Design and Operation of a Nuclear Power Station*

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INTRODUCTION

The purpose of this paper is not to answer questions on how to design and operate a nuclear power station. It is to show in a manner familiar to engineers used to large projects, such as, for example, designing and constructing a ship, or a conventional steam generating station, the picture of what must be done before an engineer can ask and answer his own questions about the design of a nuclear power station. Every large project has one or more logical methods of approach. In many cases these methods have been used for so long that groups familiar with the work have codified them and, for a project similar to others which have been carried out before, a large portion of the new job is done according to formal plans set forth in calculation sheets, progress charts and design note-books. In this paper it is hoped to give the outline of such a code for nuclear power work.

It is assumed that readers are familiar with the fundamentals of the production of power from nuclear energy and with at least a small fraction of the thousands of sketches of possible cycles or schematic arrangements for nuclear power stations. Here the working of the reactor is assumed, just as in a conventional station the fact of combustion is assumed, and the implications of that working are examined insofar as they affect the type of design which must be produced.

The initial stages of the design will be concerned with the flow sheet for the whole station. If the station is considered as a whole for one arrangement which looks feasible, it is seen that it falls into four main groups of equipment plus the civil engineering work. These four groups are:—

1. The heat source, in this case a nuclear reactor, corresponding to the fire box of a conventional boiler.
2. The steam raising plant with its attendant equipment.
3. The prime mover, in this case a steam turbine.
4. The alternator, transformers and switchgear.

Before the theoretical work can really start, it is necessary to consider carefully the duty of the station. Of course, the answers to later questions will influence the answer to this one and this statement of purpose will have to be modified from time to time in the light of experience with various aspects of the design. Let it be assumed, as a reference for the exercise, that the station will be one to be incorporated in a large power network in a densely populated country; in other words, design it for sale to the Central Electricity Authority, with an output of 100 megawatts of electricity. At this early stage of the art, it is improbable that the C.E.A. would have a site for the station firmly fixed, so a level site with ample space and good foundation conditions and access will be assumed; also that condensing will be done by natural draught cooling towers.

To make the discussion more concrete, it will be assumed that the general type of system has been decided. It is to have a thermal reactor, graphite moderated, which will be fuelled with uranium metal, possibly with a slight excess of fissile material over the natural ratio. The fuel will be in the form of rods protected by aluminium sheathing. The coolant will be a gas which is chemically relatively inert to both graphite and to aluminium. The gas which cools the reactor will be used to raise steam in a boiler similar in function to a conventional waste heat boiler. The steam will not be superheated by an externally fired superheater. The turbine will be conventional except for the fact that the steam conditions will be low compared with modern practice. Finally, the electrical equipment will be conventional. Fig. 1 illustrates the schematic design of the reactor and steam plant of just such a station.

The work to be done can best be divided among several groups. These might logically be a theoretical group, an experimental development group, a reactor design group, a power plant group, a building and services group, a progress and planning group, and an estimating group. In addition, of course, erection, contracts, purchasing, accounts, and inspection groups will be needed.

The Theoretical Group

The first theoretical work which should be done is concerned with the selection of the temperature levels at which the system will work, the steam cycle and feed heating arrangements to be used. The basic problem will be familiar to any engineer used to working with steam. It will differ from the ordinary, however, in two major respects. First, the maximum temperature in the reactor will be much lower than that in an ordinary boiler and, secondly, the power required to circulate the gas is a major factor, whereas in an ordinary boiler the power required for the forced or induced draught fans is small compared to the boiler output. Several papers have been published recently on this subject of selection of a cycle.

The next theoretical work which must be done on the reactor itself is of a nuclear physical nature. This nuclear physical theory occupies a place in reactor design analogous to that taken by aerodynamics in gas turbine design. A number of mathematical papers and a few books have been published which outline the type of mathematics required for the solution of the problem. This problem is essentially that of determining the relative proportions of fissile material and of moderator which will produce a nuclear reaction, with appropriate corrections for other material in the reactor, such as the sheathing on the uranium fuel and the cooling fluid and also of determining the minimum size core which will react. Although the type of mathematics which must be used for this study is relatively simple and fairly well known, again, as in the case of the aerodynamic calculations for a gas turbine, the subject is quite complex and it is necessary to supplement the theory with experimentally determined correction factors in addition to the basic physical data pertinent to the materials of the system. These experimental factors and the basic physical

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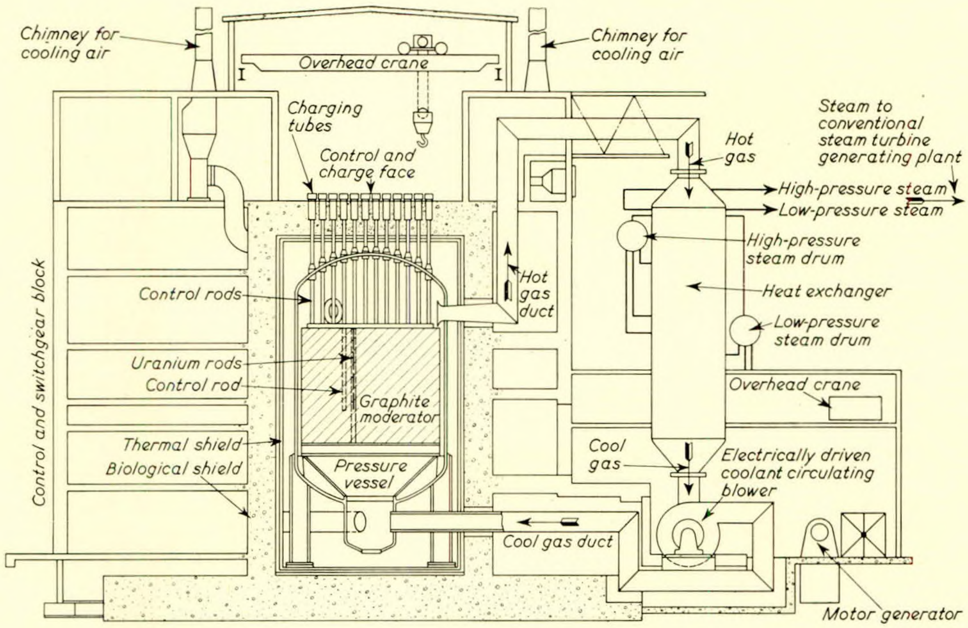

FIG. 1—*Scheme for a power reactor and boiler*

data have been determined by the nuclear physical research establishments and the designer must call on them for his information here. The manipulation of the data, however, he must master himself. The next logical step in the work of the theoretical section is to determine the probable thermal rating of the reactor. The first step in this direction is to determine the gas pressure at which the reactor will operate. Since the size of the pressure vessel is not known, it will be necessary to sketch a rough design for this vessel and to decide the safe working pressure as a function of size. Next, reasonable shapes are assumed for the uranium, for the sheathing and its fins, if any, and for the coolant channels. The heat removal from the reactor can then be calculated as a function of the pressure level and the pressure drop through the reactor, or what is the same thing, as a function of the absolute pressure of the gas and the power needed to circulate it. From the steam cycle and this calculation, it is possible to determine the size of the reactor core. The next calculation is concerned with the steam raising plant and the determination of the size which will be required, once a general type of design has been agreed. At this stage, most of the design parameters are little more than guesses, and as the work proceeds in other sections of the design office, it will be necessary to repeat all of these calculations several times in order to arrive at the best compromise of many conflicting requirements.

The next major problem to be solved is that of the system of control of the reactor itself. Various methods are available here, the most familiar one probably being that of moving into and out of the core rods or sheets of a material such as cadmium which absorb all the neutrons that strike them. The problem here is to determine the size of such control elements and the speeds at which it is necessary or safe to work them. Like most machines, a reactor has a certain inertia which shows itself in a time delay between control operation and response. If control is removed too rapidly, it is possible for the reactor to overshoot the desired power level, and possibly to damage itself. In this connexion, it is important also to determine the power level which the reactor will reach if all control is removed. In the type of gas cooled, graphite moderated reactor under consideration, it should be possible to arrange matters so that, even with all control removed, the machine will not run away to a dangerous power level. Such a reactor will be inherently much safer than one which can run away.

At this stage calculations will be made of the effect of operation on the reactor. How will the nuclear characteristics vary as the fuel is gradually used? This ageing characteristic is concerned largely with the amount of fissile material left in the reactor, including plutonium which is produced, and with the amount of neutrons which will be absorbed by the fission products produced.

Now a calculation must be made of the shielding which will be needed. This is of great importance for two reasons: not only is the shielding an essential for safety reasons, but also it is a relatively expensive item, and careful and imaginative work here can have an important bearing on the cost of the whole project.

Finally, the heat produced by radiation from the reactor in all the internal and surrounding parts must be determined in order that adequate provision may be made for cooling them to avoid thermal damage.

In addition to this work of a general nature, it is probable that a team strong enough to handle it can also be of considerable assitance to design engineers by tackling problems arising over questions of complicated thermal and mechanical stresses.

The Development Group

The development work which may be expected to arise can be divided into five major categories. These are:—

1. Mechanical.
2. Heat transfer and fluid dynamics.
3. Metallurgical.
4. Corrosion.
5. Instrumentation and electronics.

The mechanical development work will be largely concerned with such items as seals for the coolant circulation pumps, control rod mechanisms, strain gauge testing of models of major components, special valves which may be needed, mock-up testing of fuel handling devices and such things as static seals and expansion joints.

The heat transfer and fluid dynamics work will be largely concerned with experimental determination of precise heat transfer coefficients for fuel elements and of the steam plant together, possibly, with less precise work on cooling of shielding. In addition, it will probably be worth while doing model work to determine pressure drops in the coolant circuit.

The metallurgical work involved will largely concern the fuel elements and their sheaths. Since the temperature at which the fuel elements operate is the major limiting factor influencing efficiency and rating of the whole system, and hence the cost of producing power, this type of work offers the promise of high returns. A limited number of metals, such as aluminium, magnesium and zirconium, are suitable from the nuclear point of view for sheathing, consequently it is important to be able to handle these in the best manner possible. In addition, uranium is a troublesome metal to handle and experience with it is of great value to a designer. Its creep strength and expansion coefficients, for example, will influence the design of fuel element and reactor strongly.

The corrosion work will be concerned primarily with two problems. First, will a chemical reaction take place between the gas and the graphite, and if so, what will be the effect of this on the life of the reactor? Secondly, at what rate will the gas attack the uranium if a sheath develops a hole, and how will this affect the operation of the station and the type of gear which will be needed to search for defective fuel elements?

The instrumentation and electronics development will be concerned largely with equipment for monitoring the reactor and for operating the control and safety devices. Much of this equipment has already been developed, but each new reactor brings advances in the equipment needed and used for these purposes.

The Reactor Design Group

Probably the first problem to be solved by the reactor design group is that of the orientation of the reactor itself. Is it to have vertical cooling channels with the fuel rods central in them or horizontal channels or perhaps some variety of cross flow, and what position and direction of operation are to be chosen for the control rods? This question will probably be settled by the requirement to support the pressure vessel and its contents, which will weigh many hundreds of tons, in conjunction with the method chosen to place and remove the fuel. Once this question is settled, it is possible to divide the work of the reactor design amongst several groups. The first of these might deal with the fuel elements themselves, the fuel handling apparatus, the control rod mechanism, and the details of the graphite core. The diameter of the fuel and the total length of a string of fuel will have been decided by the nuclear calculations, but it must now be decided whether to make the fuel string as a single long rod or as an assembly of short ones. The strength of the sheath and of the uranium at operating temperature will have an important influence here, and against the convenience of having fewer elements to handle, if they are long, must be set the fact that the longer elements will require more head room. Once a design of fuel element is fixed, even tentatively, it will probably be necessary to have the development group check heat transfer coefficients precisely.

The design of the apparatus for placing and removing the fuel will be determined partially by the number and size of the holes which will be required in the pressure shell to accommodate this service. It will also determine the amount of space which must be left beyond the end of the core for charge and discharge purposes, over and beyond that needed to ensure proper circulation of the coolant. It is obvious that here is a place where ingenuity coupled with sound design will pay a large dividend. Even at this stage, methods must also be considered of fishing for lost fuel if the charging machine should, for some reason, drop one or more elements. This will have to be done by remote handling gear, of course.

A decision will also have to be made as to whether the pressure is to be released from the reactor for handling the fuel or whether this will be done through some lock system while the reactor is still under pressure. A decision on this point will be strongly influenced by the price of gas and by the estimates which are made as to how often the fuel will need to be handled. This frequency of handling will in part be determined by the amount of energy which can be extracted from each unit of fuel and partly by the probability that an element will last its planned life without developing a defect which would scatter fissile material through the system.

A fact which will have to be considered in the design of the fuel handling system is the radio-activity of the spent fuel elements when they are removed from the reactor. Not only will they have to be shielded in their passage from the reactor core to the place of storage, but also, since this radio-activity produces heat, it must be decided whether special cooling will be needed or whether the heat capacity of the element, together with natural convection and thermal radiation, will be enough to keep the temperature of the spent fuel element to a safe limit.

The control design of the reactor involves two types of work. In the one, mechanical and perhaps electrical means must be provided for moving the control elements. In the other, means must be designed for measuring the activity of the reactor, and through amplifiers and servo-mechanisms the appropriate signal must be transmitted to the control rods themselves. In addition, a link must be provided to connect the reactor control with the governing, safety and control system which is used on the steam plant, turbines and electrical system.

The problem on design of the graphite structure is one of building a core of a few thousand cubic feet volume out of graphite blocks, each of perhaps one cubic foot or less. The graphite must be arranged in such a manner that initially the fuel and coolant channels are true, so that there are no gaps in the structure through which neutrons or coolant can leak in appreciable quantities, and so that under the influence of repeated thermal cycling and of prolonged radiation, the soundness and truth of the structure do not deteriorate seriously. In addition, since graphite is expensive, it is important that machining be arranged to effect the maximum possible economy in the use of raw material.

The next major group of design work on the reactor itself is concerned largely with structural and pressure vessel work. The pressure vessel must be designed in a safe economical manner. Two problems will be outstanding here: the first, that of the holes in the vessel where coolant is taken in and out, where provision is made for handling of fuel and for the control mechanism. The other major problem will be that of support. The vessel itself will be very large and heavy, and its contents will weigh hundreds of tons. In addition, the vessel will undergo repeated thermal cycling, so that the supports must be flexible as well as strong. As part of the structural problem, the arrangement of the main coolant pipes connecting the reactor with the boiler will be very important. These pipes will be several feet in diameter, should be as short as possible, will have to pass through the shielding in such a manner as to allow no direct path for escape of neutrons or radio-activity from the reactor, and must have provision made for expansion and contraction in such a way as not to transmit tilting thrusts either to the boiler or to the reactor. In addition, the coolant circulation pumps will have to be accessible and protected from thrust.

The shielding of the reactor is another of the major structural problems which will fall to this group. Calculations as to the thickness required will have been done by the theoretical group but there is considerable scope for ingenuity in arrangement of cooling and of the detailed arrangements to effect economies of steel and concrete.

A third major section of the reactor design is concerned with instrumentation and with the detection of damaged fuel elements. The instrumentation of the reactor itself will be approximately as complex as that of an ordinary power station. Provision will need to be made for recording, or at least indicating, the position of the controls, for monitoring temperatures, coolant flows, power level, radiation levels in various places and the condition of the pumps, valves, etc., which are necessary for the safe working of the installation.

In addition, we have one further very important group of instruments, those concerned with defective fuel element detection. In the design of the station, if it can be guaranteed that no uranium or fission products will be allowed to enter the boilers, these need not be shielded since the radio-activity of the coolant will be slight, by reactor standards, and will not induce further activity in the material of the boilers. To guarantee this freedom from contamination, it is obviously necessary to arrange to search for fission products in the coolant stream continuously or regularly, and if fission products are found there, to determine quickly where they originate. Since a reactor contains a large number of discrete fuel strings, provision for this determination will, of necessity, be elaborate.

The final major group of design work on the reactor will be concerned with the machines auxiliary to it. The coolant circulation pumps must be designed, or at least specified for design, with shaft seals which will not permit coolant to escape and contaminate the surrounding atmosphere. Fans will have to be provided for auxiliary cooling, and sources of power for the blowers, instruments, and other machinery will be needed.

The Power Plant Group

The group that designs the power plant itself will have one novel problem, that of the boiler. Since the boiler will be taking its heat from clean gas and since the temperature differences available are small, the problem will be rather different from that of conventional boiler design. To mention only two differences, there is no danger of slagging, and there is no danger of burning out tubes. Also, the division of pressure drop on the gas side between the boiler and the reactor is a matter of considerable importance. The design of the turbines and condensers themselves is a matter for a group experienced in this type of work, and calls for little comment beyond mention of the fact that the steam conditions peculiar to this type of station will undoubtedly lead to a design which is rather different in appearance from conventional design.

The alternators, transformers and switchgear will be conventional.

Finally, this group will have to design the control system for the whole plant. In principle, this will be similar to those now used in power stations, with provision for regulation of frequency, load shedding, overspeed protection and electrical protection. It will differ in detail, however, since the performance characteristics of the reactor-boiler combination will be rather different from those of an ordinary boiler.

The Building and Services Group

A building and services group will be required to handle the architecture, the civil engineering, and the general auxiliary services to the station.

The Progress and Planning Group

It is obvious that a project of a type as new as this will require very careful planning and progress supervision, combined with rather better than average inspection, if it is to proceed smoothly. This type of work is familiar, but it is worth emphasizing that even more than in most familiar large jobs, adequate information about the state of the work is essential.

Estimating

Finally, the full time attention of a section which is competent to prepare cost estimates from first principles is necessary. In familiar work, a competent designer can almost instinctively rule out whole classes of design as being unnecessarily expensive. In work as unfamiliar as much of this will be, with the tight connexion between all parts of the project, the choice between alternatives will be more difficult and a running estimate of cost of the whole project will be of the utmost value.

CONCLUSION

In conclusion, the whole process may be summarized. In the design of a nuclear power station, there is one group of problems concerned with the specific nuclear physics of the reactor itself which is completely strange to the general engineering profession, but which has been sufficiently well mastered by the specialists so that it is now available to the engineer. Beyond this lie the type of problems with which he is familiar. Since these problems arise in a novel manner, they must often be approached from first principles, but the principles themselves are familiar even if the logical result of their application looks rather strange at first. The author has attempted to high-light the problems which will arise, but principally he has tried to show that the work involved in producing a nuclear power station is as susceptible to analysis as any other work. Once the basic nuclear physical limits have been established and the performance limits of the fuel elements have been found, the whole design of a station follows as a simple logical process.

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INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Institute on Tuesday, 8th March 1955

An Ordinary Meeting was held at the Institute on 8th March 1955, at 5.30 p.m., when a paper entitled "The Application of Modern Instrumentation and Distance Control of Machinery", by R. H. Paddon Row, A.M.I.Mech.E. (Associate Member), was presented and discussed. Mr. J. P. Campbell (Chairman of Council) was in the Chair. Eighty members and visitors were present and ten speakers took part in the discussion.

A vote of thanks to the author, proposed by the Chairman, was accorded by acclamation. The meeting ended at 7.55 p.m.

Section Meetings

South Wales Section

"Welded Fabrication, with Special Reference to the Atlantic Shipbuilding Company"

A joint meeting of the South Wales Section and the Institute of Welding was held on 22nd February 1955, at the South Wales Institute of Engineers, Park Place, Cardiff, when Mr. M. H. A. Stevens presented a lecture entitled, "Welded Fabrication, with Special Reference to the Atlantic Shipbuilding Company".

This lecture, illustrated by blackboard sketches, dealt with the many difficulties that arose in the totally welded ship, and how these were overcome. There was a tremendous interest in the subject because the construction of the vessel discussed embodied a new principle (that of building in a drydock), thus the attendance was good and representative.

Mr. Stevens was a very fluent and able lecturer, and spoke with the confidence of one who knows his subject, both practically and theoretically, and it was not surprising that there was a long and full discussion after the lecture.

The chair was taken by Mr. H. S. W. Jones (Chairman of the Section), who thanked the lecturer for providing such an instructive evening.

"The Machinery of Ship Repairing, Part I"

A General Meeting of the Section was held on Monday, 14th March 1955, at the South Wales Institute of Engineers, Park Place, Cardiff, when a lecture entitled "The Machinery of Ship Repairing, Part I", was given by Mr. R. G. Hughes.

The care taken by the author to consider in his paper the principles of usefulness, economy, maintenance and layout, justified the keen interest taken by local members in his paper.

Machinery in the workshop was often taken for granted, yet without it none of the present-day machinery could be manufactured. New construction frequently required machinery of a special type, and if all types were placed in the repair shop, some would be little used and some often, and it would be uneconomical. Therefore, for repair work the machinery must be more of the dual or utility type. Problems like this and many others were considered and solutions suggested.

The lecture was amply illustrated and delivered in a masterly fashion.

The Chairman for the meeting was Mr. H. S. W. Jones (Chairman of the Section).

"The Significance of Apparently Minor Factors in Corrosion Problems Affecting Condenser and Cooler Tubes"

At a General Meeting of the Section at the South Wales Institute of Engineers, Park Place, Cardiff, on Thursday, 24th March 1955, a lecture entitled "The Significance of Apparently Minor Factors in Corrosion Problems Affecting Condenser and Cooler Tubes", was given by Mr. C. Breckon, B.Sc., A.R.I.C., A.I.M.

This lecture, from an engineer's point of view, was of exceptional interest, when one considered the number of tube failures there were, even today.

Mr. Breckon had spent many years studying this problem. His illustrations and samples showed typical effects of corrosion and erosion, which in themselves were useful to engineers in the detection of some of the defects seen in marine pipe arrangements.

The lecture was followed by a film on the manufacture of tubes, which was also of great interest, for although, after the nut and bolt, the tube was probably the commonest of all machinery parts, very few of them knew how it was manufactured.

There was a good attendance at this meeting, and many questions were asked and answered after the lecture. A vote of thanks to the author was proposed by Mr. J. Wormald, seconded by Mr. R. G. Turnbull. The Chairman for the evening was Mr. H. S. W. Jones (Chairman of the Section).

Junior Meeting

On Friday, 25th February 1955, at 7.0 p.m., a Junior Lecture by Mr. A. G. Arnold (Member), entitled "Marine Diesel Engines", was given at Swansea Technical College, Mount Pleasant, Swansea.

This proved to be one of the Section's most successful Junior Lectures. It took place in a lecture room filled to capacity with students, marine engineers and surveyors. The lecturer was introduced by Mr. C. E. Cloudsdale, B.Sc. (Member), Principal of the Engineering Department.

Mr. Arnold, a native of South Wales, was soon deep in his favourite subject, and should be highly complimented. Not only was he interesting and instructive, but he was able to speak in a language the students appreciated, thus holding their interest and attention. By the time the lecture was completed and questions asked, the atmosphere was so free and easy that even the most timid seemed to want to ask questions.

West Midlands

A General Meeting of the West Midlands Section was held at the Imperial Hotel, Birmingham, at 7.0 p.m. on Thursday, 14th April 1955. Mr. H. E. Upton, O.B.E. (Chairman) was in the Chair and thirty-five members and guests attended.

Dr. N. J. L. Megson presented his paper entitled "Non-Metallic New Materials in Engineering". The author described how thermosetting polymers differed from thermoplastics and the methods of high and low pressure moulding. He gave an account of the construction of various plastics and their physical properties and the lecture was illustrated with slides which showed how plastics could be used to advantage. Various plastic articles were also displayed.

Nine members took part in the ensuing discussion; the Chairman expressed the appreciation of the meeting to Dr. Megson for his most interesting paper, and the meeting closed at 8.45 p.m.

Joint Meeting with the Midlands Branch of the Institution of Mechanical Engineers

At the invitation of the Institution of Mechanical Engineers, Midlands Branch, a joint meeting was held at the James Watt Memorial Institute, Birmingham, at 6.0 p.m. on Thursday, 21st April 1955, when Mr. L. Baker, D.S.C. (Vice-President, I.Mar.E.) re-presented the Twenty-seventh Thomas Lowe Gray Lecture, "Some Factors in the Selection of Machinery for Cargo Liners". The meeting was attended by 100 members of the two sections. The author considered the objectives of a cargo liner fleet, and described the effects of the type of propulsion on the Admiralty coefficient. Comprehensive data, collected from a number of ships in service using various sources of power for main propulsion, was given. The author concluded by analysing the advantages and disadvantages of both Diesel and turbine vessels.

Twelve speakers took part in the ensuing discussion. The Chairman thanked Mr. Baker for his most interesting lecture, and the meeting closed at 8 p.m.

Sydney

The Annual General Meeting of the Sydney Section was held at Science House, Gloucester Street, Sydney, on Tuesday, 29th March 1955, at 8.0 p.m. The Local Vice-President, Eng. Capt. G. I. D. Hutcheson, R.A.N.(ret.) was in the Chair and there were seventy-eight members and guests present.

The office bearers for 1955 were announced as follows:—

Chairman: Eng. Capt. G. I. D. Hutcheson, R.A.N.(ret.)
Committee: E. L. Buls
W. G. C. Butcher
B. P. Fielden
H. W. Lees
J. Munro
H. P. Weymouth
Honorary Secretary: N. A. Grieves
Honorary Treasurer: J. A. Carson.

After the business meeting, a paper by Mr. J. A. Carson (Associate) entitled "Workshop Practice in Connexion with the Manufacture of Modern Steam Turbines" was presented; the lecture was illustrated by lantern slides and nozzle sections, broach sections, and various types of blades were exhibited. Messrs. H. P. Weymouth, J. B. Jones, and H. W. Lees contributed to the discussion that followed. A vote of thanks to the author was proposed by Mr. F. J. Ward, and carried by acclamation.

Election of Members

Elected 13th April 1955

MEMBERS

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Derek Norman Moore
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Norman Albert Blundell
David Edmund Bullock
George Gordon Clarkson
Eric Custard
James Gauld
Hitendra Nath Ghose
Robert Reuben Hochstadter
Derek Ernest Ing
John Arthur Jones
David Martin Leamon
Malcolm George Macgregor, B.A.(Cambridge)
James Stanton McKenna
Kenneth Alexander Myles
Robert Hilton Oliver
Alfred Paul
Charles Stuart Ralston
Peter Stuart Webster

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Michael Osmond Davis
Charles Dick Eaglesham
Robert James Sidebottom

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William Thomas Davis
Barrie John Mullard

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James Douglas Stewart
Fred Gilbert Weaver

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
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Suniti Kumar Banerjee
Robert James Bann
Terence William Billett
Harold Clark
William Owen Crosbie
Albert Edwards
John Harold Tarlton Fowke
Bernard Kirkby Hargreaves
Ernest Frederick Griffiths
Leonard Robert Hutchinson
Thomas Edward Larmont
David Ridgway Leak, Lieut.-Cdr., R.N.
Norman Joseph Myers
George Henry Pattison
Harry Kenneth Peterson
Eric James Quinnell
Damodar Bapusaheb Sawant
David Edward Wimhurst

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
John Murray Craig Dunlop, Lieut.-Cdr., R.N.

TRANSFER FROM STUDENT TO ASSOCIATE MEMBER
Robert Arthur Gardner
Ralph Phillips

TRANSFER FROM STUDENT TO GRADUATE
Mazahir Husain, B.Sc.(Marine Eng.) (Durham)
Ayward Benjamin Webzell

TRANSFER FROM PROBATIONER STUDENT TO STUDENT
James Anthony Beaumont
Richard Dunford
Walter George Vernon Lugg

Membership Elections

Elected on 17th May 1955

MEMBERS
Vassilios Antzoulatos
Sidney Gordon Bartlett
Alfred Mitchell Benjamin
Ronald Edward Bradley, Sen. Cd. Eng., R.N.
George Vincent Broom
Leslie Charles Crabbe, Sen. Cd. Eng., R.N.
Horace Cedric Cunis
Joseph William Dagleish
Wilfred Maltby Dodds
Pierre Fauconnier
Donald Fraser, M.A.(Cantab.)
Robert Lockhart Good
Alexander Edward Stuart Gourlay
John Cornelius Uphill Hayward, Cdr., R.N.
Michael Joseph Holland, Lieut., U.S.C.G.
Charles Samuel Hunt, Lieut.-Cdr., R.N.
Bernard Joseph Kelsall
David McMinn
George Montague Walwyn Morgan, Lieut.-Cdr., R.N.
Thomas Pike
Harold Anthony Rosario
Andrew Hulton Scott
George Norman Scott
A. J. van Deinse
Fali Rustomji Vania
John Wilson
Finlay Wood
William Carvell Wood

ASSOCIATE MEMBERS
Ian Herbert Appleyard
Ronald Cameron Brown
Anthony John Chandris
Patrick Nessan Cronin
Arthur Dixon, Sen. Cd Mechanician, R.N.
Wilson Greer Dougan
Randal James Drennan
Saabas Max D'Souza
Charles William Gavin
John Roger Sykes Gorst, Lieut., R.N.
George Thomas Gosling, Lieut., R.C.N.
Frederick John Hackney, Lieut.-Cdr., R.N.
William Bowen James
Jal J. Khambata
Myo Khin
Francis Lafferty
David Henry Lang, Lieut., R.N.
Douglas Litherland
Thomas Livingstone
James Alexander McGillivray
Stanley McGuire
Ian Forbes Moffett
Leslie Francis Moore, B.Sc.(Eng.)
Thomas Dunn Morton
Meleth Madhavan Nambiar
Donald John Pepper
Jack Quaintance
Charles Leslie Robertson
Robert Thom Roxburgh
Roy Edwin Salthouse, B.Sc.Tech.(Manchester)
John Victor Scicluna
Himangsu Kumar Sen
Shiv Keshav Shenoy
Thomas Henry Smart
Rajendra Singh Thapa
Peter Henry Tyson
Michael Arthur Howard Walford, M.A.
Alan Robert Webb

ASSOCIATES
John Fraser
Leslie William Kempster
Gordon Roy Lightfoot
George Hardy Cubitt Oughton
James Alastair Lockhart Peck
Vijai Kumar Sahny, Lieut.(E), I.N.
James Leslie Scott
George Wilkinson Vosper
Henry Wilkinson

GRADUATES
Ernest Albert Adlington
Hugh Allan
Sachidanand Bhargava, Lieut.(E), I.N.
Joseph Porter Campbell
Kenneth Chambers
David Edgar Corbett
Alfred Robert Dailey
Carlton Alvin Goddard
William Edward Green
Michael Kenyon Hawkyard
Robert Patterson Hill
Frank Hipson
Ronald Hunter
Norman Vernon Jagger
Peter Leck
James McArthur Merrilees

Robert Alexander Mitchell
Balwant Rai Parti, Lieut.(E), I.N.
Alexander Ramage
Richard Smith
Kenneth Sutton
William Swindells
Fred Thompson
Clive Thornton-Jones
Roy Arthur Tredennick
Anthony Wynn Watkins
Trevor John Wright

STUDENT
Anthony Robert McKnight

PROBATIONER STUDENTS
David Edward Gue
John Sydney Michael Sutton

TRANSFER FROM ASSOCIATE TO MEMBER
James Bowman

TRANSFER FROM ASSOCIATE TO ASSOCIATE MEMBER
Joseph William Aspinall
Edwin Thomas Baker
Ludovic Baxter
Robert Alexander Blackley
Frederick Charles Bown
James Alexander Brace
Stewart Rex Cairns
Archibald Cameron
Donald Colquhoun
James Trevor Fishwick
Douglas Christopher Rodrigo Goonewardene
William Harwood
Raymond Howard George Hillier
John Henry Leigh
David Ferguson MacDonald
Ian James Herschell McKay
Andrew Allan Buchanan McMillan
Kenneth Meyer
Henry Arthur Newman
Robert Nicol
Charles John Probett
John Edgar Randle
William Naismith Robertson
Maurice William Scanlan
Tom Burnell Snowdon
Christopher Sidney Studd
Herbert Edmund Tune
Walter Turnbull

TRANSFER FROM GRADUATE TO ASSOCIATE MEMBER
Hugh Leslie Owen Thompson, Lieut., R.N.

TRANSFER FROM STUDENT TO ASSOCIATE MEMBER
Roger Briers Berry, Lieut., R.N.
Basil Francis Thatcher

TRANSFER FROM STUDENT TO GRADUATE
Donald Carr

TRANSFER FROM PROBATIONER STUDENT TO STUDENT
Peter Roland Whitehead

OBITUARY

NORMAN GEORGE (Member 11048) was born in 1903. He served an apprenticeship with the Wallsend Slipway and Engineering Co., Ltd., from 1919-24 and spent the following ten years at sea as fourth to chief engineer with various companies, including H. Hogarth and Sons, Ltd., Cairns, Noble and Co., Ltd., and Furness, Withy and Co., Ltd. From 1935-41 he was successively an engine fitter ashore, chief engineer with the Paramount Theatre, Newcastle upon Tyne, engineer instructor for the Ministry of Labour, and inspector in an aircraft factory. From 1941-47 he was at sea again, first as second and then as chief engineer; he obtained a First Class Steam Ministry of War Transport Certificate in 1943. In 1947 Mr. George went to Canada; he was employed there for two years as a machinist with the Canadian National Railway Company, for two years as chief engineer with Colonial Steamships, for one year as chief engineer with Vickers Ship Building Company, for a further year as acting chief engineer at the Wabasso Cotton Mills, and during 1954 as chief engineer with the Mohawk Navigation Company. He died on 23rd January 1955.

Mr. George was elected an Associate of the Institute in 1946 and was transferred to full Membership in 1948.

ALEC LEE HOBDEN (Member 12874) was born in 1893. He joined the Royal Navy in 1909 as an apprentice artificer and from 1914-29 he was at sea, first as engine room artificer and then warrant engineer. For the next three years he was lent to a New Zealand Division for training personnel, and in 1932, as commissioned engineer, he was appointed chief engineer of H.M. Sloops and Destroyers at Chatham. In 1936 he was promoted lieutenant(E) and served until 1938 as chief engineer of the flagship of the Fishery Protection and Minesweeping Service. After a year ashore as Stokers' Training Officer at a Royal Naval Depôt he was chief engineer of a Hunt Class destroyer from 1939-41, and then lecturer and divisional officer of an artificer apprentices' training establishment until 1944, when he was promoted lieutenant commander(E) and spent his last three years in the Navy as maintenance engineer at the Royal Naval Air Station on the Isle of Man.

After his release from Royal Naval service, Lieutenant-Commander Hobden spent four years as maintenance engineer with the Ministry of Works before accepting a series of brief appointments, as chief engineer with the Millway Shipping Company and for three trips with the weather ships *Weather Watcher* and *Weather Explorer,* and for two periods with the R.R.S. *Discovery II.* He died very suddenly on 19th March 1955, after an operation, of cancer of the lung. He had been a Member of the Institute since 1950.

ARTHUR WILLIAM ROBINSON (Member 13170) was born in 1892. After completing his apprenticeship with Walker Brothers, Wigan, he joined the Merchant Navy and obtained a First Class Steam Certificate in 1914. During the first World War he was in the Submarine Service and joined the British Tanker Co., Ltd., as third engineer in 1919, after demobilization. After serving from 1924 to 1940 as chief engineer in British Tanker Company vessels, he was appointed to shore duties supervising new construction. He retired on 31st January 1954 and died on 7th March 1955. Mr. Robinson had been a Member of the Institute since 1951.