

REACTOR PHYSICS

A Report by David Okrent

AS I perused several back issues of *Physics Today* to get some feeling for how symposia were being reported, it soon became obvious that there just is no other conference like the Geneva "Atoms for Peace" Conference. More than 2000 papers were submitted for the proceedings, 600 of which were covered in oral presentations during the nearly 80 sessions held over a two-week period. The number of topics treated far exceeded the number of sessions, and the attendees exceeded the speakers by approximately 10:1, at least in registration.

About eight and one-half sessions were devoted to reactor physics, comprising 75 orally presented papers from a total of 210 submitted to the conference in this field. All of the 210 will be reproduced in the English-language proceedings. Of these eight and one-half sessions only about one-half session was devoted to thermal nuclear data, supplemented by a few papers on fast neutron cross sections in the nuclear physics series. This is compared to the first Geneva Conference, where two out of six sessions on reactor physics were devoted to data. The nearly complete declassification of neutron cross sections and nuclear data for the first conference made comparisons thereof on an international basis truly exciting. Discussions in this field occupied much attention inside and outside the session chambers. The continued free flow of this information in the intervening years, however, sharply reduced such technical contributions to the second conference.

The sessions devoted primarily to reactor physics were the following:

- A-11 Nuclear Data
- A-12 Nuclear Data and Reactor Theory (Mostly on Neutron Spectra)
- A-13 Reactor Theory and Computing Methods
- A-14 Reactor Kinetics and Control
- B-15 Fuel Cycles (the second half)
- B-17 Reactor Physics I—Mostly Fast Reactors
- B-18 Reactor Physics II—Deuterium and Hydrogen Moderated Systems
- B-19 Reactor Physics III—Hydrogen Moderated Systems and Shielding, primarily
- B-21 Reactor Physics IV—Beryllium and Graphite-Moderated Systems

David Okrent, a physicist involved in reactor programs at Argonne National Laboratory since 1951, served as one of the 21 scientific secretaries responsible for evaluating the flood of papers submitted for presentation at the 2nd UN "Atoms for Peace" Conference, held September 1-13, 1958, in Geneva, Switzerland.

SINCE the session number corresponded to the day of the week, beginning with No. 1 Monday morning, No. 2 on Monday afternoon, etc., and not including Sunday, Session A-11 was convened Saturday morning (Sept. 6) at 9:00 A.M. sharp by Chairman E. Bretscher of the United Kingdom who promptly called on Don Hughes (Brookhaven National Laboratory) to give an invited survey paper (P/2483) "Recent Neutron Cross Sections of Interest to Reactor Design". Hughes reviewed those areas where significant new advances in knowledge have occurred since 1955, in particular the thermal absorption cross sections of fission products and the resonance parameters of fissionable nuclides. At higher energies (1 kev to several Mev), he indicated areas where considerable progress had been made in filling the gaps in partial cross sections, especially capture and inelastic scattering. (The progress in neutron capture measurements was reported in detail in a later session, A-21, by Diven of the Los Alamos Scientific Laboratory in paper P/667 and by Groshev, Pasechnik, and Kazachkovsky of the USSR.) Hughes also discussed in some detail thermal absorption in the basic reactor materials, boron, graphite, and the thermally fissionable nuclides. Boron has remained nearly static and graphite has shifted upwards slightly, while U^{235} has experienced a wide spread in recently measured values for σ_f . To emphasize this last point, the papers following on the program reported recent measurements of 605 ± 6 barns (by Soplokoglu of Turkey, P/1599, on work done at Argonne National Laboratory) and 569 ± 6 barns (by Hanna of Canada on work done at Chalk River, P/204). Reasons for this deviation far beyond the reported accuracy were not found, even when the matter was taken up by the gentlemen of the press following the session.

There was also considerable discussion concerning the disagreement in measurements of η for U^{235} , the number of fast neutrons released per thermal absorption. As Weinberg (Oak Ridge National Laboratory) put it, "the number on which the whole future of a certain segment of atomic energy depends is in uncertainty by just about the amount that makes the difference between being able to have a future or not."

Other papers presented in this session included a Canadian report on some careful studies of long-term reactivity effects (P/205), a United Kingdom paper (P/14) summarizing a considerable amount of data obtained with the pile oscillator technique, and an

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American paper (P/1847) reviewing some aspects of resonance capture in lumps.

That a lot of material was submitted which could not be covered directly in the oral program can be seen by perusing the list of papers which were assigned to session A-11 for publication in the bound proceedings of the conference. For example, among the interesting titles in this category is P/2223 (USSR) "Evaluation of the Absorption Cross Section of U^{235} Fission Fragments in the $0.025-10^6$ ev Energy Range and Calculation of Fragment Effects in Intermediate Reactors". And there are many others on varied subjects.

Session A-12, while entitled Nuclear Data and Reactor Theory, was devoted almost entirely to measurements of reactor spectra and theoretical developments in neutron thermalization. The session was opened at 2:30 on a beautiful Saturday afternoon with a thirty-minute talk by the chairman, E. P. Wigner (USA), in which he reviewed some of the major problems facing reactor physicists today. In regard to aspects of nuclear physics, he emphasized the fission process at thermal energies, where one must make assumptions about negative energy levels that are out of harmony with the spirit of resonance theory. He also discussed the fission and capture process above 10 kev, where few experimental data exist and where there are rather strong variations which were not anticipated. In the transport theory area he pointed out the problem of the "age" in water, the ambiguity in definitions of multiplication and criticality factors, and the problem of thermalization. The latter he categorized as "the last part of the physics of neutron transport in which the theoretical and experimental exploration has touched only the surface".

The session included papers from the UK, USSR, Italy, Belgium, India, USA, and Argentina. Typical of the step-by-step advances being made in the thermalization field were a theoretical paper (P/18) presented by Hassitt (UK), and experimental papers (P/2152) presented by Mostovoi (USSR), and P/10 by Poole (UK). Hassitt uses two improved approximations—a somewhat more accurate representation of the phonon energy spectrum and an approximate evaluation of multiphonon processes to obtain an improved calculation of the scattering law. Poole and Mostovoi reported on measurements of the neutron spectrum locally within lattices, using two different experimental techniques.

The considerable attendance despite the lure of the weather and the scenery attests to the widespread interest in this subject, as does also the considerable attendance at an "informal" session on thermalization held during the second week of the conference. Perhaps what the conference missed most in this area were

extensive and accurate experimental measurements of the inelastic scattering law for liquid and crystalline moderators.

Session A-13, chaired by J. Yvon (France), was devoted partly to the utilization of high-speed computing machinery for reactor-physics calculations and partly to selected topics in diffusion and transport theory. The USA has pioneered the former field, and Carlson (LASL) and Gelbard (WAPD) presented talks on the S_n method (P/2386) and multigroup, two-dimensional diffusion theory methods (P/633), respectively. Skipping ahead a bit, a third important, high-speed computing technique was mentioned briefly in session B-17, by Stratton of LASL (P/431). This latter computation involves the coupling of the neutronics and hydrodynamics equation to calculate the progress of a self-terminating nuclear burst.

The use of high-speed computing machinery in boiling reactor design was discussed by Snyder of General Electric's Vallecitos project (P/2402), in the session on reactor kinetics, A-14, complementing an earlier phenomenological discussion of the kinetics of boiling reactors by Thie of Argonne National Laboratory (P/638) and Fleck of Norway (on leave from the University of California Radiation Laboratory) (P/581), and a second paper discussed in Gelbard's talk in A-13 on the design of pressurized water reactors, using digital computers (P/1843).

Of course, the use of high-speed computing machinery is tied to its availability. The conference included several papers by representatives of smaller countries on the application of slower computers to simpler problems. One can anticipate a considerable worldwide increase in the use of high-speed computers for reactor physics, however, if finances can keep pace with scientific interest.

FOR reasons peculiar only to the problems of scheduling a vast conference of this sort, reactor physics then was shifted from the A series "Physics" to the B series "Reactors". On Tuesday morning, September 9, a session was held on "Fuel Cycles", which was roughly split between considerations of economics and physics. This session must have taken the prize for the longest paper, P/2145, on problems of "fuel burning". Comprising 240 pages, it was read (in part) by S. M. Feinberg (USSR), who contributed comments of considerable interest elsewhere in the program. In session B-5, on Research and Test Reactors, he spoke briefly of a very high-flux research reactor under construction in the USSR (P/2142). An intermediate reactor, utilizing the flux trap principle to augment the flux in a central irradiation zone, the machine is calcu-

lated to give 2.2×10^{15} n/cm² sec at a thermal power of 50 megawatts. This reactor evoked sufficient interest that it provided the major topic of discussion at an informal session in research and test reactors held late in the second week. Feinberg also noted in session B-12 that the USSR had under construction a pulsed thermal reactor, very much like TREAT (P/1848). His lively personal manner coupled with his many interesting and varied comments easily made him one of the standouts at the conference.

Early in the preparation of the conference program, at a time when session titles had to be frozen but the orally presented papers were still very indefinite, the remaining four sessions in reactor physics, B-17, 18, 19, and 21, were labeled Reactor Physics I, II, III, and IV. This flexibility was then utilized to collect papers on the physics of systems by moderator, seemingly the best parameter for a grouping of individual interests.

The session on fast systems, B-17, found only speakers from the UK, USSR, and the USA on the podium—nations with sufficiently large supplies of plutonium or enriched uranium to conduct experiments in this area. Kazachkovsky of the USSR read the third (P/2038) of four papers pertinent to fast reactors which he presented during the two weeks of meetings, his shock of dark hair by now a familiar sight. Contrary to the first conference, where the USSR said nothing about fast reactors, they now displayed an active program, with work in physics being done on systems much like "Clementine", the early, plutonium-fueled fast reactor at Los Alamos. Two American speakers read papers (P/592, 598, 637) on fast criticals in simple geometries and reported a relatively good agreement between theory and experiment. Smith of the UK in his talk (P/39) reported a measurement of the fast Doppler effect which corroborates earlier US work (P/1777, not read), showing the effect to be small.

Fast-reactor physicists are generally enmeshed in safety considerations for their reactors, and several papers in this area were also on the program. Avery (ANL) discussed a coupled power reactor critical (P/2160) which confirmed the general characteristics of the system, in particular the power distribution and the longer prompt neutron lifetime. British and American speakers both reviewed stability problems, with Thalgott (ANL) reporting (P/1845) that by rebuilding the EBR-I experimental breeder reactor with a rigid core, eliminating rod bowing, the earlier observed prompt positive power coefficient of reactivity had been eliminated.

Session B-18 was devoted primarily to heavy-water natural uranium lattices. Where at the first Geneva conference in 1955 two papers in this field were presented (from Canada and the USA), six countries (Canada, France, Sweden, USA, USSR, and Yugoslavia) participated in a panel discussion this time. The much expanded pace of work in this field has included the exchange of rod assemblies between laboratories for corroboration of measurements. As a result,

there is some indication (see P/336 of France) that the discrepancy between US and Canadian results reported in 1955 may lie with some systematic error in the US results. French and Canadian results agree well, and Canadian remeasurement of the previously reported US bucklings has produced an appropriate shift therein. Since some Swedish exponential measurements also seem to be a little too reactive, there is some indication that the methods of making these exponential measurements require careful scrutiny.

The last third of session B-18 and most of session B-19 were devoted to other papers on water-moderated systems, including a homogeneous plutonium-water critical, "Proserpine" (P/1203 from France), with a minimum critical mass of under 300 grams and an extensive series of light-water, slightly enriched uranium lattices (P/1841, USA).

It is perhaps worth noting that attendance at technical sessions was dropping off. Never very large at the reactor physics sessions, it slowly decreased till on Friday morning, there were probably less than fifty present for session B-21. And since the entire B series was held in the large assembly room, seating over a thousand on the main floor and the several balconies, it looked a bit empty.

Session B-21 started off with a paper containing a fairly controversial point (P/2146 of USSR). A. K. Krasin discussed some beryllium-moderated critical assemblies and reported that their measurements indicated a contribution of 12% to effective neutron multiplication by the $\text{Be}^9 (n, 2n) \text{Be}^8$ reaction. J. Martelly of France (P/1192) and G. Jacob of Brazil (P/2276) reported they had calculated this effect, using the basic cross-section data, and obtained only 4 to 6%. But it should be noted that in Jacob's paper there is a reference to some earlier work in the USA wherein 10% had been deduced from a critical experiment. Hence, there exists a considerable discrepancy in need of clarification.

The graphite-moderated systems discussed in the latter half of the session pointed out no such major discrepancies. Careful work on natural uranium-graphite lattices was reported by speakers from the UK and France, while the last speaker on the program for reactor physics (P/2408, USA) discussed some simple, homogeneous graphite-enriched uranium systems, which have application to possible rocket propulsion schemes, but also provide a good check on calculations for poorly thermalized systems.

That no startlingly new information in reactor physics had been heard during the two weeks was evident, both from the conversations of the physicists themselves, and the failure of Sir John Cockcroft to mention this subject in his review of the conference, Friday evening, September 12. However, as in most fields covered at the conference, a considerable wealth of excellent experiments and sophisticated calculations will be found in the bound proceedings of the conference, providing a sourcebook for students and scholars alike for the coming years.