try, it must be said that there has as yet been little sign of this trend occurring.

Conclusions

1. Research Programmes need clear objectives; this is true in all fields of research.
2. These objectives should be worked out by consultation between the people who are going to use the ultimate product of the research, the people who are going to do the research, and the people who are going to design, develop and manufacture the product arising from the research.
3. This form of consultation should continue throughout the research programme and be used as a basis for keeping the programme under surveillance.
4. Arrangements of this kind already exist in the Aerospace Field through the medium of the Joint Research Committee.
5. The extent of the consultation needed depends on the nature of the research, varying from a minimum for basic research to a maximum for applied research closely related to the final manufactured product.
6. A prerequisite for all this is that there should be a clear national policy in the area concerned upon which the research programme can be based.

**About the Author: Mr. Handel Davies is the Technical Director of British Aircraft; Limited.*

***About the Speaker: Mr. Roy Orford is Director of Rolls-Royce Limited.*

"INDUSTRIAL RESEARCH PROGRAMME AT HARWELL"

by
Dr. Walter Marshall, FRS
Director of Atomic Energy Research Establishment, Harwell

In describing the Research Programme at Harwell I intend to cover three themes; first, what factually are we doing, second, what lessons have we learnt so far, and third, how does our experience fit in with Rothschild's "customer/contractor" principle?* Because this last item is topical and of lively interest I shall, to a modest extent, stray outside a narrow discussion of the Industrial Programme itself.

Let me say immediately that I approve of Rothschild's general philosophy which, as I see it, is simply that all scientists must be accountable for what they do. Certainly, I agree that the most unambiguous way of establishing "scientific accountability" is to have a defined customer for the research. I shall, however, suggest later in this lecture that Rothschild's ideas need to be extended to deal appropriately with innovative research aimed at an eventual industrial customer.

In a limited sense Harwell has worked under some sort of customer/contractor relationship from its beginning in 1946, as much of our research programme has always been shaped by the demands of the other Groups of the Authority — until recently the Production Group, the Reactor Group and the Weapons Group. However, I would not like to press this agrument too far as this has been largely an inter-family relationship — although you will appreciate that sometimes dealing with members of the family is no guarantee of an easy life. Until the mid-1960's a large part of our work was in basic science where the "customer/contractor" can hardly be expected to apply. I think it is fair to say that what would be recognised as a true customer/contractor relationship, with outside customers, only began after 1966 with the development of our present industrial programme.

1965 and early 1966 saw important decisions on the future of nuclear power in this country, both in relation to the introduction of nuclear power stations expected to be fully competitive with other methods of electricity generation and to the development of the fast reactor system for subsequent exploitation. It then became clear that, although the development of the next generation of British power reactors would still require a lot of research work, the scale of effort required at Harwell to back this development would be smaller. This led us to examine Harwell's future role and to conclude that, although Harwell's original mission was still very important if the Laboratory were

"LONDON '73" SPECIAL NOTICE TO MEMBERS

Your UK Chapter is planning a new and different type of three-day international licensing conference for about June 1, 1973. This will be organized through a leader of a "team" of firms from each of about ten countries, the idea being to supplement morning country by country plenary speeches and panels with afternoon "workshops" which approach more closely a direct licensor/licensee discussion. In other words, this conference will, on a pioneer and on experimental basis, be a little more commercial than most LES conferences. Individual country "teams" will have individual headquarters suites as a base of operations, for hospitality, and for discussions.

LES members who are interested in being informed and/or possibly participating in this conference should contact their LES Chapter President re their own "team" or the main chairman:

Mr. John Gay, U.K. LES
U.K. Atomic Energy Authority
11 Charles II Street
London S.W. 1Y 4QP, England

United States LES members should contact the U.S. "team" leader:

Mr. William Riley
Battelle Development Corp.
505 King Avenue
Columbus, Ohio 43201

to continue with a healthy programme it would need a major new objective. Although, as you can imagine, our discussions about the new mission were complicated, and controversial to some extent, we concluded that we should use our scientific resources to the encouragement of technological advance and innovation in British industry. We, therefore, set as our objective to convert part of the Laboratory into a multi-functional research establishment to assist British industry and to accept contract research on a wide basis. At the time, of course, many questions were asked as to the validity of our conclusion but rather than go through the arguments in retrospect, I think it would be more helpful to describe what we have done so far and to let the conclusions emerge for themselves. In order to do this I have prepared several charts showing the results which we have achieved since 1966 and our projections for next year. I shall also indicate in outline our plans for the next few years. We felt at the beginning of our industrial work that a financial criterion was the only sensible one to judge the usefulness of our work to industry — in other words, "would our customers pay us for our help?" — and therefore my charts are based largely on our financial performance.

Figure 1
November 1971

A.E.R.E. Harwell
Professional Manpower on Programmes

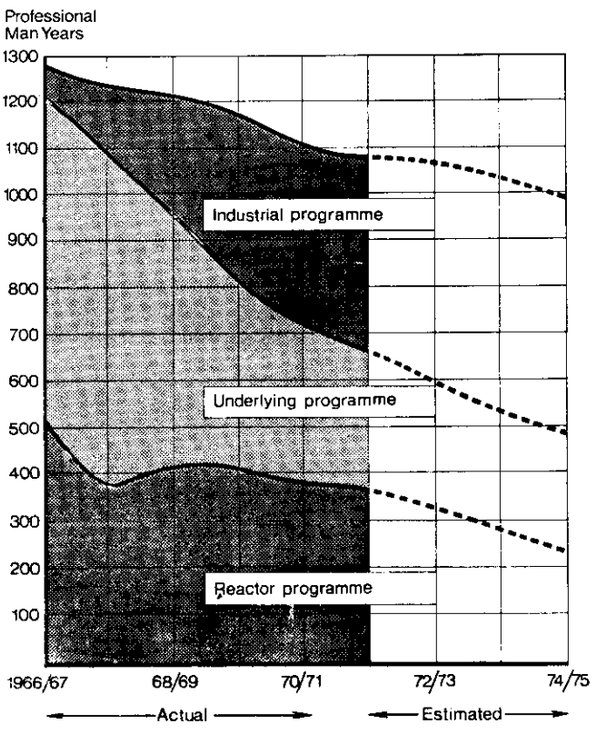


Figure 1 shows in broad outline the massive redeployment of professional manpower which we have brought about over the past 5 years. You will see that the effort on the industrial programme in 1966/67 was a modest 5%, today it is about 40% and in 1974/75 we anticipate that this will have been increased to about 50%. The reactor programme, which is the work we carry out in response to well-defined requests from the Authority's Reactor Group, has remained fairly constant over this period although, of course, the emphasis has changed so that the greatest effort is now employed on the fast reactor programme.

Perhaps the most striking change concerns our underlying programme which we have reduced by a large factor already; we anticipate a further slight reduction in this area stabilizing somewhere between 20-25% over the next few years. Our underlying programme consists of research to understand the basic science in areas connected with nuclear technology including work on materials, nuclear physics, on computational techniques, on quality control, etc. It is the only work at Harwell which is done without strict time deadlines attached to it. Indeed the best definition I can give of our category "underlying research" is "the research we do which does *not* have to reach well-defined objectives, expressed in non-scientific terms, within a time scale of a few years or less". It is a much wider category than Rothschild's "General Research".

In my view, there has been a good deal of confusion in the newspapers and technical press concerning Rothschild's proposals for long term "basic research". Therefore, I would like to take a little time to expose to you my own views with an example which will, I believe, illustrate the perils of being trapped into arguments over nomenclature.

In a commercial fast reactor all the fuel, cladding and structural materials are exposed to an intense flux of fast neutrons. As a result the atoms making up these materials are knocked out of their initial positions and become free to diffuse away. So intense is the flux that on average *every* atom of steel is displaced several hundred times during its lifetime in the reactor. Therefore, in general, we expect voids to form in the materials and the diffusing atoms to cause swelling. It does not need much imagination to anticipate that these phenomena will give rise to difficulties in the future. Therefore, we conduct a research programme on radiation metallurgy so that we shall become better informed upon the science of voids and swelling at high doses and long exposures. This is not part of our reactor programme — because it is not specifically requested by the Reactor Group against a time deadline. Because all our work in this area is published in the open literature some people would call this basic research — or to be more precise, "objective basic research". On the other hand, it is done with a well-defined objective in view, namely to solve the materials problems of the fast reactor as they become defined, Rothschild would call this "Applied Research". Naturally we prefer our own nomenclature of "underlying research".

If the underlying research programme is chosen correctly then one should be able to see a succession of occasions where it is interrupted or used to solve more pressing day to day problems. In such cases a given part of the scientific programme may change in nomenclature. For example, as part of our underlying programme some years ago we commissioned a

powerful accelerator, the Variable Energy Cyclotron, as a useful tool to study radiation metallurgy and radiation chemistry. At that time we saw only in a very general way the wisdom of this line of work but when the full magnitude of the void problem emerged from the fast reactor programme we saw how the VEC and our underlying programme could be used to solve this problem rapidly.

By using this Cyclotron we were able to simulate the effect of a year's damage in the fast reactor by a few hours irradiation and we were therefore able to investigate the void problem rapidly because we had both the existing expertise and necessary equipment. In so doing we were able to select suitable materials for the prototype commercial fast reactor and through this work we have developed a much clearer understanding of the basic structure of alloys which are best suited to resisting damage. Building the VEC and exploring and calibrating its use has been part of our underlying programme. Using that work to specify special steels to the fast reactor Project Manager is part of our reactor programme.

To sum up: it is possible to classify research by type, as Zuckerman did some years ago or as Dainton now does, into basic, strategic and tactical; alternatively it can be simply classified applied or basic as Rothschild does, by asking does it have a specific objective or not. At Harwell we use a classification which depends upon whether or not the research has a firm time deadline. All these classification systems overlap and all have some value.

I think these comments are enough to explain to you the nature of our reactor and underlying programme. But before leaving Figure 1 may I draw your attention to one other feature, the steady fall in staff numbers. This shows that the Laboratory is responding to the wish of the main "customer", the Government, to contract for less effort at Harwell. This run-down in numbers has, in fact, now gone on for a full decade.

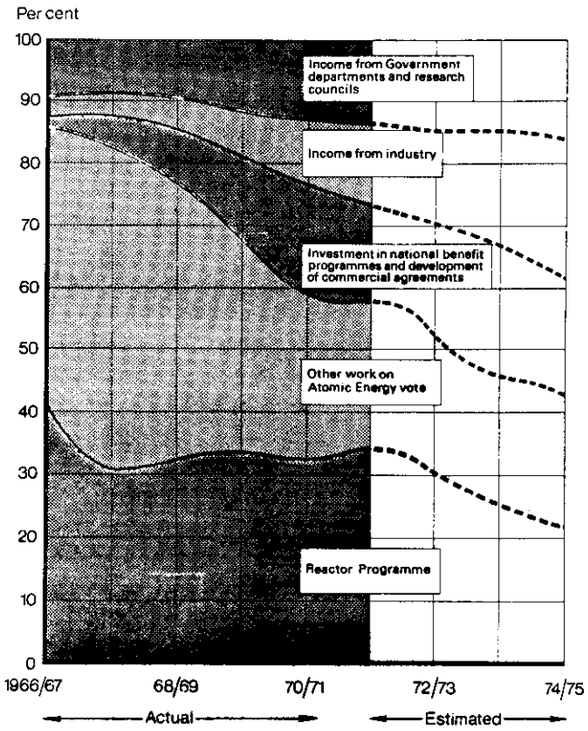
Figure 2 shows how the financing of our work has changed with the redeployment of staff shown in Figure 1. Here I have plotted the finance in terms of percentage allocation as I think this enables changes to be seen more clearly and overcomes the problem of inflation distorting curves plotted on an actual money basis.

The two sections labelled reactor and underlying express in financial terms the net cost of the programmes we have already discussed. The section labelled "Government and Research Councils" measures the actual cash received from these sources in the form of explicit contracts. The section labelled "Industry" is the actual cash payments received from industry. The latter two sections represent 27% of our budget in 1971/72. The graph indicates that this cash income will increase to almost 40% of our budget in a few years time. The actual figures achieved in future will depend on policy decisions to be made about the final category of work, labelled "Investment in National Benefit Programmes and the Development of Industrial Agreements". It is this final category of work

Figure 2

November 1971

A.E.R.E. Harwell
Analysis of Financing of Work



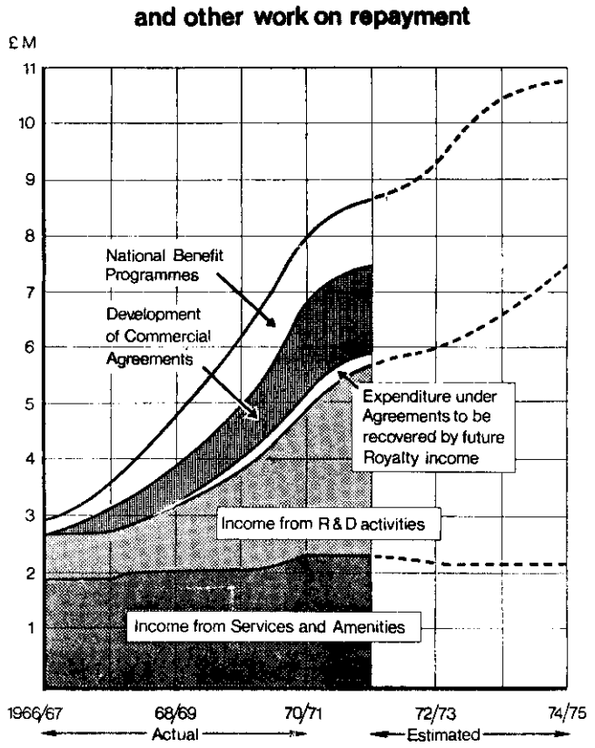
which deserves more discussion — because the other categories fall unambiguously under Rothschild's "customer/contractor" principles.

In Figure 3 I have therefore replotted, this time in money terms, a description of all our programme except for the reactor and underlying categories. This figure shows rather clearly the growth in our "contracted" programme and in this Figure I have reanalysed our cash income, whether from Government sources or industrial sources, into two parts. One part is labelled "Services and Amenities" and represents money we receive from routine operations, for example as landlord to the Radiochemical Centre or for services we provide to the Rutherford Laboratory. The other part is labelled "R & D" and represents money we receive for research and development. It is this category that is growing rapidly. The remaining portion, here analysed into three sub-portions, represents work we are doing to defined objectives and to defined time scales outside the power reactor or underlying programmes but nevertheless, under present arrangements, funded on the atomic energy vote. It is this part which deserves careful discussion to relate it to Rothschild's ideas.

First of all we can identify specific "National Benefit" programmes such as those on atmospheric pollution, on desalination and on carbon fibres which we carried out at the request of the appropriate Govern-

Figure 3
November 1971

Analysis of Financing of Harwell's Industrial Programme and other work on repayment



ment Department but are nevertheless financed from the atomic energy vote. It is likely that in future these programmes will move very firmly into the customer/contractor category in that they will be financed directly by the Government Department calling for the work to be done. These programmes therefore call for no further comment.

Secondly, we can identify a section, "Expenditure under Agreements to be recovered by Future Royalty Income", which is a special category of customer/contractor relationship. In this work we have carried out development programmes with companies where they have paid for only part of the development work and we will recover our expenditure by discounted future royalties on sales of products or a levy on throughput of a new process. For this work we therefore have a clearly defined customer, the industrial firm concerned, but by mutual agreement we have postponed full payment to a later date. This work, therefore, requires only a straightforward extrapolation of Rothschild's ideas to accommodate it.

Thirdly, we can identify a section, "Development of Commercial Agreements" which is aimed at establishing a customer/contractor relationship but which, in our opinion, has not yet progressed sufficiently for us to make an appropriate business arrangement. The existence of this kind of work reflects our changing attitude to licensing policy and since my audience today is the Licensing Executive Society I think it appropriate to enlarge upon this point in some detail.

During the early phase of our industrial programme we followed two lines on licensing.

(a) a continuation of the traditional Authority "spin-off" role in licensing instruments etc., developed originally for nuclear purposes to industrial companies, and

(b) to seek involvements with industrial companies at the early "idea stage" and to develop the idea jointly, with the company having a license on the final product or process.

Since then our ideas on the most effective way to undertake licensing activities have changed somewhat.

We learned very early that in most cases it was necessary to give exclusive licenses — the so-called principle of "Maximum Unfairness" — so as not to divide up a limited market and so inhibit development. We still think this is very important. We have also learned that it is very difficult to license a patent at the "ideas stage" and we now think it is right to develop the idea further before we become involved with an industrial partner. In doing this we do, of course, analyse the market requirements very carefully and take due cognizance of potential production problems and production costs in carrying out the early development programme. Our capabilities in producing prototype instruments and in building and operating a pilot plant scale are proving increasingly useful to industry as we can supply the "products" to allow them to test the market without the company being faced with the management and technical problems of small scale production. When we come to the licensing stage both parties are then in a position of having a fairly fully developed product which has been tested on the market and its commercial value more clearly identified.

As a result of this evolution in our thinking we now see that we shall always have a substantial category of work leading to commercial agreements but not yet with an identified industrial customer; and almost by definition this work will include the most innovative, novel and worthwhile ideas in our portfolio. As I see it there is no way to avoid judging this work on its merits and extrapolate Rothschild's ideas to accept work where, for a period of one to three years, the industrial "customer" remains unidentified. Provided this category of work is intermingled with work with immediate customers, and provided there is a history of success in involving industry this is, I submit, a modest extrapolation.

I would argue very strongly that innovative work aimed at finding an industrial customer in a few years time, must be allowed within Rothschild's philosophy and the reason for this is very simple. All innovative or novel research implies "change" of some kind or another and, as we all know, human beings dislike "change." Therefore the obvious customers for a piece of innovative research will, nearly always, reject the new ideas when first presented to them — especially if those ideas are in a preliminary form. For this psychological reason, which is deeply ingrained in human nature, it is impossible to find an immediate customer, whether in industry or in Government, for the best, most innovative ideas. It follows that the