In 1972, the IAEA held a Study Group Meeting on Gas-Cooled Fast Reactors in Minsk, USSR. The conclusions reached at that meeting have found a positive response in the scientific press.

Recognizing the growing importance of fast breeder reactors for meeting world energy requirements, the International Atomic Energy Agency will continue its efforts towards international co-ordination in this area.

Excerpts from the opening and closing addresses at the Symposium on Applications of Nuclear Data in Science & Technology, Paris, 1973

Applications of Nuclear Data

The expansion of nuclear technology during the last twenty years has created a growing demand for an organized and easily accessible body of nuclear information needed by the scientific community. Nowadays, trends in the nuclear power industry, such as the current development of more efficient nuclear reactors and the planning of thermonuclear fusion reactors, as well as the increased use of nuclear methods and techniques in practically all fields of science and technology, are continuously increasing the demand for more and better numerical nuclear information, commonly referred to as nuclear data.

In the past few years nuclear data compilation and its use has grown considerably in magnitude, scope and depth, and an even greater increase is foreseeable for the future. This was the dominating impression gained by the participants in the International Symposium on Applications of Nuclear Data in Science and Technology, which the International Atomic Energy Agency organized in Paris last year. The conference confronted the "state of the art" of nuclear data compilation with the nuclear data requirements of science and technology.

The Symposium showed that while nuclear power continues to present the most important and most strongly supported challenge to the compilation of nuclear data, an increasing number of applications of nuclear techniques in many branches of science and technology, and a growing need to protect man against nuclear radiations, call for a considerable broadening of the scope and depth of nuclear data compilation. Accurate nuclear data and an easy access to them are becoming increasingly important to scientists applying nuclear radiations and isotopes in radiobiology, medical diagnostics and therapy, activation analysis, geology, material research and other fields. The refinement in recent years of nuclear experimental techniques which has led to an enormous increase in the volume of measured nuclear data has created the additional problem of how to compile and digest the data produced and make it available in adequate and timely form to its users, and has accentuated the need for appropriate justification and priority choice of nuclear data compilation.

KEYNOTE ADDRESS

The keynote address of the Symposium was presented by **Dr. Alvin N. Weinberg, formerly Director of the Oak Ridge National Laboratory, USA, and now Director for Research and Development for the U.S. Federal Energy Office.**

In concluding his opening speech Dr. Weinberg visualized these problems under the perspectives of the growing importance of nuclear science and technology in everyman's life by saying:

"By the year 2000 we anticipate that in the United States alone there will be 500 operating reactors. The rest of the world will not be far behind. It will be a world in which the existence of radioactive nuclei will not be a scientific curiosity but an ever present factor in our daily lives. All kinds of people will have to know about radioactive nuclei: chemical engineers, geologists, geochemists, atmospheric scientists, oceanographers, paleographers, ecologists, anthropologists, veterinarians, agricultural scientists, soil scientists, economists, and political scientists. Each group will want information in a format that is easy to use, easy to transmit, and easy to remember. It will be the task of the compilers to be responsive to the needs of many sectors of our society and to provide nuclear data in specific formats for each sector.

We see therefore a strong and growing need for externally motivated nuclear compilations. It is unlikely that potential users will come uninvited to the compilers and ask for particularly useful kinds of compilations. The compiler must seek out potential users continuously and energetically. Several mechanisms might make this task a little less than impossible.

(1) There are conferences such as this one where users and compilers meet to exchange views on major problems and to work out together useful courses of action.

(2) It is possible to embed nuclear data centres in large multidisciplinary organizations. This is currently the case in the nuclear laboratories of many countries, and leads to reasonably good communication channels between compilers and obvious potential users who are connected with the nuclear energy enterprise.

(3) Committees which we mentioned earlier, such as the US Nuclear Data Committee, may be very useful in helping to establish priorities for compilation of nuclear data. Certainly the various Neutron Cross-Section Advisory Committees have been helpful both in the measurement and evaluation of data for reactor design. However, the more general fields of nuclear science and application do not have the same unifying theme or, for that matter, the centralized managerial structure as does reactor design and engineering. This will make it harder for committees to sense accurately the needs of this larger community. Moreover, committees are cumbersome: will they impose further delays on the transfer of information from experimenter to user — which after all is what we are trying to expedite?

(4) Finally, the most important ingredient is the intelligence, the energy, and vision of the individual compiler or of compiler organizations. One important issue here is how one can make the centres that have a tradition of internal motivation, a commitment to basic nuclear science, more useful to the community of applied science. One obvious, and quite simple, answer is to urge that these compilers of nuclear data become more familiar with the needs of users. After all, when a compiler establishes a priority according to the internal logic of nuclear science, it is necessary to familiarize himself with that

logic — to decide what is needed to strengthen the edifice of nuclear science. Is one being unrealistic to urge that nuclear compilers themselves accept some responsibility for the needs of the applied community that their data may serve so that, though their primary commitment remains to their science, and their primary criteria of choice remain internal, they use some cues from the applied world in setting their priorities? As a practical matter, this means that at least a few compilers in each of the basic compilation groups would acquire knowledge of and sensitivity to the applied sciences.

Establishing priorities in nuclear compilation is hardly any easier than is establishing priorities in nuclear science itself. And indeed, rather than proposing specific priorities, we have alluded to mechanisms for establishing priorities — in particular, the steering or guiding committee, and the informed individual compiler, especially the one who works in a broad, interdisciplinary setting. The two mechanisms, of course, do not exclude each other. We would only hope that this present-day tendency to centralize decisions in science by setting up central committees does not work to lessen the individual compiler's own responsibility to become acquainted with, and sensitive to, the needs of the basic and applied communities his compilations serve."

SUMMARY

The Symposium summary was presented by **Dr. W. Bennet Lewis of Canada, formerly Senior Vice-President (Science) of the Atomic Energy of Canada Limited.**

The following extract contains the main points of his address:

"The symposium was called essentially to consider how the users of nuclear data can best be served by the measurers and compilers of such data. The users appear to include almost all the producers and frontier problem-solvers of the world. The problems of the world are set by a tremendous and still rapidly-increasing total population, who, as a result of modern communications, have been made aware of what rewards can come to a human life.

The average age of the world's population is probably in the teens, and so for most the main action in their lives is yet to come. For them to achieve and accomplish, and to be able to afford the accomplishment, nuclear data play more of a role than most people realise. The contribution of nuclear data ranges from the mundane essentials of staying alive, keeping fed, and keeping warm and healthy to the most exotic projected activities such as sending eight men to land on the planet Mars.

There are problems of choice all along the route, because measuring and compiling nuclear data does not automatically provide all that the measurer and compiler seek in life. With the division of labour that has been established in the world and seems necessary to sustain so large a population, it falls to others to supply the food and life support of their servants, the measurers and compilers, who are not very productive if treated as slaves.

Dr. Weinberg's keynote address assumed that the first hurdle had been passed and that the scientists exist and have completed their basic training, so their problem is to choose the activity that is good science because it can be seen as the "art of the soluble". But mostly the chosen paths must also be seen to yield a tangible benefit within a practical time scale — a scale that now seems to be somewhat shorter than a single scientific career, but could be much longer if the politicians of the world who steer and fund the division of labour exercised such far-reaching vision.

Let me now come to grips with some of the practical choices, assuming that the choices are to guide skilled measurers and compilers to do their best.

Nuclear data use

Let me take first the medical users. As presented, it would seem that their greatest need is for a science of radiobiology worthy of the name. We were shown how inadequate are the concepts of radio-biological effectiveness (RBE) and the elementary ideas of microdosimetry and track structure to explain the extraordinarily large biological effects a small amount of ionizing radiation can have. Consider a gamma radiation dose of 500 rads to the whole human body. Although forming a very small energy density only – i.e. 50,000 ergs per gramme that would raise the temperature by no more than 1/800 degree – it is yet likely to lead to the death of a human being. Yet similar amounts applied in therapy can have beneficial biological effects.

Radioisotopes play their role in medicine both in diagnosis and in therapy. A number of isotopes, because of their convenient availability and suitable half-lives, appear in the various pharmacopoeia of the world, but there is room for more. This implies that more nuclear data, together with their evaluation and compilation, are needed. Another very striking effect in therapy comes from pursuing the ideas of RBE and linear energy transfer (LET), making it attractive to apply high-energy protons and α-particles, as well as the more exotic artificial products, the π-mesons as specific agents against localized tumours. That whole field of the mesons produced by "intermediate"-energy particle accelerators introduces the nuclear data measurers and compilers to a new region of their science which is still mostly wilderness.

I would like to pursue this metaphor of the wilderness and the garden further, as it seems so apt in this matter of the choices facing the nuclear scientists. Fortunately they are many and have individual preferences. Some will find more satisfaction in pursuing their work in well-ordered gardens, realms where the nuclear data are extensive and embodied in major compilations, programmes for interrogation by enquirers with all the data evaluated and recorded on magnetic tapes. Others will prefer pioneering with 800 MeV protons and the mesons, neutrons and spallation products they produce, exploring in the wilderness. The region of the 14 MeV neutrons from the D,T reaction is on the edge between the wilderness and the garden, calling for careful planning to make the most meaningful measurements and evaluations.

Turning to that major user-realm, nuclear power generation, we were reminded in the keynote address that a problem, of major concern about which some 22,000 pages of testimony have been recorded during the past year, is the need for better experimental information on the energy released from the short-lived fission products immediately following the shut-down of a reactor from high power. In general, the application of nuclear data to nuclear power generation is very extensive and fairly satisfactory for the established types of reactor, so very little was reported at the symposium. On the other hand, for the prospective fast breeder reactors nobody appears satisfied, and many papers relate to the outstanding discrepancies between the calculations based on the evaluated microscopic nuclear data and the results of integral experiments on reactor assemblies. Reconciling microscopic and integral data for fast reactors allows little play for the models and methods of calculation, so improvements of microscopic nuclear data are still looked for.

A major gap in time appears likely to occur before the large-scale exploitation of nuclear fission power receives any assistance from nuclear fusion. The assistance may not come as a contribution to energy so much as a contribution to the overall neutron and fuel cycles. Hybrid fission-fusion reactors and sub-thermonuclear fusion chains were shown to be still largely wilderness areas, but perhaps deserving cultivation.

Many of the users of nuclear data were only identified by a few chance words. The applications of radioisotopes as tracers to study ways of improving the growth of crops and of adjusting feed to the optimum in animal husbandry are well known, but the advances of nuclear technology are making even more convenient and suitable isotopes available. Their choice, taking into account production, transmittal and application, makes use of many of the nuclear data compilations. Moreover, under the guise of chemistry another whole technology using stable isotopes to serve as the tracers was discussed. These stable isotopes can then be identified and measured by one of several nuclear activation techniques with the aid of neutron sources such as Cf-252, or experimentally convenient nuclear reactors, or particle accelerators bombarding the sample prepared in the form of a suitable target, or compact accelerators producing 14 MeV neutrons in the field or higher-energy accelerators including microtrons and betatrons.

Some special users were identified in fields of environmental science, in oceanography, in mining and many other fields of industry and applied science.

Moreover, some advances in technology were illustrated and foreshadowed, made practical by by-products from the large-scale growth of nuclear energy. In particular, Pu-238, the 90-year half-life isotope, will become available and may be used not only in small energy sources for heart pacemakers, but possibly also as a fissile material augmenting its energy output by fission in a miniature reactor.

The experiments on controlled nuclear fusion lead to considerations of the regeneration or breeding of tritium that require an extension not only of energetic neutrons but also of particle reactions that produce tritium. New technology is required for tritium retention and recovery which may be monitored by nuclear techniques.

Very extensive studies are opening up on the detailed structures of protective surface films on which so much depends in industrial processes. Amongst these techniques are nuclear backscattering and thick target nuclear reaction studies.

Hot atom chemistry was shown to need some compiled nuclear data.

The science of plasmas and lasers also inter-relates with nuclear science in some aspects.

Nuclear Data Compilations

It became apparent at the symposium that not only the external users but also the nuclear scientists who formed the great majority of the participants were unaware of very many of the large number of nuclear data compilations available, and their special merits.

The oceanographic nuclear scientists concluded that their need was best served by a compilation presented on magnetic tape so that it could be amended, extended and updated constantly by a computer. Some other users call for the opposite extreme, a compact tabulation that presents only the information special to their needs. Both would agree that they seek accurate information. The evaluation of nuclear data for accuracy is a major work requiring all the facilities acquired by the compilers of the major basic *tabulations. It is necessary to preserve a strong line of communication between these basic compilations and the multiplicity of smaller special purpose compilations. It can be very frustrating to a user of small compilations to find different values quoted in different sets of tables for the same nuclear constant, with no guide to his choice.*

Much can be done by the measurer to help the evaluators in their difficult task. In general, much more detail needs to be given concerning the assessment of errors both concerning the methods, possible systematic errors and points of reference where measurements are relative. With a few noteworthy exceptions it is the general experience of evaluators that different measurements do not agree within the supposed limits of error. A plea may be entered that where there is room for any doubt the measurer should be brought into consultation and should regard his work as unfinished until agreement is reached with the evaluator.

The nature of the nuclear data required in compilation is continually extending. The introduction since 1963 of the high resolution Germanium γ-ray spectrometer extended the need for detailed γ-ray spectra, and as activation analysis extends to the use of higher-energy neutrons, γ-photons and charged particles, the required range of nuclear levels and isomeric states with different half-lives grows broader. Users repeatedly requested absolute intensities of γ-rays. Moreover, despite the high resolution, interferences are important and should be readily found in the tabulations. Techniques of analysis are constantly extending, involving coincidences not only between γ-rays but also with X-rays and Auger electrons.

The range of nuclei of interest not only includes the direct fission products but also nuclides resulting from neutron capture by fission products.

The successful use of theoretical relations to extend nuclear data was mentioned in several connections, including unresolved activation resonances, especially neutron resonances in reactor components and excitation functions in charged-particle nuclear reactions.

A growing collaboration is evident between regional nuclear data centres. This appears most advanced in the field of neutron nuclear data for reactors. Similar collaboration is sought in other fields, especially in activation analysis, which is becoming so complex.

The current trend in university teaching towards interdisciplinary activities is well exemplified by the field of activation analysis. It introduces students to the limitations of compilations so they not only swell the ranks of compilers but learn of the difficulties.

The data evaluators and compilers indicated a desire to reach internationally-standardized formats as well as key reference data, such as the neutron yield in Cf-252 fission. They would also like to sharpen the meanings attached to "evaluated data" and other loose phraseology used by compilers. Moreover, their work would be assisted by a wider adoption of keywords in the scientific journals. A warning was given, however, that keywords cannot uncover all the hidden, but related, data.

The symposium benefitted from the participation not only of a very large number of those who have made available their evaluations and compilations of nuclear data, but also of users covering a very wide range of application. What emerged is a general awareness of the growing magnitude, complexity and importance of the work of careful review of data for so many uses.