The Research Laboratories of the General Electric Company

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[Plate 1]

The lecturer introduced his subject by showing lantern slides illustrating the buildings of the laboratories; also certain processes and tests in progress in various departments.

I am glad of this opportunity to indicate the objectives and the modus operandi of the laboratories of which I have been Director since their foundation in 1919. Such a study may raise, I hope, in the minds of some of us, the question of what should be the objectives of research when attached to productive industry—remembering that the rate at which efficient and ordered manufacturing industry can digest new diets of innovations and novel products is inevitably limited, much more limited I think than is usually appreciated by those who are not themselves engaged in productive industry.

The staff engaged at these laboratories now totals rather over 1000. As the establishment is entirely self-contained, that number has to include all essential service personnel in addition to the professional scientific and engineering staffs. These latter number about 250. Physicists and engineers predominate in numbers over the chemists, metallurgists and glass technologists. There are also some 100 young men who are going through their professional training with us in science and in research, and working for B.Sc. degrees or Higher National Certificate qualifications on a part-time basis. Whilst they are passing through this stage they constitute our junior technical staff, to merge in time (or most of them) into the fully qualified research staff. There are, among the total number, 160 skilled craftsmen of all trades who are as much ‘on the staff’ (with equal staff status) as the professional personnel. We started in 1919 with a staff of about thirty and have grown to these numbers at a fairly even rate over 27 years.

Objectives of the Research Laboratories

Now as to our objects. I would like to dwell upon these, for it was the subject of no little discussion at the start, and I am glad to say there was then no difference of opinion, nor has there been since.

The laboratories have had three main functions.

(a) The first and most important is to give scientific service to the factories and departments of the Company.

(b) Secondly, from the intimate experience so gained with these factories and departments, to draw inspiration to formulate and carry out such longer-term
researches as in the opinion of the laboratory staff will ultimately benefit their industry.

(c) Thirdly, to join in any outside activities in which an industrial scientific staff can help the professional life of the community.

The essential fact I would like you to note is that (i) the starting-point for the grouping of the research work within the laboratories, (ii) the number of men devoted to any field of work, and (iii) especially the organizational link with factories and departments of the company we serve, are based upon the requirement of giving them scientific service in all the ways in which an up-to-date laboratory can help them.

One of these ways (covered by the second objective) is of course to watch all trends and prosecute a certain number of long-term researches which seem likely to lead to outstanding additions to knowledge or drastic changes in technology. This latter function is of course very important, but it is not in fact the primary one for which our laboratories exist.

I believe this is of interest because it seems to be a reversal of the more usual set up. Under this an industrial research laboratory is designed to keep all its thoughts and intentions upon investigations which will lead to new processes and products. The giving of scientific service to existing industry is hardly part of the design: it becomes an incidental duty which is regarded as tending to interfere with its principal and more fundamental functions.

At first sight this difference of objective may appear doctrinaire, but in fact it vitally affects the structure and outlook of the scientific side of the electrical industry so far as my Company’s part of it is concerned. I think I can also establish that the scientific approach to an industry, through an intimate knowledge of its existing products and processes, forms the most effective of all vantage points from which to get inspiration for the right sort of long-term as well as short-term researches. There are always so many investigations which can be attempted—so many temptations to unnecessary and ineffective experiment—that the choice of what to do can be a difficult matter unless dictated by first-hand intimate knowledge of the manufacture in question, in all its aspects.

In the days when it was necessary to commend to industrialists the importance of scientific research, I used to reckon that the expensive things they were persuaded not to undertake, went a long way to meeting the cost of my establishment. That is I know a common experience with many of us, but we sometimes forget it in assessing our contribution to industry.

Before I explain by examples how this works out I must just indicate the scope of the factory production units and the like which we exist to serve.

The General Electric Company

The total personnel in the General Electric Company is about 50,000. It was about half this size when we started, but its main units already existed then. Its motto has been ‘everything electrical’ so you will expect a wide scope of effort.
The Research Laboratories of the General Electric Company

The factories we were to serve were autonomous establishments widely separated geographically:

A steam turbine and heavy mechanical engineering works at Erith.
An electric cable works at Southampton.
Electrical Engineering Works for heavy rotating machinery, transformers, switchgear and rectifiers, as well as light electrical engineering plant, at Witton, Birmingham.
Electric lamps, radio valves and glass, London.
Measuring instruments and apparatus at Salford and Birmingham.
Telephone and radio works at Coventry.
Electro-medical works in London.
Electrical appliances (household and industrial) at Birmingham.
Carbon and battery works, Birmingham.
Central Sales Department in London with Sales Branches in most large cities.
A number of smaller factories for subsidiary products.

It might have been a baffling matter in 1919 to know how to begin, had it not been for the definite principle of approach which I have indicated plus the urgent request from the management to concentrate attention first on electric lamps and their utilization.

Factory collaboration

So you see us starting as a group of industrially raw but enthusiastic scientists approaching a factory staff who had long experience and were justly proud of their production skills and achievements. This was an inflammable situation in which success depended as much on a study of human nature as upon grasping the technical nature of the problems and upon learning the processes.

The problem of welding two such staffs into what is in effect a single team is in my view the essence of successful industrial research and does much to determine the form of the internal organization of the laboratory. It is a battle which is never finally won and the price of its continuance is eternal vigilance.

I have dwelt on this because the same battle has to be fought in every factory with which we collaborate. Almost invariably it falls to the lot of the laboratories to lay siege to the good-will of the factory production staffs at all levels. It is indeed an essential and most beneficial part of the training of the laboratory staff to do so—and ultimately to learn that it must not be one of their objectives to show the factory managements how clever their research people are.

Staff structure

So, in the internal structure of the Laboratories there must be a distinct group of workers with a group leader for each factory or each important section of a factory (or technical Department) of the Company. There are thirty-four of such laboratory groups, the membership of which varies from say three to twenty
qualified people each. With us the individuals in the groups are mostly physicists, engineers and chemists.

We have in addition the following strong service groups which are at everyone's disposition: analytical chemists, metallurgists, X-ray workers and spectroscopists, mechanical engineers, glass technologists, and statisticians.

These, who constitute about 10% of the scientific staff, are at the service of any of the groups working with the factories, and join in their specific researches as required.

The whole set-up is flexible and somewhat informal—partly because there is no apostolic succession of conferred authority or status or staff grades of seniority. Some thirty of the most respected members of the scientific staff are designated Leading Staff. That is the only discrimination in staff status. But the leadership referred to in this case is intellectual and also a matter of character. It is not administrative. Whilst therefore it carries its inevitable moral responsibility it bears no conferred authority. Group Leaders are not necessarily members of the Leading Staff—nor are members of the Leading Staff necessarily Group Leaders.

I must not pursue further the subject of internal staff organization—which, however, I myself find of absorbing interest. I only bring it into this description of the place in order to indicate how we manage to have some thirty-four separate groups nominally responsible to the Director.

The guidance of the work of any group under its group leader is much assisted by the attendance of its members at regular meetings with their opposite numbers from the factory (or technical department) which the group serves. At these meetings the status of products and processes is discussed from the technical and marketing standpoints. These meetings are interlocking and advisory in their character and have no authority actually to direct development or research.

This structure of interlocking meetings was a matter of gradual growth. It derives its standing from the recognition and support of the Chairman and Managing Directors of the Company—an important proviso.

Publication

From the beginning, publication of the scientific aspects of the work of the laboratories has been pressed. Papers are nominally communications from the scientific staff as a whole, under the authorship of the individuals who have been mainly responsible for the experimental work. The technical aspects of the work are also published where they are likely to be of general interest, but the publication of the technical 'know-how' of processes is as a rule reserved.

It follows that, if a competitor has a well-staffed research establishment of his own, he will be able to derive assistance from studying our scientific publications, and we his; but if he is one of those who merely seeks to trade on other people's
work, by cadging information so that he can set up manufacture on empirical lines but making no contribution to knowledge himself, we try not to help him.

There have so far been some 100 major publications to the learned societies, and there is no impediment to joint authorship with staff from outside research establishments.

The policy lying behind this is not merely a philanthropic one. It brings of course its own rewards, one of which is that no research staff can be healthy if it works under a ban on reasonable publication.

Try-out units

As the practical outcome of much of the work must show itself in better or cheaper products for the market, the test of every new development to this end ultimately lies in the making of something. It is necessary therefore for some of the groups to have nucleus production facilities with personnel whom they have trained in the particular skills required (after learning them themselves). These units are located within the laboratories in close proximity to those research workers who guide them and use them.

It has sometimes been a hard battle to persuade a factory production staff that amateurs (particularly scientific ones) can make any useful contributions by trying to produce articles themselves. I think this battle was finally won during the war. In 1940 it was obvious that there was no one ready or able to make the many types of radio valve developed for centimetric radar and the like. So we greatly intensified our amateur efforts. We called our little groups pre-production units and expanded them to the utmost till the number of their personnel reached 700. There were many tears and much perspiration, but we mastered the production problems of each new type of valve as it emerged from the research stage, and by the end of the war had made in the laboratory 360,000 valves of forty-eight types at a cost of 10½ million pounds.

I think the factor which is often overlooked is the very great educative influence which the effort required actually to produce articles has on a scientific staff. The mere making of an article or demonstration of a process can be a relatively small matter compared with putting it into efficient and uniform production whether by unskilled, and maybe unsympathetic, human effort or by skilled and complicated mechanical agencies.

In industry uniformity is a gauge of quality; but the achievement of uniformity presents major problems where every operation has a Gaussian distribution of variability, the causes of which must be found and defined, and where hundreds of such operations and components go to the make-up of the product. Herein lies one of the largest single sources of the research problems which force themselves upon the attention of such a laboratory as ours.

As you will imagine, the solution of many of them requires prolonged research, using the best available resources in the way of equipment. They constantly lead to most interesting investigations, which I hope I may now exemplify.
Sir Clifford C. Paterson

Example 1. Glass and refractories

Glass

Take, as my first example, the field of glass. We first met glass in the making of bulbs for electric lamps. These bulbs are delivered from the glass factory to the lamp factory as open ended envelopes which are then assembled with the other components on somewhat intricate machines. These melt or soften the glass at the right points by means of gas flames. Each bulb follows the previous one through the automatic machine at the shortest possible time interval needed for the melting of the glass and its manipulation. There is no chance of hand control. The timing of the operational sequences of the machine is remorselessly uniform. Thus the amount of heat applied, and the behaviour of the glass under the heat must be very uniform indeed or chaos results.

By skill in empirical operation the factory were managing to use as few as 125 bulbs for 100 good lamps. Was there anything we as research men ought to do to reduce the wastage? We undertook of course a comprehensive study of the influence of the various constituents of the glass on its viscosity over the required temperature range. It was a long road involving continuous work and study in the glass factory. In the end we reached an efficiency of 104 bulbs for 100 good lamps.

The softening point is only one factor in glass quality. The coefficient of expansion is another—ensuring that it shall seal on to other glasses without strain or with the designed amount of strain either in tension or compression. Then there are the wetting properties when sealing to metals and alloys—also the electrical conductivity where the design of the lamp requires that parts of the glass must operate at relatively high temperatures. Over the past 25 years the study of these things has led to the design of glasses for electronic devices which respond to very exacting demands, and without which the devices would not be practicable.

The composition of glasses may involve eight constituents, each having its influence upon the characteristics.

Refractories

It is well known, however, that the art of making good glass is wrapped up with the art of making good refractories in which to melt the glass: molten glass is chemically one of the most active materials—it will attack most things. Therefore, if uniform glass of known characteristics is needed, a grasp of the science and art of refractory manufacture is essential.

The problems of refractories are always with us for they are stimulated by the constant urge to produce special glasses, which are uniform and not subject to disastrous wastage. May I give one example from the work of my colleague Dr Partridge?

By X-ray and other studies we are finding that fire-clay refractory materials consist of crystals of mullite and silica set in a glassy matrix. It would seem clear that their properties at high temperatures must be influenced by the viscosity of this glassy cement. Indeed we find that the behaviour of all kinds of refractory
materials at high temperatures can be understood more readily by considering them from this point of view.

Figure 1, plate 1, shows a large fire-clay crucible run at a temperature of over 1400°C. It collapses like this through weakness after a short life under the fluid pressure of the molten glass inside. Curve A in figure 2 shows the result of high temperature creep tests on this refractory and confirms its weakness.

![Figure 2. High temperatures creep tests of pot clays.](image)

We have found that the eutectic mixture (i.e. the mixture of lowest melting-point) in the silica-alumina system is actually a glass. This is significant because this eutectic mixture is present in all fire-clay refractories.

When pure it is a very good glass and was the basis of a special glass we developed during the war for seals in silica valves; its melting-point was about 2000°C.

Unfortunately other oxides present in the fire-clay, such as alkalis, iron oxide and magnesia, combine with this matrix glass to render it more fusible and mobile. Guided by this a search for other clays has yielded a refractory whose creep characteristics are represented by curve B of figure 2 and the pot which results is shown in figure 3, plate 1, after a long life. Incidentally, the average life of the pots is now increased three times.

Following the same line of investigation, figure 4, plate 1, shows a photograph of the inside wall of a glass tank which has been operating for many months with 80 tons of molten glass. A tank costs thousands of pounds to put out of action and rebuild. You can see the general corrosion which has been going on. Observe especially the row of white blocks about 12 in. high on the left side of the picture. Refractory blocks of this shape originally extended along to the right-hand side—but here they have been simply eaten away and have gone into the glass and contaminated it. The blocks on the left were made from the new purer refractory,
which contained less of the glassy phase. These have now been generally adopted and the tank life has been lengthened greatly as a result.

It is not practical politics to make well-intentioned guess-work changes in the design and materials of these great tanks. The loss of too much money is involved in a bad shot. Anyway, if anyone makes a mistake it must not be the scientist. Therefore all the resources of the research laboratory must be invoked to establish the soundness of a proposed change before making it, and the technical staff of the factory also have to be persuaded by our arguments. Investigations to this end usually take years before practical trial is made, and even then the results cannot be established for another two years or so.

**Opal glass**

Opal glass is used to diffuse the light from electric lamps and to obscure the intensely bright filament. The opacity was an empirical matter resulting from the precipitation of some constituent from clear glass as it cooled from the molten state.

Measurements showed that the diffusing power and the loss of light by absorption varied greatly in different opal glasses. There was much argument about the nature of the precipitated particles which caused the scattering of the light. X-ray powder photographs showed us that they were, in fact, minute particles of calcium or sodium fluoride, or both. The particles are normally spherical but occasional brittleness of the glass was found to be associated with the development of sharp angular crystals. Another important result emerged from a mathematical investigation. This showed that, consistent with satisfactory diffusion, the size of the particles was critical for low absorption.

These studies of the fundamentals enabled a more efficient opal glass to be made and, more important, enabled consistent results to be achieved in the glass works. All that was 15 or 20 years ago.

One research of course often suggests another in some surprisingly different field. Thus, in 1940, when the practicability of centimetric radar was under active discussion, Ryde (remembering his earlier work on opal glasses) developed the analogous theory of the absorption and scattering of very short radio waves by rain and similar meteorological phenomena. This was followed by detailed numerical predictions of the attenuation and the magnitude of the radar echoes to be expected at different wave-lengths in the centimetre band. These provided much needed information at a critical time when actual measurements of the effects were out of the question. So much for my examples from glass.

**Example 2. Filament lamps**

One of the research objectives stimulated by intimacy with the processes of lamp manufacture was the improvement of the efficiency of the lamp as a light giver. This could be effected by many details of (a) tungsten wire processing, (b) filament coiling, (c) gas-filling and (d) glass making. The immediate incentive to improved
efficiency was the normal competition on the market for lamp quality and ability to show more economical use of the electricity for which the user paid.

It is interesting to look for a moment at what this means now from the national standpoint. Electric lighting in this country uses some 4000 million units of electricity per annum. Every 10% of electricity saved in getting from the lamp the light we want, means in the end a saving of some quarter of a million tons of coal per annum, together with the incidental saving of generating plant.

Example 3. Discharge lamps

We worked for a number of years on the above lines during which the average filament lamp efficiency was increased some 25%. It was clear, however, that little further worth-while gain in efficiency of filament lamps was likely.

A study was therefore taken in hand by a special group (also under J. W. Ryde) of the possibility of the electric discharge in gases and vapours being made to yield useful light. This turned out to be a fortunate inspiration which resulted firstly in the high pressure mercury lamp for street lighting, then the mains voltage luminescent tubular lamp for internal lighting, besides various types of compact source high intensity lamps for projection. As these lamps have now three times the efficiency of filament lamps, when they become generally adopted we shall be able to enjoy the same amount of light in our buildings for one-third the amount of electricity consumed. This was a really fine gain, of which the country has yet to reap the harvest. It means a potential saving of nearly 2 million tons of coal per annum. In terms of electrical generating plant it can mean (assuming a 10% lighting load factor) the saving of something like three large generating stations of one million kilowatts output each, or say five stations of the present size of Battersea.

These revolutions are but vaguely appreciated because they materialize over a number of years and also because of the natural inclination of the public to employ some, at least, of the advantages presented to them in having more light rather than in using less electricity.

I have no time to mention any of the many interesting problems we met—and still meet—in this field of fluorescent lighting. I refer to it because of course it is an example of a complete break away from existing practice and takes its place in the second of the objectives I mentioned at the outset. Nevertheless, I would insist that even a break-away product like this needs to be evolved from the beginning by people who have an intimate acquaintance with the appropriate manufacturing procedures and materials.

THE THERMIonic VALVE

I was tempted to take some examples from the extensive field of the development of the radio valve, which has been another of our major subjects of scientific study and development ever since its industrial birth during the first world war. This product indeed rests on the giving of scientific service through intimate
association with its manufacturing arts—and affords a wealth of evidence of the theme I am trying to develop. But time and space will hardly permit of further examples of this kind.

**Project research**

There are some categories of equipment manufacture which are assisted best when the associated research group bases its work on projects rather than on scientific service. This applies, for instance, to telecommunications, both radio and line telephony. Thus, the project for distributing television over the country by radio links on centimetric wave-lengths involves some interesting wide wave-band transmission and reception problems. Another is the use of radar techniques for injecting pulses into circuit networks; these pulses probe the electrical characteristics of the circuits and cause them, as it were, to write their own signatures in cathode-ray tube traces.

Some of the war-time projects of this kind, which our groups undertook, made history, for in the first half of 1940 they produced the first centimetric radar and made the first practical cavity magnetrons, the principle of which had just been demonstrated by Randall and Boot. This was followed by the evolution of the radar project known as Oboe, with the leadership and co-operation of T.R.E.

*User or Operational Research* is in an intermediate category. It formed the basis, for instance, of our investigations into street lighting, where it was found that visibility on the road depended upon making the road as light as possible and objects upon it as dark as possible—a principle which resulted in a radical change in the design of luminaires for street lighting and their location on the roads.

**Quality appraisement and control**

Whether research is based upon the giving of scientific service or upon the study of new projects, or whether some entire break away in product or process is in hand (wherever there is manufacture) there is always the problem of statistical appraisement of the quality of the manufactured product followed by the introduction of some system of quality control.

This has been proved, by the experience of ourselves and others, to be the key to efficient and intelligent production. We find that it is best introduced to the factory at the craftsman (or charge hand) level (not at the managerial level) by scientific men who, as I have explained, are prepared to immerse themselves in the factory regime.

The practical principles of this quality control are simple—almost childish—but the psychology is often baffling. In our experience the secret of success is to work through the intelligent engineer in the factory and to instil into him the very small but essential amount of statistical technique. The ineffective way is usually to work through trained statisticians, and to expect them to assimilate sufficient knowledge of the processes concerned to ensure a sound practical result—unless of
course a statistician can be found who is also an engineer with a gift for immersing himself in factory problems and who has patience to concentrate upon the application of quite simple statistical procedures.

Factory men of the right enthusiasms and psychology are difficult to find. Without the constant encouragement and guidance of the practical statisticians on our research staff, we find this powerful weapon of progress tends to rust and lose its effectiveness.

**Conclusion**

I could touch upon other fields of the work, for instance, (a) hard stones like diamond and sapphire and their handling, (b) crystal growing, (c) powders and the techniques for handling them, (d) heating for buildings and for industrial processes, (e) household appliances, including cooking, (f) carbon, (g) insulating materials, (h) X-ray and other electro-medical equipment, (i) steam and gas turbines, (j) heavy electrical equipment. They are very diverse, but the procedures for handling them follow closely the lines I have already sketched.

There is one group of activities which differs somewhat from these in character. We put the resources of the laboratories at the disposal of Government Departments by accepting research or development contracts for investigations for which our particular skills are suited. Probably one-fifth of the research resources I mentioned earlier are occupied in this way.

As you see, I have not attempted in this talk to give a review of the work we are doing, but rather of the way our laboratories have learnt from their experience to go about the work. I have done this not merely in order to describe the establishment, but in the hope that you will allow me to point out a consideration of general importance, the factor of efficiency in the use of scientific facilities in industry.

I sometimes feel we have the idea that we have only to do research and get explanations and knowledge of certain things and the rest follows naturally. If we do not get explanations and knowledge of exactly the right things, and if we produce that knowledge in other than a favourable psychological atmosphere, things just do not happen, or only just happen, in the industry we are trying to serve, notwithstanding all our imposing and praiseworthy treatises and reports, some of which are good of course, but how many?

An extreme case may be that of a detached research laboratory which merely publishes its reports and leaves industry to do all the thinking about whether the results can be made of use for practical purposes. How much of the whole amount of such effort really gets into an industry in a form in which it brings about advances which pay a technical dividend depends naturally upon the level which that industry has reached. But it is I fear, usually a small proportion, say 10 or perhaps 15 %. Even so, that is useful.

A stage higher in effectiveness may be the research establishment which, having done a piece of research, works hard to demonstrate the practicability of the results. What proportion of the total man-power effort of that establishment will
have been effective in producing a technical dividend in manufacturing industry? Shall we say 20 or perhaps 30%?

I contend that when scientific manpower is being employed in the manner I have been trying to indicate in this talk, its efforts have as a rule a maximum of effectiveness in producing technical progress within industry. The stimulating reaction on most research workers of being in contact with the actual application of their work constitutes one aspect of this picture. Another is the progressing of the investigations from their early stages in co-operation with the actual individuals who must implement them and make them serviceable.

I feel we need to foster the conception of the effectiveness and non-effectiveness of industrial research according to the kind of chance and help we give it to fructify, and it is to this end that I commend to you some of the considerations I have been discussing. I hope I have indicated some of the criteria which, as I see it, can give us a sense of values in regard to efficiency in the employment of scientific resources in production industry.

I do not want to hold up my laboratories as an example to be followed. Nearly every research establishment in industry has a unique problem in organization. But laboratories like those I have been describing do, I hope, serve to exemplify certain principles which are worth examination.

The Plymouth laboratory of the Marine Biological Association of the United Kingdom

By F. S. Russell, F.R.S., Director of the Plymouth Laboratory

(Delivered 6 March 1947—Received 11 July 1947)

[Plates 2 to 8]

In The Times of 31 March 1884, it was announced that a meeting would be held that day in the rooms of the Royal Society for founding a society having for its purpose ‘the establishment and maintenance of a well-equipped laboratory at a suitable point on the English coast, similar to, if not quite so extensive as, Dr Dohrn’s Zoological Station at Naples’ (M.B.A. 1887a). With Professor T. H. Huxley in the chair a gathering of distinguished gentlemen gave reasons why such a laboratory should be built. All stressed what its value would be from the purely scientific viewpoint, and all were agreed that both by fundamental research and by more direct investigations on our food fishes, knowledge of economic import would be gained. The last speaker, Mr George J. Romanes, said that there was one function of the proposed laboratory which had not received the attention it appeared to