view of the fact that, for example, 238 U inelastic scattering continues to adorn high-priority request lists as it has for many decades. The respective measurements are tedious and difficult, the analysis tools are deficient, there is little fundamental interest, and no experimental breakthroughs are in sight. These factors have likely conspired to result in an evident lack of progress.

Despite the inherently safe Integral Test Reactor with its complex fuel cycle, the importance of fuel cycles generally, and the concern for large inelastic-scattering cross sections (reiterated at this Conference), there was little new microscopic fission-product information. In view of the applied importance, and the interesting fundamental aspects of the fission products, this is puzzling.

Some very impressive fundamental studies of the fission process were presented, including energy, angle, mass, charge, and particle correlations. However, the impact on gross nu-bar and fission spectra for reactor calculations was modest.

There was little microscopic dosimetry information, though the long-standing 93 Sn(n,n') 93 Sn issue appears to have been resolved.

Data for fusion energy development

This was perhaps the strongest microscopic measurement aspect of the Conference, driven by Japanese interest.

A wealth of double differential neutron emission data was presented, largely at incident energies in the 14-20 MeV range. The distributions are characterized by reasonably known compound and pre-compound contributions and by less well known direct reactions, resulting in structure in the higher energy portions of the emission spectra. The latter phenomena are experimentally manageable, and they will soon be better defined. At energies < 14 MeV, the comparable experimental information is only fragmentary. That is a region where there is an interplay between (n,n'), (n,2n') and (n,n'p) processes, and calculations suggest large spectral changes over relatively small incident-energy ranges. These lower energy emission spectra are important to fusion energy programs, and their quantitative study will not be easy, particularly in the 10-14 MeV range. Of course, one must remember that experimental emission spectra are a sum of components from a number of processes, and thus calculations must be used to break the observed spectra into the various components appearing in the evaluated file sets. Hence, measurements only test the gross features of the calculational systems and do not directly provide the individual components requisite for the evaluated files.

The primary fusion fuel reactions (e.g., (D,T)) were not discussed at this Conference. This is not surprising as they are well known from careful measurements, extrapolated with theory.

This Conference produced little new information on energy deposition resulting from neutron induced charged-particle reactions (e.g., proton values). This is a concern, as these are major heat-transfer processes and they are essential for maintaining energy balance in the data system. The requisite measurements are difficult and have been largely concentrated about 11 MeV. Extending these experimental results to the lower energies will be difficult as the source properties are far less favorable than at ~11 MeV.

There are very large needs for fusion activity data. A few of these problems are straightforward engineering matters, but many are very difficult and will require new measurement techniques for definitive results (e.g., the use of unfolding methods, as described by a paper at this Conference). Several nice papers by Japanese authors dealt with activity measurements. However, the fusion activity needs are of a magnitude greatly exceeding the apparent respective experimental endeavors. As a consequence, large portions of the evaluated activity files are calculational estimates. This is particularly an area where a few well-chosen, if difficult, measurements should be used to validate calculational methods that will have to be used to provide the majority of the data here.

The uncertainties in the neutronic data for the lead and beryllium multipliers are of magnitudes that may well make or break entire fusion concepts. The lead case appears to be largely an (n,2n) problem, and the same is true of the two. The beryllium case seems the more complex.
with less certainty as to where the problem lies. These are serious issues that must be resolved by a combination of microscopic measurements and macroscopic tests, and that will not be easy.

**Facilities**

Realistically, future facility improvements will be more evolutionary than revolutionary. It is unreasonable to expect improvements in both intensity and time resolutions, with the largest relative potential increases with modest resources probably in the monoenergetic source area. Monoenergetic and white neutron sources will continue to be used in a complementary manner, particularly as the important data problems become increasingly quantitative and precise. In such cases the use of alternate and well-understood facilities and techniques is very desirable, as was illustrated by the precise studies of the 235\(^{\text{U}}\) of standard cross sections reported at this Conference. It is unlikely that the data field will ever again alone support a massive new facility. Therefore, future large new data facilities will be in concert with other, and dominant, research endeavors (e.g., condensed matter and fundamental-particle studies). Such correlation will inevitably result in some compromise in concept and operations. One such massive new facility (based upon spallation reactions) was described at this Conference, with results characterized by both the very large and the very small: the intensities making possible studies of very small rare and active samples that must be difficult to see, the large energies not elsewhere available at white-source facilities, and the potential for very fundamental studies. It will be interesting to watch progress with this new approach.

**Instrumentation**

This area is characterized by elegant refinement. No breakthroughs, such as a Goli detector, black detector, etc., were evident. The nature of the progress was illustrated by the very excellent refinement of ion chambers and electrostatic-magnetic devices in complex studies of the fission process. I do have a bit of Freudian concern for the fission apparatus. They seem so unhappy, with grim Wagnerian names like Tristan, Isolde, Lohengrin, etc. Can not we have a happy detector, perhaps Falstaff? Another refinement that appears to have good potential is the use of solid-state devices for obtaining high quality beta spectra. More mundane, but of equal importance, is the improved understanding of conventional detection methods that has resolved long-standing issues: e.g., the energy-dependent sensitivities of \(\gamma\)-ray detectors used in studies of capture processes generally, and the 1.15 keV resonance in \(^{56}\text{Fe}\) specifically. It seems odd to me that such uncertainties in the characteristics of relatively conventional devices have so long existed.

There was little overt note of what I feel is an instrumental advance that has the potential for profound impact on many aspects of the nuclear data activity: the advent of mini-computers (i.e., workstations), putting at the desk top the computational power of a significant fraction of a super computer, all at truly modest capital cost. I expect a very large impact by these systems on simulations (as illustrated by a facility study reported at this conference), data handling, and modeling and interpretation. Computational power, never before practically available, is now routine and is being exploited (e.g., in extensive \(R\)-matrix calculations). Moreover, these systems are in a highly developmental mode, and it is reasonable to expect a rapid enhancement in their capability, extending to parallel processor systems.

**Uncertainties**

I have the feeling that there has been a rather careless use of uncertainties and correlations. Their importance in the nuclear data activity was stressed more than ten years ago by Perey. However, it seems that reality has set in. Rigorous practical use of uncertainty concepts in nuclear-data measurements and interpretations is not trivial. Oddly, I have the impression that integral studies have more carefully addressed the issues, as illustrated by papers at this Conference. I fear that, unless we are careful, rigorous, and proper application of uncertainty principles to microscopic, nuclear-data measurements will go into default, and, if so, a powerful tool will be lost, along with the potential for applying innovative new measurement techniques (e.g., the use of unfolding methods).

I would like now to turn from technical commentary to:

**MATTERS OF APPRECIATION**

I must express my personal appreciation for this fine conference and the gracious hospitality shown by my Japanese hosts. In a bigger scope, I have been fortunate over the years to have a number of outstanding Japanese visitors with our group. They bring the ability, industry, culture and youth that we sorely need.

Now I would like to take on a different role, that of NEANDC Chairman. The NEANDC, and its previous reincarnations, has sponsored conferences of this nature since 1955. This conference is the most recent and among the most noteworthy. On behalf of the NEANDC and, I believe, all those present, I express our most sincere appreciation for this Conference and the outstanding hospitality, and for the opportunity to learn so much from our skilled Japanese associates. This expression extends to the Japan Atomic Energy Research Institute and all its personnel, to other commercial and professional sponsors, to those who worked so diligently and successfully in preparing for this Conference, and particularly to the Vice-Chairman of the NEANDC, Dr. Igari, who provided the essential leadership and direction for this Conference.

I leave you now, not knowing when, or whether ever, I shall return. To each of you my very best wishes.