cent in cattle and that a similar but rather narrower range has been found in sheep. Most of the material disappearing is carbohydrate. It is more difficult to assess the extent of disappearance of nitrogen-containing materials as the secretions augment the nitrogen of the food, but it appears that considerable losses occur from the rumen in both cows and sheep and presumably these represent the absorption of ammonia. However, losses in the intestine are more extensive when compared with the apparent digestibility of nitrogen for the whole alimentary tract.

Estimates of fatty acid production in the rumen show that they are quantitatively important. The recent work of Armstrong and Blaxter at the Hannah Dairy Research Institute indicates that at levels of feeding up to maintenance the value of the mixture of short-chain fatty acids to the animal as a source of energy is fairly constant irrespective of the quantities of each individual acid absorbed. For production purposes, rations that favour the formation of propionic and butyric acids should be more valuable than those that favour the production of acetic acid. The proportions of propionic and butyric acids increase as the concentrate part of the ration increases in cattle. In particular, starch-rich food increases the proportion of propionic acid. As yet, very little is known of the peptic and intestinal phases of digestion.

In the second part of his paper, Dr. Phillipson dealt briefly with the absorptive capacity of the intestinal tract. One of the conditions of terrestrial life is the necessity of conserving water and sodium, and the ruminant is unusually good at carrying out these two tasks.

The quantities of water and sodium secreted in the saliva alone are far greater than the quantities excreted in the faeces. The contribution made by other digestive juices still needs investigation and is likely to be considerable. Both sodium and water are known to be absorbed from the rumen and omasum, while there is no doubt that absorption also occurs along the remainder of the tract, particularly in the large intestine. It is of particular interest that in conditions of sodium depletion the sodium content of the saliva is lowered and its place is taken by potassium; there is also a diminution of the volumes secreted. A study of the rates of turnover of body constituents such as water, sodium and other elements and nitrogen in various circumstances may help in the end to understand why occasionally things go wrong.

The final paper of the symposium was by Mr. J. K. D. Dow (Unilever, Ltd.) on the application of recent scientific information through the feeding-stuffs industry.

Studies on the absorption of fatty acids in the rumen, and the connexion with hormone metabolism, indicate dietary means of regulating milk production and quality and of curing conditions such as ketosis. Chemical tests enable processed protein materials to be classified according to the needs of the animals for which they are best suited. The feeding-stuffs industry has already made use of research into the vitamin and mineral requirements of ruminants. Further research on the effect of these on roughage utilization is awaited.

Recent work on antibiotic supplements for calves has indicated results which are not applicable through the industry in the present stage of legislation. This case demonstrates the wide view which is demanded of the research worker to-day, particularly when some manufacturers may depend entirely on published scientific evidence in formulating new feeding stuffs. However, it is doubtful whether fundamental research workers have adequate facilities for testing their results under practical conditions. This problem offers a profitable field for consideration by the feeding-stuffs industry, because co-operation between the research worker and the manufacturer is essential to the efficient functioning of the industry and, ultimately, will ensure that the farmer reaps the fullest benefit.

D. P. Cuthbertson

NUCLEAR FUEL CYCLES

THE Institute of Physics, in collaboration with the British Nuclear Energy Conference, held a symposium on "Nuclear Fuel Cycles" at the Institution of Civil Engineers, Westminster, on January 22 and 23. The symposium was opened by the president of the Institute of Physics, Sir George Thomson, who welcomed some 250 members and visitors, including delegates from eight European countries. He stressed the importance of fuel cycles in relation to the large nuclear power stations now under construction in the United Kingdom. These would prove competitive with coal-fired stations only if their uranium fuel were employed in the most efficient manner.

The symposium was divided into three sessions, the first of which considered the basic physics of long-term reactivity changes and nuclear fuel cycles, the second was concerned with the optimization of fuel cycles, and the third session discussed relevant operational problems. The chairman of the first session was Dr. J. V. Dunworth (Atomic Energy Research Establishment, Harwell). The first paper presented was that by Dr. H. Rose and Mr. J. J. Syrett (Atomic Energy Research Establishment, Harwell) on "Long-term Reactivity Changes", which described the basic physical processes occurring as natural or slightly enriched uranium is irradiated in large graphite-moderated thermal reactors. The importance of these changes was emphasized since, together with considerations of metallurgical damage, they would determine the irradiation-level at which the fuel must be replaced. The overall reactivity-changes with irradiation are determined mainly by the small net difference between the large changes arising from the burn-up of uranium-235 and the formation of plutonium-239, making the problem unusually sensitive to all the relevant nuclear data. Furthermore, the plutonium isotopes formed in the irradiated uranium have large resonances in their fission and capture cross-sections at low neutron energies. The prediction of their rates of reaction with neutrons therefore demands a detailed knowledge of neutron spectrum conditions to an extent unnecessary in assessing the initial reactivity of the reactor. For these reasons, present predictions rely considerably upon integral measurements which are made on irradiated fuel

elements. Much of this work has been carried out using the *Gleep* pile oscillator at Harwell, where data have been accumulated from uranium which has been highly irradiated in the Windscale, NRX and Calder Hall reactors. Typical predictions were displayed of the long-term reactivity changes to be expected for an individual fuel element in the Calder Hall type reactor, and the dependence of the reactivity curve upon several important design parameters was also illustrated.

In the ensuing discussion, Mr. P. W. Mummery (Atomic Energy Research Establishment, Harwell) explained that the long-term reactivity changes occurring at Calder Hall have been observed directly. Their interpretation was difficult since they applied to a complete reactor, and it was necessary to allow for the effects of different irradiation-levels throughout the reactor and the variation with irradiation of the control-rod effectiveness. Even so, there were some grounds for satisfaction that these measurements were in reasonable agreement with the *Gleep* experiments. Finally, he emphasized the very high accuracy on the basic nuclear data which is demanded for a purely theoretical approach to these problems.

For a given flux distribution and fuel-cycle scheme, the long-term reactivity changes of an entire power reactor may be found by suitably weighting the contribution from each fuel element. This was discussed in the second paper, by Mr. S. E. Lewis (Nuclear Power Plant Co. Ltd.). He considered the basic theory of 'once-through' fuel cycling, in which the fuel supplied to the reactor has a constant composition and does not contain any materials produced during the irradiation of previous charges. Mr. Lewis showed how an equilibrium state is reached in a small region where the flux is uniform and maintained constant, and demonstrated the factors determining the reactivity of the region and the whole reactor during the approach to the equilibrium state. The equilibrium state is determined when fuel is added and removed continuously in such a way that in any region of the reactor all irradiation-levels are represented between zero and the maximum allowable. Certain basic fuel-cycle schemes were outlined, some of which necessitated fuel movement within the reactors. It was concluded that the delay of commencement of continuous fuel replacement could be economically advantageous, and warranted closer study.

It is necessary to investigate the local behaviour of reactor flux and heat output in the small region considered in the previous paper, as the fuel elements will have different irradiation histories. This problem was discussed in a paper on perturbations due to fuel cycles which was presented by Dr. J. G. Balfour, Dr. D. L. Booth and Mr. R. S. Bulloch (Atomic Power Projects). One-group perturbation theory was applied to the calculation of axial flux changes in a single channel caused by the non-uniform irradiation and temperature, and by axial fuel shuffling within the channel. An improved method was then developed in which the non-linear one-group diffusion and heat transfer equations were solved numerically, this being applicable even when the perturbations were large. Axial distributions of flux and of coolant temperature were illustrated both before and after neutron irradiation of the fuel. A final section of this paper described the use of the Feinberg method for estimating local channel-to-channel variations of power and flux during a continuous fuelling scheme. The work suggested that although the fission cross-section of a fuel element varied considerably over its life due to build-up of plutonium, the heat output maintained a more constant level due to the increased depression of the neutron flux.

In the discussion, Mr. Syrett pointed out that the choice of fuel cycle had an important bearing upon reactor economics. In the approach to equilibrium which lasted several years, large sums of money could be saved by a judicious choice which would reduce fuel requirements and investment charges. He explained the potential advantages of radial shuffling for giving improvements during the approach period and in the equilibrium state.

In summing up the session, the chairman emphasized the importance of reaching a practical and economic fuel-cycling procedure for the Central Electricity Generating Board reactors, one which would have to take into account many different technologies. It was imperative that during the first few years of operation of these reactors, intensive operational research should be performed to improve our knowledge of fuel-cycling problems.

The second session (chairman, Mr. L. Rotherham of the Central Electricity Generating Board) contained two papers concerned with the optimization of fuel cycles. The first, by Mr. P. R. J. French and Mr. C. S. Lowthian (A.E.I.–John Thompson Nuclear Energy Co. Ltd.), considered a once-through equilibrium fuel cycle. The influence of the fuel cycle on the optimization of the reactor design through the lattice parameters was studied, and a relationship developed between burn-up of fuel and the initial neutron spectrum conditions. The effect of enrichment upon fuel life was also discussed, together with the allocation of excess reactivity to increase reactor output or fuel life.

The second paper was presented by Dr. P. J. Grant, Mr. W. Oswald and Mr. P. D. D. Russell (General Electric Co. Ltd.) This examined economic factors affecting the choice of fuel cycle for nuclear power stations, and underlined certain aspects often overlooked. Optimization of the fuel cycle is only a part of the overall optimization of cost per kilowatt hour, which depends partly upon local conditions. Neutron economy was important, but might sometimes conflict with monetary economy. As an example, flux flattening with steel absorbers and attendant loss of neutrons at the reactor centre could yield longer fuel life and reduce power costs. The economy of enrichment, plutonium production and fabrication costs was considered, as were the present prices of nuclear fuels. The advantages of axial fuel shuffling in the Calder Hall type reactor, and the necessity for continuous charge and discharge schemes, were also discussed. It did not appear generally economic to reduce deliberately the irradiation-level below the metallurgical limit.

Mr. G. E. Darwin (Babcock and Wilcox Ltd.) commented in discussion on the importance of this limit. The uranium and canning materials would not stand up well to fuel shuffling and the necessity to operate under differing physical conditions. This would result in reduced metallurgical limits depending upon the shuffling schemes, and it was inadvisable to assume a constant limit in fuel-cycle considerations. Mr. Syrett pointed out that delaying the onset of the equilibrium charge – discharge scheme could reduce fuel requirements, and since potential savings of the order of £1 million per reactor were possible this provided an incentive for such schemes. He asked Mr. French and Mr. Lowthian whether large

computer programmes were preferable to their analytical approach to fuel cycle considerations. Mr. Lowthian replied that it might be difficult to analyse all the information provided by the machines, but agreed that machine effort was extremely useful. In response to a question by Dr. G. Davis (Israel), Mr. Mummery stated that one could not dismiss fuel cycling and on-load charge – discharge machines as luxuries, since these provided a potential reduction of the order of a factor of two in fuel costs as well as making it possible to discharge burst cartridges without losing output.

A paper on the operational problem associated with fuel cycling was presented by Mr. J. C. C. Stewart and Dr. N. L. Franklin (Risley) in the third session, for which Prof. J. Diamond (University of Manchester) was in the chair. The authors pointed out that unlike some other industries, conservative operating procedures based upon precisely specified codes of practice cannot be expected because of the rapidity of development in the reactor field. It is essential in their opinion to choose an irradiation life-time which represents a compromise between metallurgical failure-rate and reduction in fuel costs. Sums of the order of £1 million per charge might depend upon this choice. They believed that the reactor operator and fuel manufacturer must carry out a sequential experiment to study the development of fuel cycles and ultimate life of fuel elements, using the actual power reactor itself as the test vehicle. This would also allow for the introduction and testing of subsequent types of fuel element as they are developed. The authors pointed out that this would have considerable influence upon the fuel fabrication facilities required.

Dr. C. P. Haigh (Central Electricity Generating Board) remarked that as a reactor operator he had special problems to consider such as on-load refuelling. The high capital costs of reactors had to be offset by low fuel costs and a high load factor. Shut-down of one reactor for one day would cost £8,000, while a prolonged shut-down involving a complete fuel discharge would cost around £2 million. Thus the reactor operator must be somewhat conservative initially in relation to fuel cycling. Experience would be accumulated gradually on reliability, before large-scale use would be made of complex fuelling schemes.

The closing remarks at the end of the symposium were made by Mr. P. W. Mummery, who explained that the main aim of the symposium had been to indicate the implications of the basic physics problems involved in nuclear fuel cycles on the design and operation of reactors. Compromises are necessary between conflicting requirements from many fields such as physics, metallurgy, engineering, heat transfer, operational simplicity, etc. The potential advantages of various types of fuel cycle had been indicated, on the assumption that various kinds of fuel movement within the reactor were possible and that the irradiation life was limited only by reactivity. Although such cycles could not be used initially, until more experience and more information had been gained, the design of reactors should be flexible to allow for developments such as these. It would be many years yet before the best fuel cycle was established for the Calder Hall type reactor. He looked forward to a time, three or four years hence, when actual operating experience of fuel cycling on different systems might be reported at a similar symposium.

The papers presented at the symposium and a summary of the important discussion will be published in the July issue of the *Journal of the British Nuclear Energy Conference*.

H. Rose

THE ROYAL AERONAUTICAL SOCIETY

AWARDS FOR 1958

THE following awards have recently been made by the Royal Aeronautical Society: *Honorary Fellowship* has been conferred on Prof. J. Ackeret (professor of aerodynamics at the Federal Technical College, Zurich), Sir William S. Farren (technical director, A. V. Roe and Co., Ltd.), S. B. Gates (chief scientific officer and consultant to the director of the Royal Aircraft Establishment); *Honorary Companionship* has been conferred on E. C. Bowyer (director and chief executive of the Society of British Aircraft Constructors), Sir William Hildred (director-general of the International Air Transport Association).

Silver Medal of the Society has been awarded to Dr. E. A. Watson, director of Joseph Lucas (Gas Turbine Equipment), Ltd., for his achievements in the development of turbine engine combustion and fuel systems; *Society's Bronze Medal* to D. G. King-Hele, of the Royal Aircraft Establishment, Farnborough, for his contributions to Earth satellite orbital theory; *British Gold Medal for Aeronautics* to R. S. Stafford, technical director, Handley Page, Ltd., for his outstanding practical contributions to aircraft design; *British Silver Medal for Aeronautics* to D. J. Farrar, chief designer, Guided Weapons, Bristol Aircraft, Ltd., and Dr. N. H. Scarby, manager, Guided Weapon Research and Development, Ferranti, Ltd., for their practical contributions to the development of guided weapons; *Wakefield Gold Medal* to K. A. Wood, superintendent in charge at the Atomic Weapons Research Establishment, Orfordness, for his practical achievement in the development and application of electronic aids to all-weather approach and landing; *R. P. Alston Medal* to A. W. Bedford, chief test pilot, Hawker Aircraft, Ltd., for his contributions to the technique of flight testing high-speed aircraft; *N. E. Rowe Medal*, for the best lecture given before any branch by a member of a branch, to J. Dunham, Rolls-Royce, Ltd., for his paper on "Damage to Axial Compressors" given before the Derby branch of the Society; *Simms Gold Medal* to Mr. R. P. Probert, deputy director, Engine Test Facilities, National Gas Turbine Establishment, for his paper on "Ram-Jets"; *George Taylor (of Australia) Gold Medal* to Mr. H. L. Cox, of the National Physical Laboratory, for his paper on "The Application of the Theory of Stability in Structural Design"; *Edward Busk Memorial Prize* to Mr. T. R. F. Nonweiler, of The Queen's University, Belfast, for his paper on "The Man-powered Aircraft