The science base and industry

SECOND JOINT REPORT BY THE CHAIRMAN OF

The Advisory Council for Applied Research and Development (ACARD)

AND

The Advisory Board for the Research Councils (ABRC)

HER MAJESTY'S STATIONERY OFFICE

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Presented to Parliament by the Prime Minister by Command of Her Majesty
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1. Background

1.1 The Advisory Board for the Research Councils (ABRC) was established in 1972 to advise the Secretary of State for Education and Science on his responsibilities for civil science. Its present membership and terms of reference are given at Annex A. The Advisory Council for Applied Research and Development (ACARD) was set up in 1976 to advise the Government on the exploitation of research and technology and reports to the Prime Minister. Its present membership and terms of reference are given at Annex B.

1.2 In the Government's response (Cmnd 8591) to the report *Science and Government* from the House of Lords Select Committee on Science and Technology (House of Lords First Report, Session 1981–82), the Government agreed that the Chairmen of ACARD and ABRC should present periodic joint reports to the Government. The then Chairmen submitted their first joint report in July 1983 (Cmnd 8957). We have since succeeded them to the chairmanship of our respective bodies and believe it timely to present a second joint report.

2. Introduction

2.1 We have chosen as the theme of our report the science base and its links with industry. By the science base we mean the totality of research supported by the Department of Education and Science (DES). This includes research supported from Science Budget funds disbursed to the Research Councils on the advice of ABRC, research supported from general university funds from the University Grants Committee (UGC) block grant and tuition fees, and research supported through the local authority higher education sector.

2.2 A strong and innovative science base is essential to the development of the new technologies and advanced skills on which industry and the nation depends. The decade immediately following the Second World War saw the emergence and growth of a range of new technology-based industries associated with the advances made in science and technology of the previous 20 years or more (eg consumer electronics, synthetic materials, petro-chemicals, the motor industry). But these post-war technologies have now matured and have been widely adopted by newly industrialised countries. Industrial firms are now turning to the science base for help in developing new areas where new fundamental knowledge is essential to their development. Examples include advanced manufacturing technology, advanced information technology (including fibre optics and satellite communication), biotechnology and molecular electronics.

2.3 The continued economic prosperity of the United Kingdom depends critically on the extent to which in the face of intensifying international competition it is able to achieve and maintain technological leadership. The maintenance of a strong science base is vital to this goal, but is not sufficient. Despite some successes, and despite an excellent record of achievement in basic research, the UK's performance in exploiting research to produce new products and processes which succeed in the market place is disappointing; and all too often when a new product is successfully produced the UK does not follow-through with the continuous product development necessary to keep its initial lead. It is becoming increasingly urgent to ensure that the investment made in the science base contributes more effectively to wealth creation. To achieve this, the allocation of

resources within the science base needs to take more account of economic potential, and links between the science base and industry need to be strengthened and extended.

2.4 Research undertaken within the science base and within industry is all part of a single network of national knowledge and the notion that science base research and industry based research are things apart can act as a barrier to effective exploitation. Nevertheless, different sectors of industry interact with the science base in different ways. Some sectors, for example the chemical industry, have invested substantially with their own funds in the applied research needed to produce new products. They believe it is vital for the publicly-funded science base to concentrate on basic and strategic research across a fairly broad spectrum in order to complement their efforts and pave the way for the next generation of advances. Other sectors, for example, the electronics industry, where proportionately more of the R&D investment comes from public funds, look to the science base for research which is closer to specific applications. Both types of research are needed. It is important, however, for it to be understood that a more effective contribution from the science base to wealth creation does not imply that more directly applicable research should be favoured relative to basic and strategic research. Indeed, it is noticeable that those industries which look to the science base for basic and strategic research tend to be the most internationally successful and competitive. But it does imply that when areas are selected for research—and the UK has no option but to be selective—the likely potential for wealth creation should be an important factor. It also implies that whatever research is undertaken, the researchers doing the work should keep under active review its potential for economic benefit and how that might be developed, and that the exploiters in industry should be receptive to new ideas.

2.5 Economic potential will only be realised effectively if the researchers in the science base, and the exploiters in industry, accept a joint responsibility to interact at all stages of their work. Perhaps one of the most damaging concepts that has held the UK back from exploiting its scientific expertise is the simple progressive model of scientific innovation. This, in its crudest form, holds that there is a linear sequence of basic research, strategic research, applied research, experimental development, design and eventually a marketable product, with each practitioner in the sequence devoted primarily to their own concerns. In reality successful exploitation comes from interaction between research and the market place at all levels, and in all directions. Sometimes the product comes first, and the research later. The industrial revolution was powered by the steam engine without a fundamental understanding of how it worked. Fundamental work on antibiotics followed penicillin, rather than led to it. At other times basic, strategic, and development work will proceed simultaneously. One of the reasons why Japan has been so successful economically is that its integrated approach to product development has made it possible to transfer research results rapidly into the design of new products and the improvement of existing ones.

2.6 Thus what is needed is to foster a community of interest between the academic world and industry. Fortunately there are encouraging signs that this is happening, and there are valuable initiatives to build on. In this report we describe some changes that are taking place and offer suggestions for others. There is also a responsibility on Government to ensure that desirable changes are not held back by too low a level of investment. A re-orientation of activities is never easy, and it is all the more difficult in a framework of reduced funding. There are, of course, many competing claims on public funds, and the scientific community needs to recognise that; but if the community can demonstrate its commitment to using its funds to help increase national prosperity it will have a stronger case to make to Government.

2.7 We should emphasise that we have prepared this report in our capacities as chairmen, although we have consulted our colleagues. The views expressed should not therefore be regarded as statements by ACARD or ABRC, although we believe that our colleagues would not in general dissent from them.

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3. Resources

3.1 The question of what level of resources the nation should devote to the science base is, of course, an important one but the purpose of this report is not primarily to argue about the level of resources. There are other opportunities for that; ACARD has the opportunity to comment annually in confidence to the Prime Minister on any aspect of the Annual Review of Government Funded R&D that it sees fit; and ABRC can address the question in its annual advice to the Secretary of State for Education and Science on the Public Expenditure Survey which in recent years has been published and which was issued this year at the end of July. Indeed, in this year's advice the ABRC argued strongly for an increased Science Budget.

3.2 We believe it is useful, however, for us to set out here the basic data for Government expenditure on the science base and to see how this compares with other Government expenditure on R&D. The sums involved for the main components of the science base (Research Councils and UGC) are given in the following table extracted from the 1986 edition of the Annual Review of Government Funded R&D. Also given are the sums for the other civil R&D expenditure by government departments, and for Ministry of Defence (MOD) expenditure. The figures are given in 'real' terms, that is adjusted for inflation by the Gross Domestic Product deflator. 1984/85 has been used as the base year.

Expenditure on Government funded R&D

	Outturn			Plans		
	1983/84	*1984/85*	*1985/6*	*1986/87*	*1987/88*	*1988/89*
£ millions (real terms)						
Research Councils[1]	501.3	506.9	514.0	516.3	502.0	498.6
UGC etc[2]	643.7	629.9	637.9	632.9	625.4	617.9
Total of science base	1,145.0	1,136.8	1,151.9	1,149.2	1,127.4	1,116.5
Civil departments	947.8	949.9	937.5	905.4	838.0	785.7
Ministry of Defence	2,073.1	2,176.0	2,274.5	2,195.5	2,195.5	2,195.5
Overall total	4,165.9	4,262.7	4,363.9	4,250.1	4,160.8	4,097.6
Science base as % of total	27.5	26.7	26.4	27.0	27.1	27.3

1. The Research Councils' figures are less than the total Science Budget figures because they exclude the funds for postgraduate education and training, and the Science Budget grants to smaller bodies.
2. The assignment of resources to the university research effort is based on a notional attribution of universities' departments and central expenditure between research and teaching. The university sums include a component for humanities research.

3.3 It can be seen from these figures that, between 1983/84 and 1988/89:

1. MOD expenditure is planned to increase by 6 per cent.

2. Civil departments' expenditure, other than on the science base, is planned to decrease by 17 per cent.

3. Science base expenditure is planned to decrease by 2.5 per cent.

4. The science base percentage share of total expenditure drops from 27.5 per cent. to 27.3 per cent.

3.4 However, since the 1986 Annual Review was prepared the Government has announced changes in its expenditure plans in the November 1986 Autumn Statement which mean that the planning figures in the table will need revision. But it is not possible at this point to say how they will change. This is because it will take some time for departments to determine the consequences for their R&D plans of the changes in their overall expenditure levels to which the

Autumn Statement relates. The table in paragraph 3.2 therefore remains the most up to date overall picture available, although it should be viewed in the light of the reservations noted.

4. A historical perspective

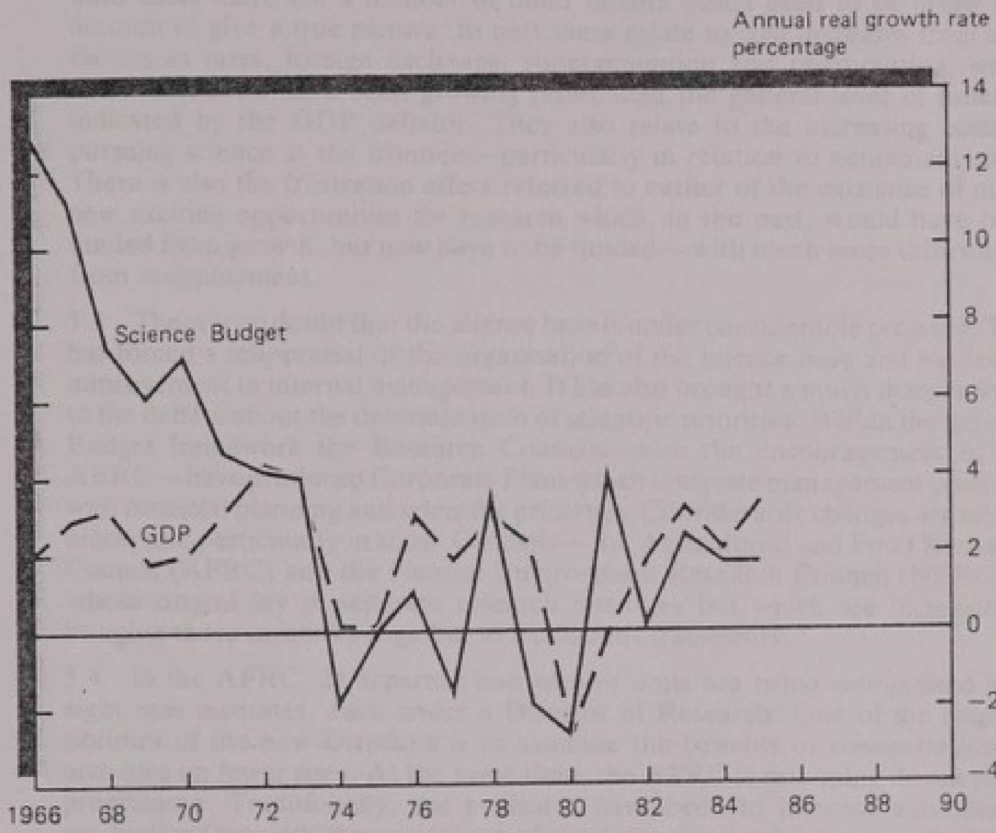
4.1 The idea that scientific research should be purposefully directed towards economic benefits is not new. The origins of Government support for the science base, which go back broadly to the first 20 years of this century, reflected just those considerations. In 1899 the National Physical Laboratory was founded, with the task of bringing scientific research to bear upon everyday industrial and commercial practice. In 1909 a Development Fund was created to provide for the scientific development of forestry, agriculture and fisheries, as a result of which a number of major agricultural research institutes were established. This initiative eventually led to the formation of the Agricultural Research Council in 1931. In 1911 a fund for medical research was set up, financed from National Insurance contributions, which was administered by a body called the Medical Research Committee. This led to the formation of the Medical Research Council in 1920. In 1916 the Department of Scientific and *Industrial* Research (DSIR) was created with a wide-ranging industrial remit whose policies and priorities were rooted from the start in economic and social needs.

4.2 In parallel with the development of a research capability directed towards specific sectors there was growing recognition of the need to expand the supply of qualified scientists and technologists from the universities. The universities were, of course, the institutions where most fundamental research was done. Science had been able to demonstrate a successful contribution to national needs through two world wars, and it seemed obvious that when the universities were expanded an expansion of university research along traditional lines should accompany the expansion of student places. There was then an enlargement of the science base rooted in the unversity tradition, with its own internal motivations towards research for its own sake. A further push in this direction came from the demise in 1964 of the DSIR, and the creation from its component parts of the Science Research Council and the Ministry of Technology, the major role of the Science Research Council being perceived as providing a supporting capability for university research.

4.3 Over the same period an understanding of the importance of science and of employing scientific staff was beginning to spread in industry. During the first 20 years of the century, Britain was still the major supplier of most of the manufactured goods of the world and most industry was content to coast along with the momentum built up in the previous century. The historical success of industry with its reliance on native resourcefulness and imagination rather than the professional application of science and technology had led to a widespread position of independence from the universities. Although a few pioneering companies and a few individuals in industry recognised the changing situation quite early, it took the world wars and the emergence of strong overseas competition before any substantial proportion of industry began to appreciate the importance of the science base. During the last 30 years an increasing number of industrial associations and individual representatives from industry have been working to build closer collaboration between industry and centres of research in the universities and Research Councils.

4.4 Nevertheless, there had been a shift of emphasis over an extended period away from the science base being purposefully directed towards economic benefits. This was perhaps masked because it was accompanied by rapid growth, with the resources available for science approximately doubling every 15 years. This rate of growth had to slow down or level off at some stage, and the turning

point was in the early seventies. The following graph shows the annual growth rates for the Science Budget* over the period 1966/67 to 1985/86 compared to the growth in the Gross Domestic Product (GDP). Both sets of figures are in real terms, ie adjusted by the Gross Domestic Product deflator.



The opportunities for research, however, have continually increased and, moreover, have grown ever more expensive. This then is the explanation for the perceived 'crisis' in research funding—the growth in opportunities is outstripping the available funds. Whatever the merits of the case for an increase in Government funding for science, it seems unlikely that we will ever revert for an extended period to the growth rates of the past. There is thus a sea-change to be accommodated. We need a renewed and concerted attempt to harness the science base as a whole to try to arrest our declining competitive position, and we have to learn how to manage and make the best use of research when it is no longer possible to rely on new opportunities being financed from new money. Instead, priorities have to be determined carefully and resources redeployed from existing activities to new ones. This can be a painful process. The UK is not alone in having to face it; other nations have the same problem.

5. Adjustments to changed financial circumstances

5.1 We can see from the table in Section 3 the actual conditions under which the Research Councils and the UGC have operated in recent years. These figures show that over the period 1983/84 to 1986/87 UGC expenditure has fallen in real terms by about 2 per cent, while Research Council expenditure has increased by 3 per cent. The overall effect on science base expenditure as a whole is a marginal increase—of rather less than half a per cent.

*The Science Budget is used rather than the overall science base, because of the greater problems in compiling figures for the latter on a comparable basis over the period.

5.2 At first sight these figures do not appear to provide supporting evidence for the considerable concerns expressed by the scientific community about the state of British science. However, as with many statistics, they cannot be taken at face value. The UGC figures are suspect because they are based on notional attributions of resources rather than actual—it is a notoriously difficult task to disentangle research expenditures from overall university expenditures. The Research Council figures are more firmly based on actual expenditures. But in both cases there are a number of other factors which need to be taken into account to give a true picture. In part these relate to cost increases from such factors as rates, foreign exchange, superannuation and restructuring, which mean that costs have been growing faster than the general level of inflation indicated by the GDP deflator. They also relate to the increasing costs of pursuing science at the frontiers—particularly in relation to equipment costs. There is also the frustration effect referred to earlier of the existence of many new exciting opportunities for research which, in the past, would have been funded from growth, but now have to be funded—with much more difficulty—from redeployment.

5.3 There is no doubt that the science base is under considerable pressure. This has forced a reappraisal of the organisation of the science base and has led to improvement in internal management. It has also brought a much sharper focus to the debate about the determination of scientific priorities. Within the Science Budget framework the Research Councils—with the encouragement of the ABRC—have produced Corporate Plans which integrate management planning with financial planning and scientific priorities. Considerable changes are taking place, and particularly in those Councils—the Agricultural and Food Research Council (AFRC) and the Natural Environment Research Council (NERC)—whose origins lay in separate research institutes but which are increasingly bringing those institutes together in a coherent framework.

5.4 In the AFRC, 24 separate institutes or units are being reorganised into eight new institutes, each under a Director of Research. One of the responsibilities of the new Directors is to examine the benefits of concentration of activities on fewer sites. At the same time, the AFRC is reshaping its scientific programme. Traditionally, the pressures have been to increase agricultural production; but with the emergence of surpluses the emphasis on research has been switched to minimising inputs so as to reduce unit costs. The Council is also building up its food research programme in response to the need—identified by ACARD among others—for more work in this economically important area. Many traditional lines of research have been cut in order to enable a response to be made to recent rapid advances in biological research which open up new opportunities of considerable potential for agriculture and food processing. The AFRC has had to absorb reductions in funding from both the Science Budget and from commissions from government departments, and is directing increased efforts to securing outside funding. In cash terms its budget has fallen from £96 million in 1983/84 to £93 million in 1987/88. AFRC estimate that, allowing for inflation, this will result in a drop in the volume of research of about 20 per cent during this period. The main mechanism for achieving budget reductions has had to be through a reduction in manpower. This is planned to fall from 6,280 in April 1983 to 4,480 in April 1987, a reduction of almost 30 per cent. Thus research volume will fall by rather less than the fall in manpower.

5.5 NERC has also been reorganising its management. The programmes of NERC's 13 institutes are being brought together under three new Directorates—earth sciences, marine sciences, and terrestrial and freshwater sciences. Its committee structure has been streamlined. In order to make room for new work, and in order to increase the level of financial support per scientist, NERC is planning to reduce permanent staff over the period 1981 to 1991 from 3,350 to 2,220. NERC is also seeking to broaden the base from which it receives income from Government commissions, and has been devising new marketing strategies aimed at the private sector.

5.6 Other Councils are changing the balance of their work. Since 1975, the Science and Engineering Research Council (SERC) has doubled the

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3.6 Other Councils are changing the balance of their work. Since 1982, the Science and Engineering Research Council (SERC) has [illegible] the percentage of its funds spent by its Engineering Board, and initiated a range of new programmes with strong industrial links. Some examples of these are discussed later. Over the same period SERC halved the percentage spent on nuclear physics. In the last ten years the Medical Research Council (MRC) has closed 23 of its units and redeployed resources into major new programmes eg in clinical molecular biology, neurobiology and diagnostic imaging. It is seeking to foster more clinical research; and it has set up a Centre for Collaborative Research which will sponsor collaborative projects with industrial, academic, and clinical interests. The Economic and Social Research Council (ESRC) has set as a major focus of its research programme the theme of 'Change in Contemporary Britain' which will promote research in such areas as the changing structure of economic activity, the implications of new technology, and the social causes of drug addiction.

5.7 A particular feature of the Research Councils' reorganisation is that the institute-based Councils are taking steps to increase their interaction with the universities. The proportion of AFRC and NERC funds which supports university-based research is relatively low, and both Councils plan to increase it. This is in recognition of the flexibility to be derived from funding limited-term university grants, and of the benefits of associating institute staff with the broader-based and more fluid university community. The MRC achieves its interaction with universities both by direct support of university research, and by basing its own units within a university, although the staff continue to be employed by the Council. In many ways this unit-based approach provides the best of both worlds for research, in that an MRC Unit can organise and commit itself to its research without the distractions of other university activities, and yet still work closely with and draw on a wide range of university expertise. In a similar way a number of AFRC's units and research stations are departments of universities or located on university campuses.

5.8 Within the UGC framework, there have also been changes. In the past the main basis for determining UGC grants to universities has beeen through adjustments to historically determined distributions. For the grant allocations over the period 1986/87 to 1989/90 the UGC has adopted a new approach. It is basing its allocations partly on teaching and research criteria which have been applied uniformly to all institutions, and partly on selective judgements on research. The calculation of resources for research is based on four components:

i. resources for 'floor' support of research through a contribution to salaries and other costs of academic and support staff. This contribution is calculated in relation to weighted student load;

ii. an allowance of 40 per cent of the income received from Research Councils and charitable bodies;

iii. a sum of £10 million distributed among institutions in proportion to their contract research income from industry and government departments, in order to encourage them to increase such income;

iv. a sum distributed selectively in the light of the UGC's assessment of institutions' research strengths, taking account of research statements from each university and of advice from Research Councils, learned bodies, medical charities and individual experts.

5.9 Within individual universities, the research activities of the institution are increasingly being considered by Research Committees. Such committees operate with different remits, but typically a committee will offer advice on plans and priorities for research, on methods for resource allocation, and have some pump-priming funds of its own to stimulate new areas of work.

5.10 It is through these channels, and through other channels—for example the provision of special funds for advanced research equipment for certain university groups—that the scientific community is increasing its emphasis on selectivity and concentration, and promoting better management. We applaud the measures that have been taken, and believe that the Research Councils and the universities have demonstrated a commitment to increased efficiency and

change in difficult circumstances for which they deserved to be congratulated, and which the Government should be prepared to recognise as providing a sound basis for increased investment. But the process is a continuing one, and there is still some way to go. We look at some of the problems below, in the context of the dual support system, and identify some other measures (paragraph 6.7) we believe should be considered.

6. The dual support system

6.1 University research in the UK is supported through the 'dual support system'. The rationale of this system is that a basic level of resources is provided through the UGC to enable individuals and groups in universities to pursue and test their own innovative ideas in research to the point where it appears they are worthy of development on a larger scale; and then a case is made to the Research Councils, or other bodies such as charitable foundations, for additional funding to pursue the ideas further. The case for additional funding is judged on its merits through committees of experts and independent referees. The additional funding is not meant to cover total additional costs; the university must continue to bear the overhead costs, and indeed is expected to make some contribution to specific costs—for example by sharing the costs of an item of equipment. The strength of the system is that it encourages creativity, particularly by young scientists who have yet to establish a reputation, by providing some resources to develop new and perhaps unfashionable ideas. But at the point where these begin to absorb substantial resources, these ideas must hold their own in a peer review.

6.2 For the system to work well universities need to be able to maintain 'well-found' laboratories, which have the resources to support research in their own right, and also to act as a secure base for externally-funded research. However, the resources are no longer available to maintain well-found laboratories across the breadth of the university system, nor for the Research Councils to support all the good proposals they receive. This has given rise to a number of problems affecting the efficiency of the system.

6.3 One is that grant applications to Research Councils are including requests for items of equipment or materials which in the past the university might have been expected to provide itself. In fact the dividing line between the university's responsibilities and the Research Council's responsibilities in this connection has never been easy to define, and different Councils, and even committees within Councils, operate on different assumptions. The system breaks down when a Research Council grant application is not met in full because it is felt that elements of it are more appropriate for university support, but the university is nevertheless unable to provide that support. The result is that the research is handicapped from the start.

6.4 More generally there is a tendency in Research Councils to make the funds available for university research grants stretch as far as possible by spreading them out among too many groups. It is perhaps an understandable reaction of the allocation committees when faced with a large number of high quality proposals to pare down each to the bare minimum, and even below, but we believe this is a false economy. Often the committees will be prepared to fund the appointment of a research investigator, but not provide adequate supporting funds for the work. Councils should face this issue squarely, and be prepared to fund fewer appointments so that the support per appointment, shared as appropriate with the university, covers the real costs of the research.

6.5 A recurring problem has always been that the greater the success of the university in being awarded research grants the greater the strain on its own funds because of the associated increase in overhead costs. This problem was recognised in the recent change in UGC allocation procedures, and these now allow for an overhead element to complement the award of research grants.

change in difficult circumstances for which they deserved to be congratulated, and which the Government should [illegible] basis for increased investment. But the process is a continuing one, and there is still some way to go. We look at some of the problems below, in the context of the dual support system, and identify some other measures (paragraph 6.7) we believe should be considered.

6. The dual support system

6.1 University research in the UK is supported through the "dual support system". The rationale of this system is that a basic level of support is provided through the UGC to enable individuals and groups in universities to pursue and test their own innovative ideas in research to the point where it appears they are worthy of development on a larger scale, and then a case is made to the Research Councils, or other bodies such as charitable Foundations, for additional funding to pursue the ideas further. The case for additional funding is judged on its merits through committees of experts and independent referees. The additional funding is not meant to cover total additional costs; the university must continue to bear the overhead costs, and indeed is expected to make some contribution to specific costs—for example by sharing the costs of an item of equipment. The strength of the system is that it encourages creativity, particularly for young scientists who have yet to establish a reputation, by providing some resources to develop new and perhaps unfashionable ideas. But at the point where these begin to absorb substantial resources, these ideas must hold their own in a peer review.

6.2 For the system to work well universities need to be able to maintain well-found laboratories, which have the resources to support research in their own right, and also to act as a secure base for externally-funded research. However, the resources are no longer available to maintain well-found laboratories across the breadth of the university system, nor for the Research Councils to support all the good proposals they receive. This has given rise to a number of problems affecting the efficiency of the system.

6.3 One is that grant applications to Research Councils are including requests for items of equipment or materials which in the past the university might have been expected to provide itself. In fact the dividing line between the university's responsibilities and the Research Council's responsibilities in this connection has never been easy to define, and different Councils, and even committees within Councils, operate on different assumptions. The system breaks down when a Research Council grant application is not met in full because it is felt that elements of it are more appropriate for university support, but the university is nevertheless unable to provide that support. The result is that the research is handicapped from the start.

6.4 More generally there is a tendency in Research Councils to make the funds available for university research grants stretch as far as possible by spreading them out among too many groups. It is perhaps an understandable reaction of the allocation committees when faced with a large number of high quality proposals to pare down each to the bare minimum, and even below, but we believe this is a false economy. Often the committees will be prepared to fund the appointment of a research investigator, but not provide adequate supporting funds for the work. Councils should face this issue squarely, and be prepared to fund fewer appointments so that the support per appointment, shared as appropriate with the university, covers the real costs of the research.

6.5 A recurring problem has always been that the greater the success of the university in being awarded research grants the greater the strain on its own funds because of the associated increase in overhead costs. This problem was recognised in the recent change in UGC allocation procedures, and these now allow for an overhead element to complement the award of research grants.

However, this has not entirely removed the problem at the research project level. The resources are still contained within block grant, and are subject to all the pressures to which universities are exposed in making their financial ends meet. They may not in the end, therefore, feed through to support the research grants which caused them to be given.

6.6 The changing nature of research, coupled with tighter budgets, gives cause for concern about the organisation of research undertaken in universities. Modern research is increasingly, although not exclusively, dependent on multi-disciplinary teams using complex and expensive apparatus. Universities find it difficult to organise themselves to undertake this sort of work—crossing the boundaries of traditional disciplines and departments, and arranging shared access to equipment facilities which are too costly to buy and maintain for a single institution. They are also constrained in making an efficient contribution to complex research programmes by the normal day-to-day pressures of other university work. These are the mirror of the questions posed about Research Council institutes. Those institutes were organised specifically for research, but there was a need to increase flexibility and promote wider-based contacts. Universities have the latter, but there is perhaps a need for a more clearly defined structure for research management.

6.7 The thrust of all these arguments is that the dual support system needs to undergo further adaptations if it is to instil confidence as an effective delivery system for research. It needs to be recognised that there can only be a limited number of well-found centres; those that are to fulfil this role should be identified and properly resourced. The responsibilities of the two sides of the system need to be better defined. Once a research project has been approved in the tough competitive processes now prevailing, it is important that its effectiveness is not undermined by a failure of one or the other side of the system to provide its share of the proper resources. There may be a case for adjusting the balance of resources between the two sides of the system, for example by transferring the overheads element within the UGC grant to the Research Councils. Internal research management within universities, and between universities, needs to be tightened. For the former, Research Committees could undertake a more active role; for the latter, regional consortia might be formed, initially to pool expensive equipment but also to discuss complementary research programmes. Research Council units need to be even more closely associated with related university research.

6.8 In order to improve the effectiveness of the dual support system the ABRC and the UGC need to consult more closely. To assist in this a joint Working Party has been established to identify problems and consider possible solutions. We are also conscious that polytechnics have a role in research, but do not operate under a formal dual support system. Nevertheless, they receive Research Council grants on the same basis as universities, and these similarly require some support to be provided from the institution; furthermore the National Advisory Board (NAB) has recently set up a research fund, and is making research grants available to selected polytechnics in response to submissions. There is also, therefore, a case for ABRC to forge closer links with the NAB, and joint ABRC/NAB discussions are planned.

7. Links with industry

7.1 Alongside the changes in management, and reorientation of scientific priorities, the Research Councils have been developing new types of collaboration with industry. The sector-orientated Councils have always had close links with their industries, and these continue to develop. We highlight below briefly and selectively (paragraphs 7.2–7.5) some particular features of these which are of interest; a full description can be found in Councils' Annual Reports and Corporate Plans. The position is somewhat different for SERC—the largest Council with the widest range of responsibilities. Having been split off from

However, this has not entirely removed the problem of the research project [illegible]. The [illegible] are still not [illegible], and [illegible] the pressures to which universities are exposed in making their financial commitment. They may not in the end, therefore, feel enough to support the research grants which caused them to be given.

6.6 The changing nature of research, coupled with tighter budgets, gives cause for concern about the organisation of research undertaken in universities. Modern research is increasingly, although not exclusively, dependent on multidisciplinary teams using complex and expensive apparatus. Universities find it difficult to organise themselves to undertake this sort of work—crossing the boundaries of traditional disciplines and departments, and organising shared access to equipment facilities which are too costly to buy and run solely for a single institution. They are also constrained in making an efficient contribution to complex research programmes by the normal day-to-day pressures of other university work. These are the mirror of the questions posed about Research Council institutes. These institutes were organised specifically for research, but there was a need to [illegible] flexibility and [illegible]. Universities have the latter, but there is perhaps a need for a more clearly defined structure for research management.

6.7 The thrust of all these arguments is that the dual support system needs to undergo further adaptations if it is to instil confidence in universities and [illegible] for research. It needs to be recognised that there are [illegible] a number of well-found centres; those that are [illegible] and properly resourced. The responsibilities of the two sides of the system need to be better defined. Once a research project has been approved by the single competitive process [illegible] it is inappropriate that it [illegible] be undermined by a failure of one or other side of the system to provide its share of the project resources. There may be a case for [illegible] contracts between the two sides of the system, [illegible] the contractual element within the UGC grant to the Research Council. Internal research management within universities, [illegible] needs to be enhanced. For the former, Research Council [illegible] for the other, research councils might be [illegible] but also [illegible] Research Council [illegible] need to be even more closely associated with [illegible] university research.

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7. Links with Industry

7.1 Alongside the changes in management, and reorganisation of scientific priorities, the Research Councils have been developing new types of collaboration with industry. The major Research Councils have always had close links with [illegible], and these continue. We highlight below briefly and [illegible] (paragraphs 7.2–7.[illegible]) particular features of those which are [illegible]; a full [illegible] can be found in Councils' Annual Reports and Corporate Plans. The [illegible] for SERC—the largest Council with the widest range of responsibilities, having been split off from

DSIR in 1964, it is interesting that SERC soon began to recognise the need to build up its own links with industry. It did this primarily through the formation of an Engineering Board through which to channel an increasing level of resources devoted to engineering. This shift in emphasis was formally recognised by the change of name, to include engineering in the Council's title, in 1981. It is largely through new approaches developed by SERC that British industry has been developing new links with the science base, and we look at these in rather greater detail in paragraphs 7.6–7.12.

7.2 AFRC can point to a range of successful products arising from the commercial exploitation of its work—one of the most notable examples being the development of synthetic pyrethroids. One of its institutes—the Plant Breeding Institute at Cambridge—has been so successful commercially that it is now being considered for transfer to private ownership. Other examples of successful individual links are the commercialisation agreement with the Agricultural Genetics Company (a venture capital company) in areas of plant biotechnology which has resulted in the funding of a number of specific new projects at AFRC institutes; and the Agricultural Machinery Partnership Scheme which is jointly sponsored by Department of Trade and Industry (DTI), Ministry of Agriculture, Fisheries and Food (MAFF), Department of Agriculture and Fisheries for Scotland (DAFS) and some 20 UK manufacturers.

7.3 MRC's principal links with customers are with the Health Departments and the National Health Service who look to MRC for biomedical, clinical, and health services research. Following the agreement in 1981 that the commissioning funds transferred to the Health Departments under the Rothschild arrangements should be transfered back to the Council, a close working relationship has been built up between the MRC and the Health Departments. The Council has initiated arrangements to help promote the transfer of research discoveries with commercial prospects to British industry. An example of these is the continuing MRC agreement with Celltech Ltd—first signed in 1980—through which the company has marketed a number of products which originated as MRC discoveries. A more recent initiative is the establishment of the Centre for Collaborative Research at Mill Hill, adjacent to the National Institute for Medical Research. The Centre acts as a focus for work of commercial importance carried out by the Council's own teams. The establishment of the Centre has been widely welcomed by industry and a number of joint projects have already been set up with a diverse range of major UK companies; these include work on the design and manufacture of synthetic peptide vaccines, the development and production of biosensors, and the use of novel enzymes in the design of drugs. The MRC has schemes for co-operative research grants, and co-operative student awards, comparable with those operated by SERC (see later). It also has an Industrial Liaison Group at MRC headquarters, which has a separate budget for patenting, and offers advice and assistance to MRC Units in negotiating collaborative and/or licensing agreements with commercial companies.

7.4 NERC decided three years ago to give a deliberate impetus to its commercial and marketing activities. As part of its marketing strategy it has set up a research marketing group at NERC headquarters, created a Brussels office which has the task of keeping in touch with developments within the European Commission in order to learn about potential contracts, and has NERC agents in Washington and Manila to seek out commercial opportunities with the World Bank and Asian Development Bank respectively. It has developed a range of marketing materials in-house, including video material, targetted to specific business sectors, for example the oil industry, local authorities and water authorities. The Council is also exploring possible 'framework' agreements of the kind that MRC has with Celltech, and AFRC with the Agricultural Genetics Company, and is examining the possibility of forming a NERC company that would operate commercially within its sector, perhaps with City financing.

7.5 The ESRC supports a number of research centres, normally housed in universities, which specialise in particular areas and it encourages them to seek

additional external funds. An example of jointly funded activity is the Macro-economic Modelling Consortium with the Treasury, the Bank of England and the Science Policy Research Unit at Sussex University. The Council operates an 'Open Door Scheme' which provides a research consultancy for all sides of industry, and operates its own version of the Teaching Company and Co-operative Awards Schemes (see later).

7.6 The new links pioneered by SERC have developed primarily from its Engineering Board's policy of promoting focused programmes in areas of identified national need. Some of these programmes have been developed through Special Directorates of which there are currently four (Application of Computers to Manufacturing Engineering; Biotechnology; Information Technology; and the Teaching Company Scheme). Two former Directorates—Polymer Engineering and Marine Technology have moved out of SERC. The former is now a constituent part of the British Plastics Federation and the latter is a Company Limited by Guarantee, whose members are from industry, Department of Energy (DEn), DTI, MOD, SERC and The Fellowship of Engineering. The objective of the Directorates is to determine and direct a programme of research, in close consultation with industry, and provide intensive support for it over a period of about eight years. After that it is the intention that they should move outside SERC into industrially-based host organisations. As noted above, two have already made the transition.

7.7 On a smaller scale, but still representing a commitment to selected research areas, there are a number of Specially Promoted Programmes, for example covering such areas as the design of high speed machinery, chemical sensors, low dimensional structures, and protein engineering. A further scheme — the Co-operative Research Grants scheme — promotes an active partnership between academic and industrial researchers through joint SERC/industry funding of a collaborative research project. This aims to encourage research which both advances understanding, and leads to results that can be exploited by the industrial partner.

7.8 We commend all these schemes which we see as having the desirable virtues of concentrating effort on identified areas of national importance, bringing in industry at an early stage so that it can both influence the direction of the research and more easily make use of its results, and forging close links between the academic world and industry which of themselves will lead to an increase in understanding.

7.9 There are, however, two schemes which we see as being of particular importance in that they combine the elements of research and training in a way that is of considerable value to industry. These are the Teaching Company Scheme — already mentioned as one of the Directorates — and the Co-operative Awards in Science and Engineering (CASE) scheme.

7.10 The Teaching Company Scheme is jointly funded by SERC and DTI and operates through teaching company programmes. In these programmes a university or polytechnic team takes part in a company plan intended to achieve a major change in the company's techniques and procedures. The objectives are to raise industrial performance by the use of academic expertise and the introduction of advanced technology; to develop and retrain existing staff; and to encourage able graduates to train for careers in industry. The academic team consists of permanent academic staff, together with graduates recruited in consultation with the company for two-year academic appointments as Teaching Company Associates. The Associates are normally based full-time in the company and work in collaboration with company and academic staff on tasks within the programme. In addition, the university or polytechnic arranges induction and tuition in accordance with personal needs. Associate appointments may lead to higher degrees but more importantly they invariably lead to posts in industry, often with substantial responsibility and reward, either at the participating company or elsewhere.

additional external funds. An example of jointly funded activity is the [illegible] Consortium with [illegible] Coventry, the Bank of England and [illegible] Research Unit at [illegible] University. The Council operates an Open Door Scheme which provides a research consultancy for all kinds of industry and operates its own versions of the Teaching Company and Co-operative Awards Schemes (see later).

1.6 The new fields supported by SERC have developed primarily from its Engineering Board's policy of promoting funded programmes in areas of identified national need. Some of these programmes have been developed through special Directorates, of which there are currently four (Application of Computers to Manufacturing Engineering, Biotechnology, Information Technology and the Teaching Company Scheme). Two former Directorates—Polymer Engineering and Marine Technology—have moved out of SERC. The former is now a constituent part of the British Plastics Federation and the latter is a Company funded by Government, whose shareholders come from industry, Department of Energy (DEn), DTI, MOD, SERC and The Fellowship of Engineering. The objective of the Directorates is to determine and direct a programme of research, to effect coordination with industry and provide other management for it over a period of about eight years. After that it is the intention that they should move outside SERC into industrially-based host organisations. As noted above, two have already made the transition.

1.7 On a smaller scale, but still representing a commitment to selected research areas, there are a number of Specially Promoted Programmes, for example covering such areas as the design of high speed machinery, composite materials, [illegible], robotics, and polymer engineering. A further scheme — the Cooperative Research Grants scheme — promotes collaborative research between academic and industrial researchers through joint SERC and industrial funding of a collaborative project. This aims to encourage research which both advances understanding and leads to results that can be exploited by the industrial partner.

1.8 We commented in the introductory chapter on some of the favourable [illegible] of [illegible] on identified needs of industry [illegible] particularly at an early stage so that it can both integrate the direction of the research and more easily make use of its results, and become more closely involved [illegible] the academic world [illegible] undertaken.

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7.11 The Teaching Company programmes are supported through a grant from the scheme towards the basic salaries of the Associates and academic support costs, normally complemented by an average contribution of one-third from the company. There are currently some 200 Teaching Company programmes in operation. These are mainly concerned with batch manufacture in the mechanical and electrical engineering industries, but the scheme is being widened to include industries and functions other than manufacturing. We believe the Teaching Company Scheme has been very successful and would strongly support a further expansion. The Scheme helps companies to bring themselves up to date through close contact with the best academic expertise, and the collaborative postgraduate training given is, we believe, closely in tune with industry's needs.

7.12 The Co-operative Awards in Science and Engineering scheme is a variation of the normal SERC research studentship in which a postgraduate student is supported at an academic institution while undertaking research leading to a higher degree. In the CASE scheme the project undertaken by the student is devised and supervised jointly by representatives of the academic and industrial partners, and is of commercial significance to the company. The project may be in any area of research, design or manufacture, and SERC will normally waive any claim to industrial property rights. A student is required to spend part of the time working at the industrial partner's establishment. The company benefits from a studentship not only by obtaining an economic way of solving a problem of commercial importance, but also through the use of the scheme as a means of recruitment. In return the company contributes to the cost of the studentship, pays travelling and subsistence expenses while the student is working at the company, and is encouraged to supplement the normal level of student grant. About 900 CASE studentships are offered each year. We strongly support this route to a higher degree both because we see value in having research projects based on real problems of industrial relevance, but also because the training involves learning about how industry actually operates. We would be glad to see CASE further expanded. Some examples of Teaching Company and Co-operative Research Grant Schemes are given at Annex C.

7.13 Despite the value and success of the schemes described above, they do not amount in total to as large an amount of interaction with industry as we believe is needed. Thus, in the course of an enquiry into the potential for private sector funding of scientific research, undertaken at the request of the ABRC (published May 1986), a Working Party chaired by Professor Mathias reported that:

> 'We detected a widespread feeling that the Research Councils maintained too low a profile, and could do far more to generate awareness of the facilities and expertise which they had to offer. (paragraph 183).
>
> We found that, in general, companies' attitudes towards the Research Councils appeared to be that their prime functions were to carry out basic research and training, fund university research, and provide centralised facilities. It was generally accepted that these were important on a national scale, but were not of much direct relevance to the needs of industry'. (paragraph 184).

7.14 The Working Party also investigated the attitude of companies towards university research. It found these varied considerably. At one extreme there were companies who were well satisfied with the performance of universities in carrying out basic research and providing a supply of highly qualified manpower, and had developed close working relationships with particular departments and individuals. At the other were companies who considered that academics were deficient in their lack of industrial orientation, and were hampered in developing this through their commitments to teaching and examinations, academic priorities which emphasised early publication of results, and generally the more relaxed time-horizons of the academic world.

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> "We detected a widespread feeling that the Research Councils maintained too low a profile, and could do far more to publicise the merits of the facilities and expertise which they had to offer. (paragraph 3.11)
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> We found that, in general, companies' attitudes towards the Research Councils appeared to be that these bodies were there to carry out basic research and training, fund university research, and provide centralised facilities. It was generally accepted that these were important to industry as a whole, but were not of much direct relevance to the needs of industry (paragraph 3.9)."

7.14 The Working Party also investigated the attitude of companies towards university research. It found three varied views. Generally, on the one hand there were companies who were well satisfied with the performance of universities in carrying out basic research and providing a supply of highly qualified manpower, and had developed good working relationships with particular departments and individuals. At the other end of the spectrum were companies who considered that academics were indifferent to their lack of industrial relevance, and were reluctant to undertake joint work, through their concentration on teaching and academically-orientated projects which emphasised early publication of results, and generally the more relaxed time-horizons of the academic world.

7.15 But an important finding of the Working Party was that there was much more common ground between the Research Councils, the universities, and industry than the various parties appeared to realise. It found that in strategic research there were many possibilities for co-operative funding, with public and private funding paying complementary roles, particularly in different proportions at different phases in the evolution of such research programmes. It found that where such collaborative projects existed they were greatly valued by industry, who saw them as a means of increasing mutual understanding, enabled them to make rapid contact with new areas of work without an irreversible commitment, and provided access to the skills and facilities of centres of excellence in a cost-effective way. We believe an increase in the number of such projects is highly desirable, as a means of generating the close links and shared understanding between the academic world and industry out of which successful exploitation is likely to come.

7.16 Two industrially-based initiatives are particularly worthy of note. ICI has a Joint Research Scheme through which it funds research projects in universities of interest to both the universities and the company. Between 1974 and 1981 it has funded about 70 projects, and during 1984/85 awarded grants totalling about £0.5 million. In addition it sponsors three joint laboratories with universities; at Manchester for polymer science; at Liverpool for bio-engineering; and at Leicester for molecular biology. BP has set up a Venture Research Unit to support university fundamental research in any fields which show promise of substantial industrial relevance within a decade or so. Awards are made to the university to cover the cost of the work including salaries, capital items, consumables, travel, services, and overheads. The Unit is presently supporting 22 teams with a current budget of £1.5 million.

7.17 We would like to see other major companies develop similar joint programmes with universities and believe they would find them to be a rewarding investment. But in many respects the problem of promoting interaction is greatest with the small to medium sized companies. Large companies with their own substantial research teams have generally recognised the value of keeping in touch with university work of interest to them even if they do not fund it directly or jointly. Small to medium sized companies often do not have this capability and find it more difficult to engage in constructive interaction. In part we would hope that initiatives like the Teaching Company, Co-operative Research Grants, and CASE can help to build bridges through expanding into this sector of industry. In addition we believe that universities and Research Councils should consciously devote more management effort to improving their relationships with small to medium sized firms through a variety of different approaches. For example, these could include the preparation of registers of university and Research Council work which can be made available to interested firms, the use of university consultancy clubs which would function as a springboard for other kinds of industrial collaboration, a more aggressive effort to market science base research to potential users, and a national brokerage scheme for the Research Councils to put small companies in touch with local academic research.

7.18 We have been following with interest a recent initiative in the United States of America which aims to improve academic/industrial collaboration. In 1984 the Directorate for Engineering of the National Science Foundation (NSF) initiated a programme to support Engineering Research Centres at universities around the nation. The Foundation's purpose in supporting these centres was to provide cross-disciplinary engineering research opportunities for academic staff and students in close association with industry; to develop fundamental engineering knowledge in order to enhance the nation's industrial competitiveness; and to prepare engineering graduates who possessed the diversity and quality of education needed by US industry. Industrial support and collaboration was to be provided through contributions of cash or equipment, participation of key people, and membership on advisory committees.

7.15 But an important finding of the Working Party was that there was much more common ground between the Research Councils, the universities and industry than the various parties appeared to realise. It found that in strategic research there were many possibilities for co-operative funding, with public and private funders playing complementary roles, particularly in different proportions at different phases in the evolution of such research programmes. It found that where such collaborative projects existed they were greatly valued by industry, which saw them as a means of increasing mutual understanding, enabled them to make rapid contact with new areas of work without an irreversible commitment, and provided access to the skills and facilities of centres of excellence in a cost-effective way. We believe an increase in the number of such projects is highly desirable, as a research programme [illegible] the [illegible] and shared understanding between the academic world and industry out of which successful exploitation is likely to come.

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7.17 We would like to see other major companies develop similar joint programmes with universities and believe they would find them to be a rewarding investment. But in many cases the problem of providing interaction is greater with the small to medium-sized companies. Large companies with their own substantial research teams have generally recognised the value of keeping in touch with university work of interest to them even when it is not directly or plainly useful to product development [illegible] the Teaching Company, Co-operative Research Grants and CASE [illegible] In addition we suggest that universities and Research Councils should consider [illegible] a variety of different approaches. For example, these could include the preparation of registers of university and Research Council work which might be of interest to industry, the use of [illegible] which would [illegible] and a national [illegible] scheme for the Research Councils to put small companies in touch with basic scientific research.

7.18 We have been interested [illegible] in the United States of America [illegible] to improve academic/industrial collaboration. In [illegible] the National Science Foundation (NSF) [illegible] programme to support Engineering Research Centres at universities [illegible] The Centres [illegible] to provide [illegible] of fundamental and [illegible] and to [illegible] the quality of [illegible] and membership on advisory committees.

7.19 The initiative is on a substantial scale. The first six centres were established in May 1985, and a second group of five centres in March 1986. The subjects covered by the centres include such topics as Intelligent Manufacturing Systems, Composites Manufacturing, Advanced Combustion Engineering and Compound Semiconductor Microelectronics. Typically NSF support for each centre is in the region of $1–2 million per year for five years. The response of industry has been strong; the equivalent of $13 million had been committed by industry for the first six centres by November 1985.

7.20 The importance of this initiative is that it demonstrates how one country, which already has a better integrated industrial/academic system than the UK, is preparing itself to meet what it believes to be an increasing challenge to its competitive position from other nations in the years ahead. There may well be a case for the UK to develop a small number of similar centres here. We are pleased to note, for example, a recent initiative at Cranfield Institute of Technology to set up a Computer Integrated Manufacturing institute (CIM), with substantial support from industry, which provides teaching and training and undertakes research in this subject, and the establishment of the new Centre for Electronic Materials at the University of Manchester Institute of Science and Technology (UMIST) which will undertake collaborative research with industry on the next generation of materials for use in electronic engineering components. What is clear is that the UK must take its own initiatives to ensure it does not fall further behind other nations in its economic exploitation of research. The competitive edge we need can come from the science base if this is properly utilised.

8. Some new approaches

8.1 One of the most difficult but necessary tasks in deciding on a selective distribution of resources to reflect economic potential is to identify which areas hold the most promise. This was the subject of a report issued by ACARD in May 1986 entitled *Exploitable Areas of Science*. The report pointed out that several countries with major scientific and technological capabilities had well developed mechanisms for holding national debates between industry, science and Government about the strategic directions of their scientific programmes and the associated policy. The UK, however, had no such capability and needed one. The report recommended that the UK should establish a process for drawing together relevant knowledge; establishing communication between science, industry and Government; assessing the potential market exploitation of developments in science and technology well in advance; and changing priorities for support for research, both public and private, in line with this assessment. It was not suggested that all the budget for UK science should be treated in these terms; it was accepted that the long-term interests of the UK also required that part of the budget should enable individual scientists to pursue on their own initiative areas of research they judged to be fruitful.

8.2 The report recognised that for the process to be effective in achieving change it was essential that the resources put into R&D had to be translated into industrial products. This could only be achieved if industry were an active and committed participant in the process. ACARD have advocated that the process should therefore be separate from and funded independently of Government, and have appointed economic and management consultants to conduct technical and policy studies with the aim of advising how the process can be instituted, funded and operated to involve industry, Government and the scientific communities in an effective partnership.

8.3 To some extent a start has already been made in identifying exploitable areas, and setting up collaborative programmes to exploit them. The largest and most well-known of these is the Alvey Programme for research into information technology. The collaborative partners are industry, the academic world, SERC, and central Government. The programme is planned to extend over five years at a total cost of £350 million, £200 million from Government and the remaining

£150 million from industry. A similar but smaller collaborative scheme is known as JOERS (Joint opto-electronic research scheme). Other examples of moves towards increased collaboration and co-ordination can be seen in the creation of the British National Space Centre, and the new Co-ordinating Committee on Marine Science and Technology. All these schemes were born of the realisation that the UK must increasingly determine its priorities, concentrate its resources, and develop a programme which will directly involve all those with a contribution to make to the enterprise, and an interest in its ultimate success. We see considerably more scope for developing similar schemes in a range of other areas.

8.4 A new approach from Government which was announced in July 1986 is to set up a Science and Technology Assessment Office located within the Cabinet Office. The function of the new office when it is fully established will be to gather and analyse information on the contributions Government support for R&D makes to the competitiveness of the UK economy. The office will work in conjunction with departments and will advise on the shape, content and conduct of their R&D programmes. It will advise Ministers collectively on the relative priorities between R&D programmes. We believe this is an important initiative which will provide a valuable mechanism through which the Government can examine how its own R&D activities relate to its economic objectives. The Assessment Office will need to interact closely with whatever forum is set up as a consequence of the Exploitable Areas of Science report.

8.5 In an initiative taken in 1985 which could have far-reaching implications for the way universities relate to commercial exploitation, the DES announced new arrangements to give individual researchers and their universities new incentives and wider scope for exploiting their research. These arrangements were determined after a period of consultation following the decision in 1983 to end the British Technology Group's right of first refusal for the exploitation of Government funded research. Under the new arrangements, universities were invited to take upon themselves exploitation rights and asked to submit an account of the procedures they intended to adopt under a specified series of headings. Their proposals were then examined by a Scrutiny Group. To date, 33 university and university colleges have submitted satisfactory arrangements, and have been authorised to undertake their own exploitation work. They are able to retain their share of royalties and receipts without loss of general or specific grants.

8.6 We warmly welcome this initiative. We believe that benefits will flow from it both to the UK economy and to individual institutions. But more generally we see benefits arising from a changed climate of opinion within universities towards industry and exploitation. If universities are to be successful in exploiting their research they will need to develop commercial practices which will pave the way for an increased understanding and collaboration with industry generally. We hope, too, that universities will recognise that this change not only represents an opportunity for them, but also a responsibility to ensure that work with commercial potential is recognised and that its potential is realised. We also see potential in individual academic researchers becoming 'academic entrepreneurs' and setting up their own companies to exploit their research ideas. We detect and welcome a growing sympathy with this approach in both the Research Councils and in a number of universities.

9.0 The way ahead

9.1 We have described in this report how the rapid growth for science funding in the past has now levelled out, and how the science base has been adapting to that situation. We have advocated a stronger emphasis on harnessing the science base for economic benefit, and have described promising initiatives which are bringing the academic world, industry, and Government closer together. In this concluding section we comment on the implications of these developments for the work of ABRC and ACARD.

9.2 We noted in Section 5 that the Research Councils with the encouragement of the ABRC had developed Corporate Plans which integrated management planning with financial planning and scientific priorities. It is intended that the

Councils will update these plans on a rolling basis, and that the Corporate Plans will form the main background to the ABRC's examination of Councils' activities which leads each year to the advice to the Secretary of State on the size of the Science Budget and its allocation. But just as Councils have felt the need to frame their activities in the context of a strategic plan so too has ABRC increasingly felt the need to develop a strategy of its own alongside which to consider Councils' plans.

9.3 The ABRC is currently preparing such a strategy document. It is intended that this will be wide-ranging, and cover such issues as resources, management, scientific priorities, international comparisons, national/international balance, and relationships between Research Councils and users (commissioning government departments and others). It will also address the dual support system and the relationship between the ABRC and the UGC and NAB.

9.4 The ABRC is also continuing to develop a programme of policy studies. One area it intends to examine is postgraduate education, and it has set up a working party under the chairmanship of Sir Alwyn Williams to review present policies and practices for the support of postgraduate-taught courses. It will be commissioning further studies on international comparisons for research support to update the material prepared by the Science Policy Research Unit for a report issued earlier this year. This later study will be undertaken in collaboration with the National Science Foundation in the USA. In view of increasing concern about the provision of advanced equipment, a study is planned to survey existing advanced equipment in university and Research Council laboratories with a view to identifying the need for and the use made of such equipment, and its costs. In an attempt to learn more about the outputs of the research process a bibliometric study is currently under way to examine the potential of publication counts and citations as a measure of the output of research centres.

9.5 ACARD will continue in its reports to identify opportunities for commercial exploitation of R&D in specific sectors of industry; it will also highlight any problems that stand in the way of exploitation and recommend solutions to both Government and industry.

9.6 A considerable volume of the R&D undertaken by industry is funded by Government in support of its procurement activities. Two recent reports by ACARD on the medical equipment and software industries have discussed how public sector procurement policies are not operating in the best interests of these industries. As it is likely that a similar state of affairs also obtains in other industrial sectors, ACARD intends to consider this problem in more detail. Well considered actions concerning the policies that govern public procurement could have a widespread and beneficial effect on the level of industrial R&D and on the innovative capacity of UK industry generally.

9.7 Many of today's large industries which employ significant numbers of staff grew from scientific developments made many decades ago. Although many start-up, 'high tech' companies have been set up in the UK to exploit today's scientific advances, there often seem to be factors which militate against them growing beyond a limited size. ACARD considers that the reasons for such limitations to growth need to be fully analysed and, if necessary, steps taken to remove any constrictive constraints which might prevent companies from growing and thereby fully exploiting the economic benefits to be gained from the research which underpins their activities. The Council has started a study, 'Barriers to Growth', to bring together information on this matter.

9.8 In the final analysis it is industry operating in the competitive environment of the market place that must recognise it has the ultimate responsibility to see the potential of research performed under the aegis of the science base and use it to enhance its own innovative capacity. Firms that do not have a commitment to innovation and a healthy R&D base, with staff at all levels capable of recognising the opportunities afforded by the results of their own and others' research and able to formulate what research is necessary to meet future needs,

will not flourish. We would urge industry generally to give a higher priority to R&D and to recognise the sometimes irreversible damage that low levels of R&D investment can have on their competitiveness in market places that are increasingly assailed by innovative products.

FRANCIS TOMBS
ACARD
70 Whitehall
London SW1A 2AS

DAVID PHILLIPS
ABRC
Elizabeth House
York Road
London SE1 7PH

Annex A

Advisory Board for the Research Councils

Membership (as at 1 August 1986)

Professor Sir David Phillips, FRS (Chairman)	— Professor of Molecular Biophysics University of Oxford
Professor R L Bell	— Director-General of ADAS Ministry of Agriculture, Fisheries and Food
Sir Walter Bodmer, FRS	— Director of Research Imperial Cancer Research Fund
Sir Sam Edwards, FRS	— Scientific Adviser Department of Energy
Mr J W Fairclough	— Chief Scientific Adviser Cabinet Office
Mr H Fish, CBE	— Chairman, Natural Environment Research Council
Mr J S Flemming	— Economic Adviser to the Governor, Bank of England
Sir James Gowans, CBE, FRS	— Secretary, Medical Research Council
Sir Douglas Hague, CBE	— Chairman, Economic and Social Research Council
Dr M W Holdgate, CB	— Chief Scientist and Deputy Secretary, Department of the Environment and Chief Scientific Adviser, Department of Transport
Dr D Jack, CBE	— Director of Research and Development Glaxo Holdings Ltd
Professor J L Jinks, CBE, FRS	— Secretary, Agricultural and Food Research Council
Sir John Mason, CB, FRS	— Treasurer of the Royal Society, Pro-Chancellor of the University of Surrey
Professor P Mathias, CBE, FBA	— Chichele Professor of Economic History, University of Oxford
Professor E W J Mitchell, CBE, FRS	— Chairman, Science and Engineering Research Council
Mr J R S Morris, CBE, FEng	— Chairman, Brown and Root (UK) Ltd
Professor R O C Norman, FRS	— Chief Scientific Adviser Ministry of Defence
Professor F O'Grady, CBE	— Chief Scientist Department of Health and Social Security
Dr D H Roberts, CBE, FEng, FRS	— Joint Deputy Managing Director (Technical) General Electric Company
Mr O Roith, FEng	— Chief Engineer and Scientist Department of Trade and Industry
Sir Peter Swinnerton-Dyers, FRS	— Chairman, University Grants Committee
Sir Francis Tombs, FEng	— Chairman, Rolls-Royce plc; and Chairman, Advisory Council for Applied Research and Development

Sir Alwyn Williams, FRS	— Principal and Vice-Chancellor of the University of Glasgow
Sir Martin Wood, OBE	— Deputy Chairman, Oxford Instruments Group Ltd

Terms of Reference

The Advisory Board for the Research Councils was established by the Secretary of State for Education and Science in 1972 with the following terms of reference:

i. To advise the Secretary of State on his responsibilities for civil science with particular reference to the Research Council system, its articulation with the universities and departments, the support of postgraduate students and the proper balance between international and national scientific activity;

ii. To advise the Secretary of State on the allocation of the Science Budget amongst the Research Councils and other bodies, taking into account funds paid to them by customer departments and the purpose to which such funds are devoted;

iii. To promote close liaison between Councils and the users of their research.

Reports

Reports published by ABRC since the appearance of the first joint report of the chairmen of ACARD and ABRC in July 1983.

The Support given by Research Councils for In-House and University Research. The Report of a Working Party of the Board (Chairman: Mr J R S Morris)	1983
A Study of Commissioned Research. Report by Sir Ronald Mason, FRS	1983
Scientific Opportunities and the Science Budget 1983	1984
Scientific Opportunities and the Science Budget 1984	1984
Further Advice on the Science Budget 1984	1985
Fixed-Term Contracts for Scientists in the Research Councils: A Report to the Secretary of State for Education and Science (unbound)	1985
Science and Public Expenditure 1985	1985
High Energy Particle Physics in the United Kingdom (Chairman: Sir John Kendrew)	1985
Future Facilities for Advanced Research Computing. The report of a Joint Working Party (Advisory Board for the Research Councils, Computer Board for Universities and Research Councils, University Grants Committee) (Chairman: Professor A J Forty) ISBN 0 901660 736	1985
The Brain Drain: Summary of Findings of an enquiry by the ABRC	1985
Science Budget: Allocations 1986–87 *Planning Figures 1987–88 — 1989–90*	1985
Report of the Working Party on the Private Sector Funding of Scientific Research (Chairman: Professor P Mathias)	1986
Science and Public Expenditure 1986	1986
ABRC Science Policy Studies No. 1: *Evaluation of National Performance in Basic Research* (ABRC, The Royal Society, Economic and Social Research Council) ISBN 0 85403 289 4	1986
ABRC Science Policy Studies No. 2: *International Comparison of Government Funding of Academic and Academically Related Research* (ABRC, Science Policy Research Unit, Sussex University) ISBN 0 903622 29 7	1986

Annex B

Advisory Council for Applied Research and Development

Membership (as at 1 August 1986)

Sir Francis Tombs, FEng (Chairman)	— Chairman, Rolls Royce plc
Mr A D Bain, FRSE	— Group Economic Adviser, Midland Bank plc
Mr M Bullock	— Corporate Finance Director, Barclays Bank plc
Mr J F Coplin, FEng	— Director of Design, Rolls Royce plc
Sir Kenneth Durham	— Chairman, Unilever plc
Professor G M Edge	— Chief Executive, PA Technology
Mr A K Gill, FEng	— Group Managing Director, Lucas Industries plc
Mr E Hammond	— General Secretary, Electrical, Electronic, Telecommunications and Plumbing Union
Mr G Lomer, CBE	— Technical Director, Racal Electronics plc
Professor J S Metcalfe	— Professor of Economics, Manchester University
Dr D S Oliver, CBE	— Director of Research, Pilkington Brothers plc
Professor Sir David Phillips, FRS	— Professor of Molecular Biophysics University of Oxford: Chairman of the Advisory Board for the Research Councils
Mr C Read, CBE	— Consultant
Dr C H Reece	— Director of Research and Technology, Imperial Chemical Industries plc
Sir Rex Richards, FRS	— Director, Leverhulme Trust
Professor S D Smith, FRS, FRSE	— Professor of Physics, Heriot Watt University; Chairman, Edinburgh Instruments Ltd

In addition, the Chief Scientific Adviser, Cabinet Office, the Chief Scientific Advisers of the Departments of Energy and of Transport and of the Ministry of Defence, the Chief Scientist and Engineer of the Department of Trade and Industry and the Chief Scientist of the Department of the Environment serve as Assessors to the Council.

Terms of Reference

The Advisory Council for Applied Research and Development was established in 1976. In April 1986, ACARD subsumed within its remit the Information Technology Advisory Panel (ITAP). ACARD's original terms of reference were revised and extended in 1982 and are now:

To advise the Government and publish reports as necessary on

i. applied research, design and development in the United Kingdom;

ii. the application of research and technology, developed in the United Kingdom and elsewhere, for the benefit of both the public and private sectors in accordance with national economic needs;

iii. the co-ordination, in collaboration with the Advisory Board for Research Councils, of these activities, with research supported through the Department of Education and Science;

iv. the role of the United Kingdom in international collaboration in the fields of applied research, design and development related to technology.

Reports

Reports by ACARD published since July 1983 are:

Improving Research Links between Higher Education and Industry (1983) (with the Advisory Board for the Research Councils) ISBN 0 11 630784 6

New Opportunities in Manufacturing: The Management of Technology (1983) ISBN 0 11 630823 6

Exploitable Areas of Science (1986) ISBN 0 11 630827 3

Software — A vital key to UK competitiveness (1986) ISBN 0 11 630829 X

Medical Equipment (1986) ISBN 0 11 630830 3

All ACARD reports are available from Her Majesty's Stationery Office.

Annex C

Examples of Teaching Company and Co-operative Research Grant Schemes

Volex plc and the University of Salford

Volex plc, formerly Ward and Goldstone, is a company whose product lines include automobile wiring harnesses, specialised cables for communications, instruments and electrical accessories. Its first Teaching Company programme with the University of Salford was authorised in 1981, and a second began in 1984.

The programmes have been associated with the design of two new products — the 'Salplex' automobile electronic wiring system; and the 'Saltest' computer for simultaneous assembly, monitoring, and testing of vehicle wiring harnesses.

The Salplex system is a versatile time-division multiplexing system, by which control information for a vehicle is transmitted on a single wire, and yet each transmitter/receiver unit around the vehicle is independent with no requirement for central control. The system operates much faster than previous centrally-controlled systems and without problems of radio interference. The project was awarded the Techmart Technology Transfer Trophy in 1984.

The Saltest computer unit is designed to test vehicle wiring harnesses at high speed. The computer monitors every wire connection and pin number in the loom as it is being assembled, continually and finally tests the harness, and gives a quality control printout listing operator number, Saltest number, date and time of build, 'OK to use', or a failure ticket. This last feature saves time in production, and enables repetitive faults to be pin-pointed quickly and accurately.

British Federal Ltd and Birmingham Polytechnic

This Teaching Company programme is a partnership between British Federal Ltd, part of the Laird Group, and Birmingham Polytechnic's Electronic and Electrical Engineering Department. The programme started in 1982 following a feasibility study into multi-axis robot control. By 1984 the programme team had developed a wide range of welding machines employing microprocessors, microcomputers, and programmable logic controllers. It had also designed a central monitoring system for robot lines and sophisticated hand-held programming controls for welding equipment, as well as being actively interested in the development of centralised control of groups of robots within a total manufacturing system.

iii. the co-ordination, in collaboration with the Advisory Board for Research Councils, of those activities with research supported through the Department of Education and Science;

iv. the role of the United Kingdom in international collaboration in the fields of applied research, design and development related to technology.

Reports

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Improving Research Links between Higher Education and Industry (1983) (with the Advisory Board for the Research Councils) ISBN 0 11 630826 8

New Opportunities in Manufacturing: The Management of Technology (1983) ISBN 0 11 630825 X

Exploitable Areas of Science (1986) ISBN 0 11 630827 2

Software — A vital key to UK competitiveness (1986) ISBN 0 11 630829 X

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As work progressed, the original team expanded and began to develop and implement a universal programmable logic control program which would be able to cope with the increasing high degree of sophistication and complexity demanded by the customer. This led to the Microman 8 microprocessor-based control system. This was very successful, and the Ford Motor Company placed a £2m order with British Federal for 45 robot welders and controllers for two plants. The programme is now being extended to support further development of the Microman 8 through design and manufacture of a second generation universal programmable controller which it is hoped will have world-wide sales appeal.

English Clays and Reading University

Many industrial processes involve the handling of particulate suspensions. High concentrations are preferred for the greatest handling efficiency. Unfortunately, at high concentrations, particles aggregate or flocculate with intolerable increases in viscosity and resistance to pumped flow. Reagents are added to hinder the associations and keep the material free flowing. To date, controlled amounts of reagent are added and checked by subsequent laboratory analysis, but it would be preferable to have a continuous monitoring of the efficiency of the reagent which can vary with product demand.

The Optics Group at Reading University is undertaking a co-operative research grants project, funded jointly by SERC and English Clays Ltd, on the fast characterisation of particulate suspensions through a new generation of electro-optical methods. Electro-optics is the study of the change in optical properties of a material when subjected to an electric field. The application of an electric field causes particles in suspension to rotate and align, and the transition from a random array to a full or partially aligned array can be detected by monitoring an appropriate optical property.

The Group has developed an optical monitor based on electro-optical light scattering. Although the intensity of normal light scattering is a possible indicator of particulate size, the field-induced change in intensity as individual particles begin to flocculate is a much more definite indicator. The signal is then used to regulate reagent addition. The project has already resulted in two patents and a commercial instrument.

Babcock Wire Equipment Co Ltd and Liverpool Polytechnic

Braiding is a process applied to textile yarns and metal wires to provide structure, reinforcement or electrical screening in a wide variety of products. Familiar products include hydrauiic hoses and co-axial cables; a less familiar application is in the laying up of glass and carbon-fibre reinforcements for aircraft propellor blades. Improvements in speed, efficiency, and versatility of braiding machines hold the key to remaining competitive in this field on a world basis.

Liverpool Polytechnic has been working with Babcock Wire Equipment Co Ltd on a research project aimed at doubling the speed and spool capacity of their existing machines. This co-operative research grant project embraces fundamental studies on motion design and implementation, optimisation of path dynamics, spool and carrier dimensions for maximum material capacity, and control of wire tension. Life tests are currently proceeding in anticipation of prototypes of complete machines.

Netlon Ltd and the Universities of Strathclyde, Oxford, Sheffield, Nottingham and Bradford

The Netlon process is a method for integrally extruding polymeric mesh structures in one step, from the molten polymer to the finished product. It was invented in 1958, and Netlon Ltd has licensed the process in 26 countries.

As work progressed, the electrical team expanded and began to develop and implement a universal programmable logic control program which would be able to cope with the increasing high degree of sophistication and complexity demanded by the customers. This led to the adoption of a microprocessor-based control system. This was very successful, and the Dynal Nobles Company placed a £2m order with British Federal for 45 room welders and controllers for two plants. The programme is now being extended to support further development of the Micronica F through design and manufacture of a second generation universal programmable controller which it is hoped will have world-wide sales appeal.

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Rabrock Wire Equipment Co Ltd and Liverpool Polytechnic

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Nation Ltd and the Universities of Strathclyde, Oxford, Sheffield, Nottingham and Bradford

The Nation process is a method for compositionally converting pellets made of particles in one step, from the molten polymer to the finished product. It was invented in 1978, and Nation Ltd has licensed the process in 20 countries.

The Netlon process produces biplanar structures with the sets of strands being in two distinct planes. Research begun in 1978 showed that it was possible to produce a uniplanar material in which the molecular orientation of the polymer passed through the mesh junctions, resulting in a structure in which there was no discontinuity in molecular orientation. This produced a material of high tensile strength, and high tear resistance, which was called Tensar.

Netlon Ltd identified a number of potential applications for the new product — for example the reinforcement of steep embankments, blast walls and sound barriers, the control of cracking and absorption of energy in cement-based composites, the reinforcement of bituminous materials for highway construction, and the replacement of steel strips in reinforced soil-retaining walls. There was, however, virtually no basic information available about the physical properties of molecularly orientated polyolefins, and this was needed if the potential applications were to be properly evaluated.

The company therefore entered into co-operative research grant schemes with the civil engineering departments of the Universities of Strathclyde, Oxford, Sheffield and Nottingham, under the guidance of an overall steering committee. Each university undertook research into different aspects of the problem: Strathclyde investigated testing methods for determining physical properties, and modelled the design of grid reinforced soil structures; Oxford modelled the degree of surface stabilisation of soft ground by using polymer grid reinforced fill; Sheffield investigated the behaviour of polymer grid cement-based composites; and Nottingham examined the characteristics of bituminous highway materials when reinforced with polymer grids and the response of pavement structures which included grids. At a later stage Bradford University became involved, and undertook research designed to improve the consistency of the polymer sheet before its transformation into Tensar structures, and so improve the quality of the final product. Subsequently Bradford and Strathclyde became the co-operating partners in a Teaching Company scheme, based at Netlon Ltd, which undertook further work on the behaviour and properties of polymer grids.

The results from the university work were very productive, and were instrumental in translating what was originally a laboratory specimen into a fully accepted, mass produced, civil engineering product. A symposium was mounted in 1984 to report on the work and promote wide discussion of potential applications. It was attended by 400 delegates from 27 countries. A large manufacturing plant was brought on stream in this country, and a plant in Atlanta, Georgia, was also completed and brought into production. In the last five years many millions of square metres of high-strength polymer grid have been used for a wide range of applications. Netlon Ltd has received Queen's awards for Tensar technology and Tensar export achievement. The company also received the prestigious engineering MacRobert Award for the Tensar development.

Note: The first two examples have been extracted from the regular Teaching Company Newsletters produced by SERC/DTI; the second two examples come from the special edition of the SERC Bulletin produced for Industry Year 1986. The final example was the subject of the 1986 Philips Lecture at the Royal Society.

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