THE ROLE OF GOVERNMENT RESEARCH ESTABLISHMENTS:
A Study of the Concept of Public Patronage for Applied Research and Development

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SUMMARY

This thesis follows the argument that, to fully understand the current position of national research laboratories in Great Britain one needs to study the historical development of the government research establishment as a specific social institution. A particular model is outlined in which it is argued that institutional characteristics evolve through the continual interplay between internal development and environmental factors within a changing political and economic context, and that the continuous development of an institution depends on its ability to adapt to changes in its operational environment. Within this framework important historical precedents for formal government institutional support for applied research are identified and the transition from private to public patronage documented. The emergence and consolidation of government research laboratories in Britain is described in detail. The subsequent relative decline of public laboratories is interpreted in terms of the undermining of a traditional role resulting in legitimation crisis. It is concluded that it is no longer feasible to consider the public research laboratory as a coherent institutional form, and that the future of each individual laboratory can only be considered in relation to the institutional needs of its own sphere of operation. Nevertheless the laboratories have been forced into decline in an essentially unplanned way which may have serious consequences for the maintenance of the scientific and technical infrastructures, necessary for material progress in the national context.

KEYWORDS:

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PREFACE

At present a large number of research establishments are maintained under the direct supervision of government departments in Great Britain involving a considerable deployment of both capital and manpower resources. During recent years the function of these establishments has been subjected to considerable scrutiny, and current developments concerning a number of them pose a continuing uncertainty with regard to their future viability and role.

Past debates on issues pertinent to public research have tended to highlight the immediate institutional context of the public laboratories and the related issues of management, control, and institutional location. As yet, however, there is little in the literature which attempts to examine the wider historical context of these laboratories as a particular institutional structure with a role established through historical tradition. Such a context would allow such factors as the changing priorities placed on the role of scientific research in public policy, the changing relationship between institutions of science, government and industry, along with the changing position of Britain as a political and economic power, to be examined and assessed. This thesis, indeed, argues that the current dilemma concerning the future role of government research establishments can only be fully appreciated in terms of fundamental historical changes in these factors.

The research on which this thesis is based began in October 1978 with the support of a research studentship funded by the Science Research Council/Social Science Research Council Joint Committee. It continued the author's interest in public research institutions, an interest which had developed during previous postgraduate study and research in

the Technology Policy Unit, University of Aston in Birmingham. The idea of studying the public research establishments, however, came directly from Dr. Russell Moseley, who had previously produced one of the few historical studies of government research institutions in Britain. His own work dealt exclusively with the development of the National Physical Laboratory in its social and political context. Rather than extend his approach to another specific institution, it was decided to take a more general view of the rise and development of the government research establishment in Britain as a social institution, drawing on material relevant to specific institutions, where appropriate to a broader analysis.

Early in the present study it became apparent from the general historical literature that in terms of function various precedents existed for the institutional support for technical research which, although ostensibly "private" in terms of patronage, had explicit nationalistic objectives. A clear-cut distinction between private and public initiative, which is usually presented in studies of science policy, became blurred as the work of some of these institutions was examined closely. Some of the parallels to modern institutional support were quite remarkable. It was also felt essential to locate the context for the establishment of national laboratories in the nineteenth century expansion of government-sponsored scientific activities.

In this way the first section of the present thesis began to take some form. Bacon's A New Atlantis, a futuristic blueprint for public institutional support for research, was an obvious starting point and the aim of the first three chapters, forming Part I, is to demonstrate that, far from being an isolated utopia, A New Atlantis predated a continual social evolution of institutions culminating in the incorporation of government laboratories in the twentieth century. In contrast Part 2 (chapters 4-7), concentrates on the institutionalisation of the public research laboratory and its subsequent development to the present time.

The approach taken initially was inevitably very descriptive and empirical. The danger of such an approach, however, is that it can develop its own momentum and obscure more theoretical issues. Concerned to develop a more theoretical approach, a considerable attack was made on the literature relevant to the long-term analysis of scientific, technological and institutional change. Many of the texts examined had their own individualistic approaches, none of which proved satisfactory in the present context. More abstract approaches were difficult to reduce from a general level to encompass the detail of research I was involved with. It was late in my studies that I first stumbled across the structural-functionalist approach which Roger Hahn had utilised in his study of the Paris Academy of Science and of which Joseph Ben-David had provided a critique. It readily became apparent that the explicit tenets of this model had more implicitly been used in my own approach. By studying a number of definitive papers in the structural-functionalist tradition of institutional analysis I was able to significantly clarify many of my own ideas further, and provide what I hope is a more convincing theoretical base for this thesis than might have otherwise have been the case.

The material I was able to utilise in developing my analysis was, as always, limited by the availability of suitable primary sources. The study of modern public institutions in Britain, beyond the period in which public records are available, has its own peculiar difficulties which inevitably affect the degree to which any accurate analysis can be made. There is at present no real solution to this problem beyond the conventional method of supplementing available published sources with selected interviews with individuals closely involved in the practice of government science and policy. Despite the limitations of such an approach it is one I have followed, and I am grateful to those who sacrificed time to allow me to benefit from their own knowledge and experience. A full list of interviews with brief biographical details of the participants is included in Appendix 2.

In the research on which the earlier chapters were based the wide range of the study inevitably meant I had to draw on a wide range of secondary literature although primary sources were consulted where time permitted a more detailed study. Access to public records meant that the detailed origins of a number of government laboratories could be examined along with other valuable documentary material relevant to public policy for research in the inter-war period. Annual reports of individual research boards and laboratories provide a valuable record of the scientific work of the laboratories, although for the type of study undertaken the annual reports of the Department of Scientific and Industrial Research are of greater value and have been extensively cited. Further material was obtained through a systematic study of Parliamentary debates and Select Committee proceedings. Various other published sources were used, a selection of which is presented as a bibliography.

The production of this thesis would not have been possible without the assistance of a number of people. The difficulties of locating research material was made easier by the help from the staff of the libraries of the Universities of Aston in Birmingham, and Birmingham, of Birmingham Central Reference Library, and of the Public

Records Office, Kew. I received invaluable support and comment from a number of my colleagues in the Technology Policy Unit among whom I would like to mention Fred Steward, who allowed me to try out some of my work on his students, and Barry White and Anne-Marie Coles, who both read and commented on various parts of this thesis. The way Gill Crawford transformed my illegible script into immaculate type was, as always, impressive. Finally I owe a great debt to my supervisor, Russell Moseley, who introduced me to the subject and provided continued support and encouragement and, where necessary, incisive criticism.

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INTRODUCTION

The origins of the national research establishment as an institution for the pursuit of applied research belong almost exclusively to the twentieth century, although the conception was presented as early as the seventeenth century.[1] Much later, an isolated protagonist for the role of the state in such matters, Alexander Strange, outlined the potential role of government in the systematic patronage of applied research in national centres in support of public policies.[2] The institutionalisation of government science occurred, nevertheless, in more pragmatic circumstances, in the context of the wider material needs of a complex industrial society in which science was slowly being recognised as having strategic importance for the goal of material progress.

In Britain the establishment of the National Physical Laboratory in 1900 marks an important precedent in the history of government laboratories.[3] This new laboratory combined in terms of capital, management and control, both public and private patronage, and typified the institutional hybrid of academic and industrial research. Its work related both to short term immediate and well defined needs as well as more open-ended long term research. The alliance of formal and informal control, coupled with a dual functional and non-functional remit, became a characteristic feature of the role of the government research establishment. Following the establishment of the National Physical Laboratory the previously fragmentary nature of state aid for applied research began to develop in a more systematic manner with the creation of more comprehensive schemes and organisations for the promotion of scientific research in the fields of medicine, agriculture, industry and defence.[4] Thus the vision outlined by Bacon in utopian form assumed a recognizable appearance as the concept of specialised national centres for applied scientific research became an accepted, indeed dominant, institutional form through which national schemes of research operated.

During the inter-war years many new national laboratories came into existence under the direct responsibility of government departments. The Department of Scientific and Industrial Research, set up during the First World War, was an important focus for many of the new research initiatives in such areas as food, fuel, building, timber, road construction and water pollution, which became centred on national research laboratories.[5] A new naval establishment, the Admiralty Research Laboratory highlighted increased military interest in basic scientific research, along with the expansion of existing locations such as the Royal Aircraft Establishment at Farnborough. These notable developments were themselves eclipsed by the events of the Second World War which brought an unprecedented mobilisation of the scientific resources of the country. The successful application of science, or more accurately - scientists, to wartime demands provided the mainspring for a remarkable post-war expansion in government applied research, relevant to all aspects of both civil and military interests, but most striking in the spheres of military and atomic energy applications. In the context of this expansion the central government research laboratory remained the crucial institutional foundation for such a policy.

During the period of post-war expansion, the government laboratory as an institutional form retained its unique role in the vanguard of state support for the applied scientific and technical infrastructure of British society. Any inherent problems rarely surfaced to pose serious threats to their survival. Doubts, however, relating to the effectiveness of many of the national laboratories can be detected in the mid-1950's, although for another decade the establishments continued to operate in a relatively sympathetic political environment. It was during the mid-1960's, in the context of worsening economic problems, that the role of the public laboratory and the value of its contribution came seriously into doubt for the first time. Such doubts materialised at a time when the general elevation of science and technology as determinants of material progress was itself beginning to be seriously questioned. Accountability for the spending of public funds became a fashionable issue and, faced with a deteriorating position of support, many national laboratories entered a period of reorientation under severe political pressure, reflected in major changes in the way they operated and were funded, and accompanied by declining staff numbers. At the time of writing a great deal of uncertainty remains concerning the future status of many of the national laboratories. The time is opportune, therefore, for a retrospective study of the emergence and development of national laboratories as institutions of public policy.

In contrast to the significance of national laboratories as institutions of government policy and institutions of applied science, they have received little attention from historians and, even more surprisingly, little note from students of government administration and policy. There is little in the published literature which throws light on the historical role of government laboratories in Britain either individually or collectively. The most common sources at present remain commemorative, official and semi-official histories of a small number of institutions, which not surprisingly vary considerably in breadth, quality and critical analysis. Commemorative volumes have been published documenting the histories of the National Physical Laboratory, the Forest Products Research Laboratory, and the Building Research Station.[6] The study of the National Physical Laboratory covers only its first fifty years, concentrating on its internal development and is superficial in character. In addition, official publications exist documenting, primarily from published sources, the history of two particular areas of research at the National Physical Laboratory.[7] The study of the Forest Products Research Laboratory is similarly limited. The history of the Building Research Station, written by a former director of the establishment is more ambitious and attempts to place the evolution and development of the laboratory in a wider context using a variety of source material. An important area of neglect remains any historical analysis of the growth of defence research establishments in Britain. Some commemorative material of relevance has been written[8] but the only serious institutional history has been two volumes documenting the early history of the Royal Aircraft Establishment.[9] The latter was the personal initiative of the former head of the establishment's Structures Department, a promising series which came to a premature end as a result of the death of the author. Only one major official history relating to government research establishments has been the responsibility of a professional historian; Gowing's study of the United Kingdom Atomic Energy Authority.[10] Presenting clearly the political context for the establishment of British work on atomic energy, Gowing's work includes an assessment of the initial role of the Authority's major research establishment, Harwell, although a more detailed analysis of its subsequent work has yet to be written.[11]

Semi-official accounts, which include material relevant to the history of various government establishments, can be found in a number of further publications.[12] This type of material is further extended by an enormous quantity of descriptive literature, much of a promotional character, written by laboratory staff describing the work of individual institutions. An extensive range of this literature appears in the bibliography.

Apart from Gowing's study of the Atomic Energy Authority, referred to previously, the only academic historical studies relating to the government research establishments in Britain have dealt exclusively with the National Physical Laboratory.[13] Hutchinson's work was limited in scope and provides little of relevance to a historical view of the development of government research beyond a brief, if important period. As yet Moseley's work alone has considered the historical development of a government laboratory in Britain in the context of the wider issues relating to public policy for scientific research. His work sheds much light on the relations between the National Physical Laboratory, the Treasury, and the Department of Scientific and Industrial Research, including the roles adopted by both the scientific community and civil servants in determining the orientation of the laboratory. Nevertheless, while the National Physical Laboratory was historically the most important of the civil laboratories, it cannot be considered a typical national research establishment and it has its own peculiar history. Although as the first major establishment it set a number of procedural precedents which were extended to other establishments, the circumstances of its origins, particularly its relationship with the Royal Society, set it apart from other laboratories, so as to make it far from typical.

In the realm of public policy studies the national laboratories have received even less attention. An isolated exception is the work of Gibbons and Gummett which examined the introduction of the so-called "customer-contractor" principle into the management and control of publicly funded research.[14] The same authors have analysed the redeployment of resources in a public laboratory.[15] It is clear, however, that nothing has yet been written which examines in a broad historical manner the establishment of the role of government research laboratories and the factors which moulded this role and conditioned subsequent developments. Yet at the present time it appears that in other countries attention is turning to the study of the national laboratory as an institution both in historical and policy studies.[16]

The government research laboratory is only one aspect, albeit a major one, of the general relations between government and science. This more general theme has attracted increasing attention from both historians and policy analysts in recent years. As is often the case it is the older and long established institutions which have primarily attracted the attention of historians.[17] In view of this it is particularly surprising that no detailed history as yet exists of the Laboratory of the Government Chemist, an institution which was at the centre of both the general increase in government responsibilities during the nineteenth century and the development of public scientific institutions to meet the needs of public administration.[18] It is in the study of the nineteenth century relations between science and government that several important contributions have already been provided. A classic study in this area is that of Cardwell, a work which mapped out the important institutional developments in the organisation of scientific institutions in England in the nineteenth century.[19] The strengths of Cardwell's study, however, mainly lie in its analysis of educational institutions, and it provides little with respect to the growth of government science in direct support of administrative needs. In contrast the work of MacLeod has examined in a more detailed way the role of scientists in the context of the expansion of domestic social legislation in Victorian Britain and the related pressures upon central government to patronize scientific research.[20] Both the work of Cardwell and MacLeod have concentrated on the institutionalisation of public science in predominantly a domestic context. Although internal pressures of an expanding industrial economy fostered the growth of government science, a different perspective, of no less importance, was provided by Britain's colonial and imperial expansion. In this context the studies of Basalla provide an important recognition of the way public science in Britain was influenced by her maritime role and thus was shaped by, and indeed contributed to, colonial and imperial expansion.[21] This theme has recently been taken up by Brockway and used to interpret the nineteenth-century history of Kew Gardens as a botanical centre which serviced the needs of Empire.[22]

Despite the important precedents of government patronage of science in the nineteenth-century, it is usually recognised that government involvement in scientific research and development is primarily a twentieth-century phenomenon. As yet historians have given little attention to developments in public policy and science in the twentieth century apart from those studies already cited.[23] Students of public policy have likewise tended to neglect national scientific institutions, in stark contrast to the high proportion of public funds devoted to science and technology. Among isolated exceptions, some attention has been given to the role of scientific advisors in public policy.[24]

The close identification of public patronage for research and development with the actions of constitutional government, particularly through funding mechanisms, is highlighted by much of the literature. From a historical perspective such initiatives as the establishment of the Royal Observatory in the seventeenth century and the Board of Longitude in the eighteenth century are usually portrayed in historical accounts as isolated examples of public support prior to the main movement towards public patronage. This is seen as gaining ground in the nineteenth century whilst the institutionalisation of public patronage is identified as primarily a twentieth century phenomenon. Yet one particular theme of the present thesis will attempt to establish that such a strict distinction between "private" and "public" spheres of society, along with an identification of patronage with financial support, disguises a continuous evolution of various forms of public patronage from the end of the sixteenth century onwards. Indeed, Britain's development as a colonial and imperial power was enabled by an association of private and government interests, closely linked to the development of scientific and technical knowledge. Thus the concept of "public" patronage takes on a wider meaning which recognizes the role of private institutions in assuming surrogate government functions.[25] Many private societies established in the eighteenth and nineteenth centuries, with the object of furthering scientific and technical knowledge, often had explicit nationalist, colonial, and imperialist objectives which complemented public policy. As will be shown later certain activities of ostensibly private organisations such as the Royal Society of Arts in the eighteenth century and the Royal Institution in the nineteenth century, although reflecting sectional interests within society, were notable precedents for later formal government institutions. The expansion of the formal administrative features of government in Victorian Britain laid the basis for the transition from informal "public" patronage through private organisations towards new state institutions.[26]

In this context the government research establishment represents an historically specific institutional form which assimilated functions previously carried out in quite different institutional settings. Such transformations of organisational form and function involve essentially qualitative changes. Although quantitative indicators may be utilised to gauge the development of an established and well defined institutional form, analyses of transformation must consider particularly qualitative changes in form and function. It is worth considering, for instance, those two widely quoted studies which attempt to analyse the growth of government science using quantitative indicators representing manpower and expenditure.[27] Such an approach, however, is fraught with difficulties. For example, during the nineteenth century government science developed in the functional context of immediate practical needs. Thus, its content was usually highly empirical, to such a degree that it is not obvious, and indeed was not clear to contemporaries, what can be considered to be "science" and what cannot.[28] The resulting problem of classification makes it difficult, if not impossible, to utilise official statistics, such as Parliamentary estimates of expenditure on science for the period, in a way that can accurately describe the level of scientific activity in the various functions of government. Both the studies of Pike and Randman, cited previously, used a definition of a "scientist" from modern manpower studies. This proves particularly inadequate in the context of Victorian Britain when a formal institutional division of labour in scientific activities was non-existent or at most immature. This was particularly true with regard to military and maritime related research, where a distinct civil scientist was only slowly emerging, and where most experimental work remained in the hands of service personnel with scientific training. In consequence of such a lack of formal demarcation of scientific activities from other more general headings the use of Parliamentary estimates of government expenditure as a measure of the level of public scientific activity provides a severe underestimate. Indeed, in the contemporary debates in Victorian Britain on the subject of public provision for science, the inability to distinguish between fundamental research and scientific services, closely related to administrative needs, provided for observers, as MacLeod has indicated, a bi-focal image.[29] Thus, scientists at the time looking at government spending would claim that little was spent on research, while Treasury officials looking at identical expenditure figures reached quite opposite conclusions. While not denying the usefulness of quantitative indicators in certain specific respects, it is, nevertheless, the case that any treatment of institutional change and transformation must place a great deal of emphasis on the detail of qualitative change, rather than rely exclusively on quantitative measures. The present study is thus oriented towards identifying the manner in which the government research laboratory emerged as an institutional form from its historical antecedents, investigating the social context which influenced its subsequent development.

It is possible to consider institutional change as an evolutionary process with particular forms of organisation having a distinct and historically specific life cycle. In the literature relating to the history of scientific institutions this particular model was used by Hahn in his study of the Paris Academy of Sciences.[30] Hahn considered the scientific organisation as a social unit in the possession of a set of activities, clearly defined functions and concrete organisation.[31] Developing this argument he considered that, while initially the role and institutional form of the unit are defined by a complex set of antecedent cultured traditions and historical circumstances, its very existence in a state of equilibrium for a period of time leads to the establishment of expectations, modes of behaviour, and the adoption of values peculiar to the unit itself. These are strongly reinforced when the institution is provided with some measure of autonomy that indicates self-perpetuation. As the parameters of the social system in which it operates change the unit seeks to maintain its original equilibrium by adjusting its internal dynamics. When tensions due to changing circumstances prove too strenuous, the institution, according to Hahn, inevitably disintegrates.

Such a model, deriving from the structural-functionalist school of sociology, has possible analytical power in respect to the development of the government research establishment. Hahn's particular application of it has however been subjected to severe criticism by Ben-David,[32] who argues that, although such a pattern of institutional rise and decline can be identified for national scientific societies in different countries, it is not attributable to the historical specificity of the institution, but rather to quite separate and specific constellations of interests and resources. In particular, he claims that the decline in academies was not a general phenomenon which occurred simultaneously in other countries, and that many of them continued to perform the same functions as their seventeenth and eighteenth century predecessors. Ben-David's objections need, however, to be closely examined, for it can be argued that the evidence he uses to support his case is questionable and indeed rather than contradicting Hahn's assertions, it simply suggests that the latter's model is somewhat simplistic and does not conform to the more developed ideas of structural-functionalist analysis. As Ben-David suggests, the Royal Society of London did indeed survive and remain an active institution. However, this was not achieved by merely continuing the tradition established by its founders, for as MacLeod has argued, its survival through its turbulent years of the first half of the nineteenth century depended on important reassessments and reform of its constitution and functions.[33] Indeed, at the heart of the structural-functionalist analysis of organisations is the recognition that institutions can survive periods of crisis by adaptation. Through reorganisation and reorientation a redefinition of function in terms of contemporary social conditions can be encompassed. Such a re-orientation, it may be argued, often reflects changes within the class structure of society and the relationship between class structure and power in respect of the perceived imperatives of material and cultural life. In the long term over-riding pressures in society will act through various means of both coercion and persuasion to bring about either the complete disintegration of the institution or revolutionise its function. In these terms the simple cyclic model of Hahn is clearly inadequate and must be augmented by conditions which recognise the ability of an institution to survive crisis by redefinition of function and which at the same time recognise that reorientation in itself does not guarantee survival. Indeed it may be suggested that an institution may simply increase its vulnerability by reorientation into an area of higher competition in which it fails to establish sufficient uniqueness to attract patronage and maintain the relative autonomy of the institution coupled with the legitimation necessary to ensure survival and continued development.

A more general overview of the contribution of the institutional school to organisational analysis has been provided by Perrow.[34] As this study points out the major conceptual framework of this school is that of structural-functionalism, indicating that functions determine the structure of organisations and that structures can be understood by analysing their functions. Because the interchange of structure and function goes on over time a "natural history" of an organisation is needed.[35] Current crises or competenc es cannot be understood without seeing the way they were shaped. It is therefore a characteristic feature of the school that it places great emphasis upon the study of actual organisations with histories and functions in society. As one of the pioneers of the approach has noted, the study of an organisation as an institution implies paying attention to its history and to the way it has been influenced by the social environment.[36] Thus we may be interested in how its organisation adapts itself to existing centres of power in society, often unconsciously; from what strata of society its leadership is drawn and how this affects policy; and how it justifies its existence ideologically. As Selznick suggests, we may ask what underlying need in the larger community - not necessarily expressed or recognised by the people involved - is filled by the organisation or by some of its practices.[37] Selznick himself contributed towards an understanding of the conceptual basis of this approach in a number of early influential papers which introduced the principal ideas of this type of analysis.[38] In a late publication he effectively summarised the approach to institutions as adaptive social structures:

> Taking account of both internal and external social forces institutional studies emphasise the adaptive change and evolution of organisational forms and practices. In these studies the story is told of new patterns emerging and old ones declining, not as a result of conscious design but as a natural and largely unplanned adaptation to new situations. The most interesting and perceptive analyses of this type show the organisation responding to a problem posed by its history, an adaptation significantly changing the role and character of the organisation. Typically, institutional analysis sees legal and formal changes as recording and regularizing an evolution that has already been substantially completed informally.[39]

In developing his methodological argument Selznick distinguishes between the term "organisation" and "institution". The former relates to what he calls an "expendable tool," a rational instrument engineered to do a job.[40] The latter he sees as more a natural product of social needs and pressures, responsive and adaptive. The transformation of expendable technical organisations into institutions is marked, according to Selznick, by a "concern for self-maintenance", as living association blends technical aims and procedures with personal desires and group interests.[41] As a result various elements in the association have a stake in its continued existence, and, moreover, the aims of the organisation acquire a certain permanence and stability. Thus as an organisation acquires a distinctive identity it becomes an institution. According to the structural-functionalist view this involves the taking on of values, ways of acting and believing, that are deemed important for their own sake. Self-maintenance becomes more than bare organisational survival; it becomes a struggle to preserve the uniqueness of the institution in the face of new problems and altered circumstances.[42]

Thus the institution develops basic needs, essentially related to self-maintenance, repetitive means of self-defence, and day-to-day activity interpreted in terms of function served by that activity for the maintenance and defence of the institution.[43] Indeed a basic postulate of the structural-functionalist approach is that the basic need of all institutions is the maintenance of integrity and continuity which directs attention to a set of derived imperatives.[44] These, according to Selznick, represent a number of generic needs including security of the institution in relation to environmental social forces, stability of lines of authority and communication, stability of informal relations, and homogeneity of outlook. Of particular importance is continuity of policy and of sources of its determination providing permanency and legitimacy for its undertakings. As Selznick points out, arbitrary or unpredictable changes in policy undermine the significance of (and therefore the attention to) day to day action by injecting a note of capriciousness.[45] Crisis for the institution accompanies the breakdown of consent or control, in which the legitimacy of formal authority is called into question.[46] In such a situation the institution is under pressure to adapt to new environmental forces. One particular process which Selznick identified as a factor in averting crisis he calls "Cooptation".[47] This involves absorbing new elements into the leadership or policy determining structure of an institution as a means of averting threats to its stability. Nevertheless, institutions have inherent resistance to change resulting from deep seated values emphasised by historical tradition. The resolution of this struggle brings either the transformation of the institution itself or decline as new alternative institutional forms arise.

The organisation of the following chapters reflects an attempt to utilise this theoretical framework to examine the emergence and development of the government research establishment as an institutional form which is historically specific, and part of a sequence of different institutions which perform the function of undertaking applied scientific research in support of national material needs. In contrast to a sequence of institutions undertaking a specific functional role, individual institutions may go through a sequence of functional change in which continued survival is dependent on assimilating new roles which are accepted as legitimate. These two complementary aspects are reflected in the organisation of the present thesis. Thus Section 1 (Chapters 1 - 3) examines the evolution of antecedent institutional forms, against the background of political and economic pressures which encouraged and provided a framework for the exploitation of organised technical knowledge. Particular emphasis is given to the technological imperatives resulting from the growth of trade and industry, imperial expansion, and the consequences of international political and economic competition. Chapter 1 considers the ideas, presented by Francis Bacon in New Atlantis in utopian form, describing a comprehensive system of national research institutions. This is contrasted with the economic and political developments which provide a context for his work. Chapter 2 analyses the first initiatives to establish institutional mechanisms for the support of applied research for national needs. In particular the important public role of private societies and institutions is highlighted. Chapter 3 in contrast examines the growth of government science in the nineteenth century and the parallel moves towards the formal institutionalisation of public research institutions, culminating in the establishment of the National Physical Laboratory along with more comprehensive schemes of government applied research.

Section 2 of the thesis concentrates on one particular institutional form of public patronage, the departmental research establishment. Considering the establishment of a number of individual research laboratories Chapter 4 examines the process by which the research establishment became institutionalised as an organisation within government. Close attention is placed on the environmental factors which gave rise to individual laboratories and conditioned their development. The establishment of a common "ideology" of operation is also examined along with the notion of the value of different kinds of research. Chapter 5 considers the post-Second World War expansion of the public laboratories. Changes in their operational environment brought new laboratories into existence while concurrently the first elements of unease concerning any disparity between the needs of society and the role of the laboratories brought modifications into the operational ideology of a few of the laboratories. Chapter 6 identifies the first real signs of crisis, and lack of confidence in the public laboratories which gained ground during the 1960's and culminated in radical changes in the formal management and organisation of government applied research. Nevertheless, as Chapter 7 will describe, the government research establishment continues to operate in an environment of uncertainty, and that, far from successfully transforming the operational ideology of the establishments, a clear role for the laboratories in line with contemporary national needs has not been established. With the legitimacy of the laboratories thus undermined they have become extremely vulnerable. A concluding chapter examines the current implications of these trends and considers possible future options with regard to public research institutions and in particular what place if any exists for the government research laboratory as a part of public policy or whether in terms of its status as a formal institution it has effectively outlived its utility and will disappear as public policy favours alternative institutional mechanisms. Overall the utility of the descriptive model outlined previously for the analysis of the historical development of institutions will be assessed with regard to its further application to problems of institutional development in public policy.

SECTION ONE

The concept and early institutional context of public patronage for applied scientific investigation 1600-1915.

The concept of public patronage for applied scientific investigation in central national institutions was presented as early as the seventeenth century in Bacon's *New Atlantis*. Moves to establish such a programme, however, came initially from private associations of individuals. Research in such a context remained an individualistic activity until the nineteenth century when the organised research laboratory began to appear as a familiar institution. Concurrently research in support of public policy became an accepted part of government activity. Both these developments provided an immediate context for the establishment of the National Physical Laboratory in 1900. Although the National Physical Laboratory represented a significant precedent for the establishment of national laboratories in Britain, the circumstances behind its establishment highlighted the transition from private to public patronage of applied research for national purposes.

CHAPTER ONE

A New Atlantis: Francis Bacon and the vision of public patronage

Although Francis Bacon was not the first person to conceptualise the production of organised knowledge within a materialistic utilitarian framework[1] his writings formed a major influence on the belief that collective scientific endeavour was a revolutionary factor in material life. In his lifetime and for many years afterwards he remained unique in promoting the establishment, albeit in the context of a utopia, of state sponsored institutions for the systematic development of science and technology for the material improvement of human life. Such ideas were fashioned in the context of a turbulent period during which England began to emerge in the world as a major economic and political power.

Industrial Expansion

In the period from the end of the reign of Henry VIII to the beginning of the Civil War, England along with Scotland emerged from industrial backwardness to become the leading European centre in mining and heavy industry, with the greatest expansion occuring between the years 1575, when Bacon was fourteen years of age, and 1620, six years before his death.[2] Wealth resulting partly from captured Spanish gold and the slave trade, and the resources becoming available following the redistribution of monastic lands, encouraged a substantial investment in mining, metallurgical trades and textiles, along with a number of industries established in England for the first time.[3] It also provided merchant capital with increasing control over production and encouraged the establishment of new forms of enterprise. Increasingly, traditional trade practices were giving way to partnerships and joint-stock companies, managed by absentee landlords and shareholders, and the employment of hired labour. The expansion of English trade, and the application of various technological improvements, encouraged the transformation of industrial production to a scale of enterprise, in many industrial sectors, beyond the capacity of ordinary artisans.[4] A considerable extension occurred in the use of machinery driven by water and horsepower, with commercial objectives primarily aimed at a reduction in labour costs in the interest of quantitative production.[5]

One important consequence of these changes in industrial practice was that technology and invention became part of the consciousness of the classes with interests directly or indirectly related to industrial development and seaborne trade, classes which in the same period were assuming positions of importance in national life. These classes included merchants, landowners with industrial interests, lawyers, statesmen, and various sections of the gentry with vested interests. Both Bacon and his father belonged to this social group. Along with the concentration of industry came growing social problems brought by urbanisation and related pressures on food production and the development of agriculture. The successful application of technological solutions to some of these problems reinforced the concept of material progress and highlighted profitable opportunities. In turn, the process of invention provided the promise of social prestige as it became valued as an activity legitimate for all social classes to pursue. Thus, the late sixteenth and early seventeenth centuries saw the first of the modern tradition of "projectors", speculators and inventors.[6] As Bernal has observed:

"Once profit was legitimate and novel methods could promise riches, novelty was to be embraced rather than shunned."[7]

The development of the coal industry was typical and exemplified the large investments made in capital intensive production during the Tudor and early Stuart period. The gradual substitution of coal for wood as a fuel both for industrial and domestic purposes reflects what was a crucial transition from a feudal to an industrially based economy.[8] In the 120 years after 1560 coal production increased fourteen fold.[9] Indeed Nef has estimated that, by the outbreak of the Civil War, London probably consumed more coal than was mined in all of the Low Countries.[10] By 1630 about one half of all Scottish shipping was engaged either in the salt or the coal trade.[11] Recurrent fuel shortages resulting from deforestation encouraged heavy investment in coal mining and attempts to substitute coal for wood in various industrial processes. Lime burners and smiths were the first industrial users of coal and they were joined, by the sixteenth century, by brewers, brick and tile makers, saltmakers, dyers and malt dryers. The problems entailed, however, in the substitution of coal for charcoal in iron smelting, were to remain outstanding technological obstacles. Although successful innovation using coal was not to come until the eighteenth century, the experiments made from the early seventeenth century onwards provided inventors with a wide range of experience upon which they were able to draw for the knowledge required to solve, eventually, the difficult and complicated problems of iron metallurgy.[12]

The move towards a coal burning economy brought another characteristic of modern industrialisation - pollution,[13] only one of many problems which the expansion of industry created and which central government found difficult to ignore as the rise of a national economy undermined the traditional system of local regulations. The Crown itself saw industrial control as an important route to political power and a source of revenue independent of Parliament. Elizabeth, James I and Charles I, in turn did everything in their power to build a comprehensive system of industrial regulation.[14] With corruption rife in court administrations and magistrates often unwilling to enforce laws against their own interests,[15] government control, however, began to break down, particularly after the accession of James I, contributing to the constitutional crisis which was to culminate eventually in civil war.

Francis Bacon, in high office, was at the centre of the various attempts to regulate industry. Through the promotion of industrial monopolies in the hands of royal patentees the Crown sought to obtain an interest in every new industry that developed. Bacon, himself continually defended the royal monopolies, as gradually a system designed originally to foster new commerce became degraded into a system of plunder. He was prominent on nearly every case brought before the Commissioners for Suits and, in the latter part of the reign of James I, Bacon came into contact with every patent issued.[16] Indeed the Commons investigation into monopoly abuse in 1621 was to lead to Bacon's impeachment and the establishment of the Statute of Monopolies of 1624, which declared the royal monopolies illegal, and established the patenting of new inventions within the framework of civil law.

Overseas Trade and Development

Industrial development coincided with and complemented the expansion of English overseas trade, encouraged by new corporate trading companies, and protected by regulations introduced by a sympathetic government. Although the process by which maritime trade passed from the control of foreign to English merchants extended from the thirteenth to the mid-sixteenth century, not until the Tudors applied considerable state support for the fostering of sea-power could domestic mercantile interests be protected and legislative measures enforced.[17] The history of Britain's modern navy began under Henry VIII, who provided the basis for a system of naval administration and a considerable increase in the size of the royal fleet. With state support, the financial power of London merchants was channelled into speculative trading missions. Trade with Africa began in 1551, and the following year under the protection of navy vessels an expedition was mounted to Guinea. Concurrently the Muscovy Company began to penetrate the markets of Eastern Europe. A close relationship was maintained between private and Crown interests in speculative trade. For instance Hawkin's slaving mission of 1564 was financed by a group which included London merchants, Navy officials, Privy Councillors and the Queen herself.[18]

In the reign of Elizabeth I, the promotion of ideas of Empire and colonization appears with its potential for absorbing displaced labour.[19] However, what the Tudors groped towards, the Stuarts established by founding the first Crown Colonies. Bacon, was himself a member of a company of adventurers granted patents in 1610 for an attempt to colonise Newfoundland.[20]

In the New World, European adventurers, particularly the English, had only a passing interest in the scientific problems posed by the new continent compared with the immediate attractions of precious metals, the search for a North-West Passage and generally exploiting the wealth of newly discovered lands.[21] One important by-product, however, from the voyages of discovery, resulting from a mixture of utilitarian, aesthetic and intellectual motives, was the establishment of the botanical garden as a new institutional feature, a notable antecedent of the modern applied science laboratory. From as early as Columbus' second voyage in 1493, plants and animals began to be exchanged between the New and Old Worlds, a process, which, by the end of the next century, was having a profound effect on the economies on both sides of the Atlantic. Botanical gardens were established specifically for the study and growth of novel commercially promising plants as well as for aesthetic reasons. The first were associated with medical schools in Italy and Padua, and Bologna, set up in the 1540's.[22] Elsewhere in Europe public gardens were founded in Zurich (1560), Leiden (1577), Paris (1591) and Montpellier (1598). Although England lagged behind these developments a number of gardens were maintained in private hands, one of which was owned by Bacon.[23] The first institutional botanical garden in England was set up at Oxford in 1621, initially associated with the medical faculty. Before the end of the century the Oxford botanical garden was to become the principal botanical testing ground for the observation of, and experiments on, plants returned from the overseas colonies.

Ideas and Learning

During the course of the sixteenth century, encouraged by the social emergence of new important economic groups forming a receptive intelligentsia, the invention of printing and publication, and the impact both economically and ideologically of the Reformation, the social function of knowledge began to undergo a radical transformation. Reflecting the growing urbanisation and the spread of capitalism throughout Europe the emphasis became more secular and naturalistic, pragmatic and utilitarian. The function of knowledge as one of reconciliation of humankind with the world was being challenged by concepts extolling the control of nature through the knowledge of its eternal laws, from an emphasis on final ends to greater consideration of mechanical causation. Experience was increasingly to be respected against authority.

From Italy, Germany and other countries where the capitalistic mode of production first developed in a distinct form, and from Spain and Portugal, whose navigators were opening up the world to trade and colonisation, a succession of influential writers began questioning, describing and rediscovering the physical and natural world. By Bacon's lifetime a considerable literary tradition existed extolling the study of artisans at work. As early as 1434 Battista Alberti (1404-72) in his Trattato della Pittura emphasised the work of smiths, builders and shipwrights as legitimate areas of study.[24] The work of Paracelsus (1493-1541), Agricola (1494-1555) and Biringuccio (d.1540) all contributed to the destruction of the barrier separating the industrial craftsmen from the speculative thinker, who was encouraged to study the methods of production, to enter shops and factories, and to ask questions of craftsmen. The industrial workshop and furnace was to be the laboratory of the scholar. Likewise Luis Vives in his Diffusion of Knowledge, published in 1531, encouraged the study of cooking, clothing manufacture and agriculture; ".... wherefore and how they were invented, pursued, developed and preserved, and how they can be applied to our use and profit."[25] Leonardo da Vinci also typified this approach, attempting to break away from mere empiricism to generalisable concepts of applied science, to a mechanics capable of general application, and thereby providing an inspiration to a succession of talented Italian writers on hydraulics and applied mechanics, and the application of such knowledge in civil engineering and industrial development.[26]

In parallel the voyages of discovery undertaken in the late fifteenth and throughout the following century contributed towards a revolutionary shift in consciousness. Indeed, Farrington has suggested that Bacon's vision was shaped more by the geographical revolution than the Copernican revolution, the latter hypothesis which was rejected by Bacon.[27] The overseas exploits of the experimental navigators were extensively documented and disseminated to the English speaking public, a literature inspired by the revelations of the New World and patronised by the growing literate middle-classes. Three important Spanish writers in particular, Oviedo, Monardes and Acosta, who described the flora and fauna of the New World, made a large impact on English readers.[28] They typified the opening phase of the "scientific revolution", with its emphasis on description and criticism. Their description of the Americas presented a cosmology, geography, astronomy, a native population and a natural history, that demanded a new scientific nomenclature and synthesis more adequate than those offered by ancient and medieval authorities.[29]

Thus the world became a stage for the empirical study of nature, providing an abundance of experience to challenge and undermine the decaying web of medieval thought, and highlighting the need to replace the redundant threads of myth and superstition with the real world problems posed by the navigators; to understand natural forces in order to control them. The New World, the New Atlantis, and the artisans' workshops provided the first laboratories for the modern scientific mind.

During the first forty years of Bacon's life the commercial and industrial transformation of England coincided with important developments in intellectual activity. Social groups thrown into prominence following the dissolution of the monasteries provided the legitimation and patronage for new trends in education and the application of experimental methods.[30] The legal profession, London merchants, professional statesmen such as Bacon's father, and numerous members of the gentry gave patronage and support, both to commercial and intellectual speculation, giving rise to a new generation of scientist-philosophers including such as Thomas Digges, Thomas Hariot and William Gilbert.[31] Thomas Hood, another scholar was financed by a group of London merchants to lecture in the 1580's on subjects including mathematics, geography, and navigation, a symbiosis of merchant capital and learning similarly reflected in the establishment of Gresham College.[32] Another scholar occupying a prominent position in the Elizabethan Renaissance was John Dee, his ideas half-magical, half-scientific, animated by the Hermetic vision of the unity of magic, science and religion. Among his friends and patrons could be counted a host of eminent national figures including Sir Francis Walsingham, Lord Burghley and the Earl of Leicester, who as the young Robert Dudley was tutored in science at the instigation of his father the Duke of Northumberland.[33]

Dee was frequently consulted about the voyages of exploration and was for thirty years technical advisor to the Muscovy Company. He had an apocalyptic vision of England's future proposing the building of a powerful navy to foster the building of an "Incomparable BYTISH IMPIRE"[34] with the British Isles the centre of world trade. His

Mathematical Preface to Euclide published in 1590, and considered to be a possible influence on Bacon's thought,[35] was written with the explicit intention of encouraging common artificers to combine their skills with experiment to produce new works for the common good.

The 1570's, a crucial period in Bacon's formative development, saw Ramism with its emphasis on utility become a transient academic influence in English universities, and a dominant influence on the early centres of new intellectual traditions such as Gresham College.[36] Although Bacon rejected both Ramism and neo-scholasticism in his writings, and was to a great extent detached from the hermetic and alchemical traditions, he undoubtedly borrowed the idea of science as servant of nature subjected to human domination, as well as the concept of knowledge as power, from these sources.[37] Crowther has further suggested that Bacon's formulation of inductive logic started from suggestions provided by the work of Ramus.[38] Bacon, however, wanted to depart from arbitrary uncontrolled personal research to an emphasis on organised collaborative endeavour. The promotion of institutions incorporating such a function recur in his writings culminating in the explicit utopian vision of New Atlantis.

New Atlantis

Bacon's New Atlantis published after his death was an unfinished work. Throughout his lifetime, however, his writings reflected an intense conviction that abstract learning should give rise to useful discoveries. In one of his early works he inquired:

> Shall we not discern as well the riches of nature's warehouse as the beauty of her shop? Is truth barren? Shall we not thereby be able to produce worthy effects and to endow the life of man with infinite commodities?[39]

Later, in a speech delivered by a fictional Privy Councillor during a theatrical production, written by Bacon, the collaborative nature and institutional character of his proposals are presented. The Councillor implores the Prince of the nation to endow four great works - a library; a museum of artifacts and fossils; a garden and zoo; and a still-house "so furnished with mills, instruments, furnaces, and vessels, as may be a palace fit for a philospher's stone."[41] In a later private memorandum, Bacon enthuses over the merits of a college for research and invention.[42] In <u>The Advancement of Learning</u> Bacon suggests the need for state endowment:

> as secretaries and spials of princes and states bring in bills for intelligence, so you must allow the spials and intelligencers of nature to bring in their bills.[43]

The most explicit description of the institutional character of his programme of research, however, remains that in <u>New Atlantis</u>.[44] On Bacon's fictional island the wise men of Salomon's House have an all embracing mission as stated by the "Father" of Salomon's House:

> The End of our Foundation is the knowledge of Causes and Secrett Motions of Things; and the Enlarging of the bounds of Humane Empire, to the Effecting of all Things possible.

Described in detail are various facilities and workshops within Salomon's House. Thus, caves provide a location for the study of "Coagulations, Indurations, Refrigerations, and Conservations of Bodies", the simulation of mines and investigations into the production of "New Artificial Metalls". In high towers meteorological studies take place, with specific reference to the possibilities of artificial control of weather. In lakes, studies are made of fish and fowl, pools are used for the desalination of salt-water, and violent streams and cataracts "serve use for many motions .... likewise Engines for Multiplying and Enforcing of Windes, to set also going diverse motions". In orchards and gardens, "By Art", plants are produced which can be harvested beyond normal seasonal restrictions, and novel fast growing varieties are developed. "Brewhouses, Bake Houses and Kitchens" provide for investigations into food and beverages and the study of health and medicines receives a prominent position.

In "Fournaces", "Sound" and "Perspective" houses various "diverse Mechanical Arts" are practised with specific reference being made to the generation of heat by motion, as well as to hearing aids and communications - "We have also means to convey Sounds in Trunks and Pipes, in Strange Line and Distances". The martial arts are not neglected, however, and work in Salomon's House involves "Ordnance and the Instruments of War", producing new compositions of explosives. Reference is made to the possibility of airborne flight and "Shipps and Boates for Going under Water".

Along with these areas of study Bacon also envisaged a division of labour which has become characteristic of modern day research. The gathering and analysis of information in Salomon's House was carried out by "Merchants of Light" who travel to foreign lands, "Depredatours" who survey all the existing literature, and "Mystery Men" who study methods of production. Others undertake experimental investigations of relevance to practical applications. The process of progress is cumulative as new experiments "of a Higher Light" lead to greater insights into the physical and natural world. Considerable support is provided by assistants and apprentices.

Despite the inspiration Bacon received from the intellectual and commercial context of his life, New Atlantis, nevertheless, was to remain an isolated vision. It remained a utopia, "a project of Experiments that can never be experimented", as Abraham Cowley later wrote in 1661,[45] at a time when Bacon's writings had acquired posthumous popularity. During his lifetime Bacon received little encouragement. Despite his intense advocacy of collaborative investigation, Bacon, ironically, had few friends and remained socially isolated. Ambitious for statesmanship from his youth, once he attained senior government office he remained essentially an administrator, never receiving real political power. His period of high office, coincided with a time of political reaction compared with the exciting times of his youth. Most of the great Elizabethan figures who had patronised speculative adventures in trade and knowledge were dead. Dee in his later years became an obscure figure neglected and poor. Two, whom Bacon considered possible supporters of his ideas, Lord Northumberland and Sir Walter Raleigh were both without political favour and interned in the Tower of London.

In contrast to the revolutionary impact of Bacon's ideas, his general view of the State tended to be conservative and authoritarian, accepting its supremacy in all religious and political matters, and regarding recurrent attacks on the Royal prerogative as subversive. In New Atlantis this supreme authority is vested in the Fellows of Salomon's House, who utilise their power with benevolence, rationality and honesty, in direct contrast to the corrupt and arbitary administration in which Bacon held office. He tended in many matters to be out of sympathy with merchants with interests in trade and industry, particularly in their perception of the correlation between freedom from absolutist government interference and the material improvements promised by the new philosophical ideas. Despite his advocacy for radical change in the social function of knowledge, Bacon remained unaware of the significance of many of the progressive scientific ideas of his time.

When finally the constitutional struggle unfolded, after Bacon's death, the contest was between the Royal prerogative and the common law. On the side of the law were ranged the majority of the gentry and the traders who represented the growing middle classes. Bacon, however, was advocating a "prerogative" associated with a kind of state yet to come into being. He advocated institutional forms that had not yet assumed a concrete recognisable existence. One senses that Bacon himself anticipated the enormity of his design whilst underestimating the age that would elapse before it could be realised. Early in his writings he recorded that; "I hold it enough to have constructed the machine though I may not succeed in setting it on work."[46] Thus New Atlantis written in his last years is presented in utopian form, unfinished and unpublished. Before his strategy could be realised tremendous changes would occur within the institutions of society. Modern science would emerge as a coherent cognitive system and method, and the professional scientist would assume a position of recognised importance as a factor in material reproduction.

CHAPTER TWO

The Ascendancy of Private Patronage

Introduction

As the fear of religious and political persecution lifted during the latter part of the seventeenth century, the desire and opportunity to form private associations to further corporately defined objectives grew. 'Espinasse has elsewhere drawn attention to the enthusiasm and hopefulness expressed by many writers after 1660, a distinguishing attitude being the feeling of belonging to a revolutionary movement, extolling the value of social usefulness and the power of experimental methods.[1] These sympathies pervaded the nature of the various societies and clubs which grew out of the informality of fashionable coffee-house meeting places which proliferated in the Restoration period. Such developments were often the product of individual initiatives and suffered in consequence through a lack of sustained support and thus continuity. They, nevertheless, reflected wider economic and social aspirations of the day.

With respect to scientific interests the most significant of the new private societies was the Royal Society of London. Although an interest in technological matters featured strongly in its early programme this was not to last for reasons which will be later examined. As other influences began to dominate the Royal Society alternative initiatives for the sponsorship of technological research were presented. In 1722 for instance an anonymous pamphleteer urged the formation of a society "For the Preserving and Improvement of Operative Knowledge, the Mechanical Arts, Inventions and Manufacture".[2] This writer, while conceding that the Royal Society had "made the most wonderful Progress in their Inquisition of Causes", bemoaned the fact that the "Production of Effects", was lacking "for want of the United Labours of Many, and the Support of a Publick Purse."[3] Later, in 1738 the Royal Society, itself, was unresponsive to a proposal that it should endow a fund to assist inventors.[4]

During the course of the seventeenth century however, various societies were established with the explicit aim of promoting the technical arts, industry and commerce. The present chapter charts these various institutional developments in private initiative for public purposes. Many of these societies were so-called "premium" societies offering prizes in recognition of successful innovation. One of the earliest was reputedly the Dublin Society for Improving Husbandry, Manufactures and Other Useful Arts, founded in 1731 although the formation of the more specialised Society for Improvers in the Knowledge of Agriculture in Scotland, predates it by eight years.[5] Also in Scotland the founding of the Society for Improving Arts and Sciences and Particularly Natural Knowledge in 1737, formed the basis for what was later to become the Royal Society of Edinburgh.[6] Many of the new societies, susceptible to the whims of fashion and dependent on individual patronage, did not survive for long. An example was the Anti-Gallican Society which during its brief existence from around 1750 to 1759 offered prizes to encourage discoveries intended to reduce the level of French imports.[7] Another was the Select Society of Edinburgh, founded in 1754 "for Encouraging the Arts and Manufactures of Scotland", and which boasted the support of such luminaries as Adam Smith and David Hume.[8] A mere decade later this Select Society had the more humble objectives of "Promoting the Reading and Speaking of the English Language in Scotland".

In England a major initiative which will receive particular study in the present chapter was the formation of the Society of Arts in 1754. This new Society quickly became a major venue for London's fashionable society figures and was patronised enthusiastically by Dr. Johnson's Circle, itself reminiscent of the way the Royal Society had attracted Dryden, Evelyn, and Waller less than a century earlier. The example provided by the Society of Arts provided a proliferation of imitators both abroad as well as in other metropolitan and provincial centres of Britain, where such societies acted as harbours of culture and a focus for the assertion of regional interests and loyalties, complementing the national orientation of the London Society.[9]

For many of the technical societies established during the eighteenth century a word which recurred in their declared aims was "encouragement". As Thomas Mortimer, an early historian of the Society of Arts proclaimed: "Encouragement is much the same to arts and sciences as culture is to vegetables".[10] The premium policy of many of the societies for rewarding achievement should not, however, be taken as implying that they were merely passive organisations reacting to the whims of change, for they were often important in initiating research programmes. With respect to its agricultural interests for instance, the Society of Arts called into being a nationwide team of investigators, experimenting and observing in widely differing conditions over extended periods of time. Trials were usually precisely stipulated and detailed directions were issued. The various societies were, in addition, important clearing houses for information and materials such as seeds, chemicals and scientific instruments, as well as fulfulling the role of bringing together the efforts of individuals into a more collective ideal. They promoted the diffusion of new modes of production through their extensive communication networks or correspondence, meetings and journals. In this way during the eighteenth century the metropolitan and provincial societies adopted a mantle seemingly abandoned by the Royal Society and provided a major institutional instrument for the pursuit of knowledge bearing on immediate practical application in the interests of corporately determined public purpose.

As the present chapter will also indicate by the early years of the nineteenth century, the initial role adopted by the Society of Arts was itself becoming obsolete and a long period of decline and adjustment followed. Amateur enthusiasts were being overtaken by increasingly specialised groups, reflected in the formation of new, more professionally oriented societies, often oriented more to the needs and personal interests of their membership rather than to explicit external goals.

New associations such as the Royal Institution provided a model for the growth of provincial bodies, many in the emergent industrial centres with an emphasis on education more suited to the needs of industry and industrial society. In addition its laboratory facilities provided employment for professional scientists such as Humphrey Davy and Michael Faraday.

In parallel with the work of societies, a tentative relationship was developing between scientific activities and formal government administration, in the context of economic and political changes. The establishment of the Royal Observatory and later the Board of Longitude represents early elements of the process of "formalisation" of public policy. A similar example of isolated government action was the creation of the Honourable Board of Trustees for Manufactures in Scotland a body which administered the "Equivalent", funds arranged in perpetuity from the union with Scotland in 1707, for the development of Scottish fisheries and manufacture. This board in turn commissioned various programmes of related investigations.[11] Further initiatives to create formal government structures for investigation in technical areas came in the late eighteenth century, with the establishment of the Ordnance Survey and the more short lived Board of Agriculture. A more pervasive incorporation of technical investigation into the administrative activities of government did not develop, however, until the nineteenth century in consequence of rapid industrialisation, the expansion of trade, and severe social dislocation. The industrial revolution in Britain which is usually identified as becoming pronounced in the latter half of the eighteenth century provided the important context for many later institutional developments.

The Royal Society and Technology

An abundant literature exists to confirm the richness and diversity of interests contributing to the formation of the Royal Society of London in 1662.[12] Despite the continuing controversy over the balance of influences on the Royal Society it remains indisputable that the impact of Bacon's ideas on its affairs was great. Indeed Houghton has pointed out that in its early years the Royal Society was imbued with a utilitarian and commercial spirit far beyond anything ever envisaged by Bacon.[13] Sprat's promotional history emphasised how the Society in this early period was committed to putting these ideals into practice.[14] At the same time the Society saw that its continuity and survival was dependent on the need to maintain a neutral position; "not meddling with Divinity, Metaphysics, Morals, Politics, Grammar, Rhetorick or Logicks".[15] The inherent contradiction between the desire to be both a disinterested guardian of knowledge and yet to be actively involved in the direct application of experimental results became apparent in practice. In 1693, for instance, the Royal Society provided an individual with a testimonial for a new method of grinding glass to the immediate consternation and objection of the whole of the London trade.[16] Two years later the Society was unwilling to give a similar opinion on an invention for stocking weaving for fear of a similar reaction.[17] In its crucial formative years the Royal Society was indeed very wary of controversy. Sprat's history warned of the dangers of corruption entailed in "the marrying of Arts too soon".[18] When William Petty submitted the design of his famous double-bottomed boat for the Society's attention its Council refused to give a verdict recording that "the matter of Navigation, being a State Concern was not proper to be managed by the Society".[19] The pursuit of astronomy in contrast, while obviously of relevance to the contemporary needs of navigation and an explicit reason for Royal patronage for the Royal Observatory could be suitably distanced from its sphere of application by its cognitive coherence in a way that many technological considerations could not. This maintenance of neutrality, while at the same time emphasising the utility of knowledge, was crucial to the establishment of legitimation conditioning the evolution of scientific institutions and shaping their final character, and explains partly the reasons for the disengagement of the Royal Society from direct consideration of technological issues and the dwindling of the early connections between the Society, science and industrial practice.

This process of disengagement has been recognised by various writers. Merton, for instance, discovered that the number of papers specifically on technology which appeared in the Society's Proceedings fell sharply after 1690 in parallel with a significant increase in the publication of material related to astronomy, physics, botany and medicine.[20]

After the pioneering work of Boyle, Hooke, and Mayow, interest in chemistry, a subject regarded as particularly related to industrial practice, showed a marked fall. Indeed a mere 29 papers concerned with more technical aspects of chemistry appeared in the Philosophical Transactions between 1701 and 1750, in contrast to the 80 papers published before 1700, and in spite of the considerable expansion of the chemical industry, the increasing importance of chemical processes to industrial production and marked technological innovation.[21] The decline of the fortunes of the Society's History of Trades project, inherited directly from the Baconian tradition was characteristic of the Society's change in orientation. The project was actively promoted in the early years, particularly by Boyle, Petty and Evelyn and a little later by one of the most popular committees. By 1671, however, enthusiasm for the venture had abated and any continued attachment to it was restricted to personal endeavour.[22]

Although a clue to the abandonment of early technological enthusiasm in the Royal Society has been suggested already any monocausal answer would be misleading and other factors undoubtedly contributed. The group most fervently associated with technology was a small, if prominent group, from the outset and a number were distracted almost immediately by external circumstances. Some of this group rose to occupy prominent official positions such as Wilkins, Moray, Alexander Bruce and the occurrence of the Great Fire of London and the Dutch Wars were only two of the factors which absorbed the energies of such fellows. By the last decades of the century most of this group were, indeed, dead, including Wilkins (d. 1672), Moray (d. 1673), Oldenburg (d. 1677), Bruce (d. 1681), all of whom were prominent in determining the Society's early impetus and orientation. Robert Boyle, perhaps Bacon's greatest disciple in the Royal Society died in 1692. The loss of these activists contributed to the instability of the Society and inspired a conscious effort to improve its status in the 1690's, with an emphasis on the cultural attributes of scientific activity to attract the class conscious gentlemen and aristocrats. In the same period invention and technical development became associated with speculative ventures, many of dubious character and prone to charlatanism.[23] Concurrently the intellectual success of Newton reduced the pressure on the need for more direct extraneous sources of legitimation and provided the cognitive base on which natural philosophy could develop. Thus, according to Merton, once science was established with this degree of functional autonomy the doctrine of basic scientific knowledge as a value in its own right became an integral creed of scientists, and institutionalised values were conceived as self-evident and required no direct vindication.[24] Nevertheless, the need for class patronage remained until the relationship between science and material reproduction made the need for direct forms of class patronage redundant as science became accepted much later as a professional activity.

Thus the intellectual success of the Society's work by the end of the seventeenth century compared much more favourably with any direct impact it had made on technological development in these early years. In contrast the problems inherent in implementing fully the Baconian programme were profound. Despite Bacon's exhortations many class conscious fellows were unlikely to submit to contacts with the working environment of tradesmen and craftsmen. Despite Boyle's detailed plans for a comprehensive study of mining production methods, he remained frustrated through inadequate information.[25] Much of the technology of the period remained far in advance of any theoretical basis and the material generated by the Society's committees tended to be descriptive rather than prescriptive as a result. By the beginning of the eighteenth century, however, the Royal Society was successfully established and recognised as the major national institution devoted to the production of knowledge of natural phenomena. Experimental learning connected with the applied arts and sciences was to remain the responsibility of private individuals until the emergence of new institutional forms of collective patronage.

The Society of Arts

The foundation of the Society of Arts in 1754 marks a distinctive milestone in the collective patronage of material development through the encouragement and practice of experimental investigation and the collection and dissemination of technical information.[26] The first public announcement of the new Society summarised its nature and function thus:

> Some of the Nobility, Clergy, Gentlemen and Merchants, having at heart the Good of their Country, have lately met together, in order to form a Society for the Encouragement of Arts, Manufactures and Commerce, in Great Britain: by Bestowing Rewards from Time to Time for such Productions, Inventions, or Improvements, as shall tend to the Employing of the Poor, to the Increase of Trade, and to the Riches and Honour of this Kingdom, by promoting Industry and Emulation.[27]

Robert Dossie, a consulting chemist with strong associations with the Society in its early years regarded its task as being fulfilled by cultivating experimental research, collecting information and providing the channel to transmit the results to the public.[28] The membership of the new society rose to 2,000 by 1760,[29] and with total income amounting to £22,000 between the years 1755 and 1763,[30] it established a prominent place in contemporary London society.

In 1787, Samuel More, Secretary to the Society proudly boasted of the independent nature of the Society of Arts: "without any connection or dependence on King or Government",[31] a statement misleading if one considers the evidence provided by Allan.[32] Most of the Ministers of the Crown appear to have joined the Society along with statesmen of all political parties. Both Clive and Pitt were subscribers and the 1758 membership included a number of prominent officials including the First Lord of the Treasury, the Chancellor of the Exchequer, the First Lord of the Admiralty and the Attorney General. An analysis of the 1764 membership reveals various officers from the Treasury, the Secretary of State's Office, the Admiralty, Navy Office, War Office, Pay Office, the Mint, and the General Post Office.[33] Between 1754 and 1764 110 peers were members along with prominent bankers and magistrates.[34] Thus during the first half-century of its existence the Society was associated through its membership with both the legislative and executive branches of government. Its founding members and guiding officers were unsuccessful, nevertheless, in their quest to secure direct financial support from the State for the Society's programme.[35] Despite this failure to secure support the Society had continuing contacts with the Board of Trade on various economic matters and on at least three occasions this resulted in legislation.[36] In addition customs' figures were provided for the Society to enable it to assist in the national struggle to ensure a favourable balance of trade.

The diverse range of the Society's activities make it the precursor of many areas of later government intervention and in certain areas it was clearly in advance of contemporary developments.[37] The promotion of invention was effected through six main committees covering the polite arts, agriculture, manufacture, mechanics, chemistry, and colonies and trade. The major instrument of the Society's policy in its early period was the "premium", identifying problem areas, framing their solution and rewarding successful investigators or patrons. The Society, in addition, acted as an information centre providing a focus for the immense correspondence from its domestic and colonial membership. Consideration of its activities suggests that the Society's direct impact on technological change was incommensurate with its effort, although the indirect benefits of its work were undoubtedly considerable, if impossible to quantify. It had a major role in identifying and drawing attention to problems of national concern and its constant appeal to experimental investigation opened the way to more specialised organisations.

In their widespread search for indigenous new materials, the chemists associated with the Society analysed geological samples highlighting the need for central analytical facilities.[38] The Society also pioneered advances in land survey and map making before giving way to a more powerful patron, the Ordnance Survey.[39]

Although not featuring in its original programme, agriculture was to take a prominent place in the Society's intersts, a reflection of both the crucial relationship of food production and urbanisation associated with industrialisation, along with the extent of the Society's country membership.[40] The Society of Arts was at the forefront of the movement to introduce new methods of production, new crops, mechanisation, and land reclamation. As Luckhurst emphasises: "Experiment became the keynote of every kind of agricultural activity which the Society sought to stimulate."[41] As more specialised organisations replaced the Society's role in stimulating agricultural development and as the balance of the economy shifted, its concern in this particular area gradually diminished.[42]

It is generally recognised that the success of the Society's efforts in the development of manufacturing industry was negligible compared with its impact in other areas.[43] Although its membership included some of the most illustrious innovators of the time,[44] in retrospect the Society's efforts in this sphere appear somewhat naive and sometimes contrary to what can now be seen as the most significant developments of the day. As Trueman-Wood has noted, it failed to recognise the significance of many of the important inventions introduced into manufacturing practice.[45] By contrast, in the area of industrial health and safety, the Society was a pioneering institution, encouraging the substitution of injurious materials used in production and the development of protective apparatus for workers exposed to dangerous work practices. Without the coercive support of legislation, however, the impact of the Society's efforts was destined to be slight in an environment dominated by economic motives.

In retrospect the Society of Arts appears as an institutional product of a mature mercantilist society, in which concern for the balance of trade was a major motivating factor. The interests of the Society in its first fifty years, and the policies produced by its various committees reflected the balance of its membership and particularly the economic and cultural hegemony exerted by the nobility, clergy, gentlemen and merchants who made up the majority. A desire to encourage industry was directly associated with the motive of increasing Britain's share of world trade. In addition, its membership, conscious of the desire for social stability, saw the work of the Society acting as a panacea for the convulsions resulting from the experience of rapid industrialisation. The promise of material progress was the placation of the masses through the provision of useful employment and the cheap availability of the necessities of life. These sentiments were typified by the efforts of William Shipley, recognised as the guiding light behind the founding of the Society. Thus in his initial proposals he saw the utility of the Society of Arts as:

> .... particularly for the introducing of such manufacture as may employ great numbers of the poor, which seems the only way of lessening the swarms of thieves and beggars throughout the Kingdom, and relieving parishes from the burden they labour under, in maintaining the poor, as well as rendering the multitudes of the unemployed lower class of people useful to the community and happy in themselves.[46]

Yet implicit in the rapid material progress of the late eighteenth century were revolutionary forces undermining the existing hegemony and thrusting new classes into prominence. However, the policy of the Society remained tied to the traditional paternalistic nationalism of the landed classes and auxiliary class factions. Contact with the emerging industrial power groups was peripheral and doubtless this distanced the Society from the heart of the industrial revolution. Nevertheless the fact remains that the Society pioneered many fields later to become the responsibility of formal government. Most important it raised the concept of public patronage in the national interest. A rationale for intervention which has frequently been cited since, although often in more sophisticated terms, appears in the Society's first book of rules and orders:

> The profits due to invention and labour are sometimes remote, often uncertain and consequently, to the multitude insufficient; therefore, to add a spur to industry, to promote agriculture, increase and improve manufacture, and extend trade, no method seems so well adapted as that of bestowing premiums or rewards which may excite men to undertake and accomplish useful designs.[47]

The institutionalisation of Science in the Mercantilist framework

It has already been suggested that the relationship between the expansion of trade and the drive of colonialism presented an important reference point for the investigation of natural phenomena. After the Restoration this trend continued and was associated with many of the institutions either established specifically for scientific investigation or else supporting experimental research for more direct utilitarian motives. Botany, astronomy, geophysics, and cartography were all stimulated and remained crucial allies to the discovery and exploitation of the more inaccessible regions of the globe. The maintenance of a favourable balance of trade became a dominant national object associated with the mercantile ambition of amassing national wealth. In this context the Colonies became important sources for the supply of cheap raw materials and gradually developed into important markets for the products of Britain's manufacturing sector.

Williamson asserts that sea-power "... was at once the object and instrument of the colonial system".[48] In the period 1660 to 1688 the merchant marine approximately doubled in size, particularly in association with the growth of colonial trade with the West Indies and North America.[49] Crucial to the establishment of the Royal Observatory in 1675 was the perception of the importance of astronomy to the improvement of navigation.[50] The continuing co-operation between the Royal Society and the British Government in astronomical, geophysical and botanical studies, rested on the symbiosis of scientific development with economic and political power. In the last year of Queen Anne's reign the Board of Longitude was set up by the Government specifically to encourage research into one of the most pressing needs of the day - an adequate method for determining longitude at sea.[51]

Both the Royal Society and the Society of Arts devoted considerable time to colonial affairs.[52] Henry Oldenburg laid the firm foundation for the Royal Society's correspondence with both the Colonies and Continental Europe intended to make the Society "the general Banck" of experimental learning as Sprat expressed it.[53] Both societies had strong contacts with colonial administrations as well as with employees of the major colonial trading companies. Between 1663 and 1783 twenty of the Fellows elected to the Royal Society became governors of British North American Colonies.[54] Similarly most of the colonial governors and many colonial officials were represented in the membership of the Society of Arts. The overlap between intellectual and utilitarian factors encouraged trading companies to materially assist the Royal Society.[55] Contributing to the advancement of knowledge they reaped the profits in the form of improved maps, safer navigation, and wider and more economic uses of raw materials provided by the colonies, along with infinite goodwill. In its turn the Society of Arts devoted many of its activities to colonial development, particularly with respect to the exploitation of raw materials, both inorganic and botanical. In the West Indies the main idea which directed its interests and efforts was the introduction of the known and tested products of India and the East Indies in general; to discover new sources of revenue by introducing fresh industries and new economic plants.

One of the earliest ventures of the Society of Arts was to encourage land in the colonies to be allocated for "gardens or nurseries for making experiments in raising such rare and useful plants as are not the spontaneous growth of the Kingdom or of the said Colonies".[56] In this way the botanical garden became more oriented towards the needs of production from its earlier emphasis on medicinal supplies. At the instigation of the Society, General Melville, Governor General of the Windward Isles and a member of the Society, was instrumental in establishing such an experimental garden on St. Vincent in 1765 and later a similar venture was underway in Jamaica.[57] From 1793 onwards the Society of Arts offered 100 guineas for the establishment of a garden in the Bahamas, although without success in this instance.[58] In 1787 the East India Company formally acknowledged the economic importance of the company's employee's individual botanical labours by endowing a botanical garden at Calcutta, where its Superintendent, Dr. William Roxburgh was, inevitably, a corresponding member of the Society of Arts.[59] The Society in turn provided institutional support for the colonial gardens in various ways such as providing machinery, assisting with the transfer of seeds, and acting as a general clearing house for information.

In the last quarter of the eighteenth century Kew Gardens in London inherited the role of the great exchange house for the colonies. In 1772 the gardens at Kew became the direct responsibility of the Crown and Sir Joseph Banks, acting in an advisory capacity was given the opportunity of putting into effect a scheme which had long been in his mind; to organise the scientific study of plant life in the dependencies of the Crown, an initiative he considered necessary for their rapid economic development.[60] Masefield considers Kew to be closely connected with the development of agricultural services in the tropics and suggests that the colonial botanical garden was the immediate precursor to the Colonial Agricultural Departments.[61] Following a period of decline in the early part of the nineteenth century Kew was revitalised and established as the major imperial centre for the study of the many problems associated with transplantation and acclimatisation.[62]

Botanical gardens constitute the first notable precursor of the modern applied research station. Modern connotations of a botanical garden emphasise the ornamental character and disguise the important commercial function of the gardens in the eighteenth and nineteenth centuries. Before the full impact of developments in chemistry and geology on industrial progress was felt, botanical studies had a much greater relevance, with natural products providing key raw materials in industrial processes. The economic exploitation of plant life was crucial to the eighteenth century economy and trade, and remained central to imperial trading relationships.

The Industrial Revolution and institutional innovation

During the latter half of the eighteenth century the means of industrial production were transformed by a series of radical innovations in the organisation of manufacture. The factory system matured and became diffused, conditioned by such factors as the plasticity of social relations, the efficiency of communications and the availability of finance capital. Traditional techniques of production, whether in a domestic rural or urban craft setting, could not survive as a primary means of production in the face of the successful substitution of repetitive mechanical artifacts for human skills, and the harnessing of inanimate power sources to replace animal and human strength.

Innovations in textile manufacture were, in the first instance, more concerned with the social organisation of the workplace. Mechanisation was not, in itself, a novel idea, but had often previously floundered on the rocks of social reaction. Traditional materials, particularly wood, and familiar power sources such as animal and water power continued to be utilised and remained important into the nineteenth century, although gradually the advantages of technological change became overwhelming.

Iron was increasingly replacing wood as a principal structural material as metallurgical techniques and the consequent economies of production improved. The steam engine as a power source increased in popularity, often in tandem with traditional sources. As Marx noted, the invention of Watt's second and so-called double-acting steam engine marked a notable change in that a prime mover had been found:

> that begot its own force by the consumption of coal and water, whose power was entirely under man's control, that was mobile and a means of locomotion, that was urban and not, like the water-wheel rural, that permitted production to be concentrated in towns instead of like the water-wheels, being scattered up and down the country.[63]

Industry thus began to be predominantly associated with urban life. Output in primary, secondary and manufactured goods expanded, stimulated by continuous technical change, stable home demand and the continued expansion of trade into wider world markets, providing the basis for sustained economic growth. Old established industries were transformed by the impetus coming from improvements in such secondary goods as bleaches, dyes and related chemicals. New industries such as the machine tool industry and engineering emerged and concurrently the social division of labour became more marked and specialised.

Most scholars recognize that science contributed little in any systematic way to these many radical changes.[64] Empirical trial and error predominated most important technological changes of the period. Abstract knowledge in most areas was, as yet unable to make any sustained contribution to technical change. Indeed the impact of the industrial revolution arguably had a greater effect on the development of organised science. However, to assume that scientific investigations had no part to play in the industrialisation of Britain in the late eighteenth century and early nineteenth century would do a great injustice to the impressive studies of Musson, Robinson, Schofield and others who have indicated the many important contacts between science and technological progress in this period.[65]

Chemistry had for long been tinged with the promise of profit from material application, a factor which probably hindered its acceptance in the strong aesthetic context of organised science in the eighteenth century exerted through the aristocratic consciousness of the Royal Society. The isolated endeavours of individual Fellows such as Peter Shaw (1694-1763) and William Lewis (1708-1781) maintained an interest in chemistry within the Royal Society although any direct impact on industrial progress was slight.[66] More important was the ideological impact of the work of Shaw, Lewis, and others as propagandists. A number of these chemists toured the country as itinerant lecturers, and found work in the growing numbers of Dissenting Academies and the few university positions in chemistry.[67] In addition a steady stream of technical literature stressed the advantages of chemical investigation for material gain. Some demand for chemists as consultants for analytical work came from the technical societies such as the Society of Arts.

As the chemical industry began to take on some of the features characteristic of the modern industry.chemical analysis became important with regard to maintaining a consistent quality of material inputs and monitoring the production process. A minority of more adventurous industrialists became interested in the contributions scientific investigation could make in manufacture.[68] Nevertheless, few as yet grasped in full the concept of the systematic exploitation of scientific investigation for the direct transformation of production. It is in this context that Josiah Wedgwood stands out with his remarkable, if unsuccessful, attempt to establish a co-operative research organisation for the purpose of performing scientific investigation for the pottery industry.[69]

Perhaps the most pronounced characteristic of the industrial revolution was the stark polarisation which appeared between the predominantly agricultural rural community and the new urban centres of manufacture. Previously the city had been more a centre of commerce and culture and any concentration of production was a secondary phenomenon. Industrial production before the industrial revolution was decentralised, either in a domestic or craft-based setting or related to immediate raw material resources and access to sea-ports. The land had a strong relationship with industrial production. For instance fields were used for bleaching and natural organic products from animals and vegetation provided key raw materials. One consequence was that the landed classes had direct interests in production not only through land ownership but also through their commercial interests in forestry, mining, chemical production, tanneries etc. They retained in addition responsibilities for the provision of elementary public services, moral education, and the maintenance of law and order.

Many of the early factories grew up in rural locations, attracted by cheap water power, the availability of labour, and the freedom from restrictive regulations of traditional urban communities. With the growth of industrial cities, however, the emphasis began to change. Thus the population of England and Wales rose from around 6.5m. in 1750 to reach 16m. just less than a century later, most of this increase represented by urban growth.[70] Manchester, populated by a mere 17,000 in 1760, had 180,000 inhabitants by 1830.[71] In 1835 Ure estimated that around 614,000 people in the United Kingdom were then employed in factory work.[72]

Urban industrial growth paralleled a sharp decay in country life, which by the 1790's had reached catastrophic proportions, particularly in parts of southern and eastern England.[73] Rural poverty became a major problem, providing an unmanageable burden for the traditional rural pastoral system. In 1776 the Poor Rate amounted to over £1.5m. annually and by 1803 had risen to over £5.3m.[74] A new wave of philanthropic schemes appeared in an attempt to alleviate rural poverty.[75] Unlike the Society of Arts; which had sought to counter poverty through general economic growth resulting from the encouragement of technical change, the new schemes supported more selective forms of intervention. In a time of booming economic growth, along with a glut of inventions, the problems of poverty were more recognisable as structural in origin. Although faith in the application of entre-preneurial spirit to agriculture was a strong motivation in itself, the seriousness of rural poverty allied to the spectre of the French Revolution encouraged more short-term solutions. Berman has characterised the response as "scientific philanthropy",[76] combining the ideological role of education with an extension of the concept of industrial efficiency to household economy by harnessing scientific investigation to aspects of domestic life in areas such as fuel economy and cottage building. It was in this context that the Royal Institution was founded in 1799, and represented a notable step in the direction of professional scientific organisation for public purposes.

The Royal Institution: the public laboratory as an institution for social change

The Royal Institution was the first major scientific laboratory in England and formed an important development in the public conception of science and its social function. As well as offering scientific instruction, it provided institutional support for the notable research of Humphrey Davy and later, Michael Faraday.

Support for this initiative came in its early years predominantly from the landed classes and drew a similarly fashionable coterie to that which had made the Society of Arts such a centre of the social and cultural life of London fifty or so years earlier. Berman has noted that although industrial and commercial classes were represented in the proprietorship they formed an uneasy relationship with the landed gentry.[77]

Although ostensibly a public and nationally oriented body during its first decade of operation, devoted in principle to the "application of science to the common Purposes of Life", the Royal Institution was initially more a private corporation serving the immediate economic interests of the strongest elements of its membership.[78] Particular close relationships existed with the Board of Agriculture.[79] Indeed, in many respects the Royal Institution served as the Board of Agriculture's laboratory, with Davy as its salaried employee. In 1805 the Board of Agriculture provided Davy with a soil analysis laboratory and among other tasks was requested by the Board to undertake geological and mineral surveys.[80]

At a time when the landed classes were under severe pressure to adapt to a changing economic order, this base was insufficient to provide the Royal Institution with continuing financial viability.[81] Under financial pressure its managers attempted to broaden its appeal by emphasising a national and public role for the establishment and by soliciting for government contributions. Thus the report of the managers in 1809 asserted that:

> Something must be done to give it more the form of a Public Establishment, than of Private and Hereditary Property. It can hardly be expected that a general Interest should be excited for the Improvement of a few individuals ... the Proprietors must sacrifice ... personal interest and advantage to erect a public, national and permanent Establishment devoted, and dedicated to the cultivation of science, and to the promotion of every improvement in Agriculture, Manufactures, and the useful Arts of Life, that may be conducive to the happiness and prosperity of the British Empire.[82]

Berman has pointed out that the social composition of the Institution's governing body duly underwent a complete transformation. By the 1830's middle class professionals held over 60% of the governing positions, with the landed classes a mere 6%,[83] almost a complete reversal of the balance in its early years. These new professional classes identified themselves with what Berman calls the "legal ideology of science", a notion of social engineering that arose in response to predominantly urban social problems and was reflected in the expansion of medical and legal administration, police and forensic services, factory and pollution legislation during the nineteenth century. This was part of a general rise of professional consciousness that affected medicine, education and government administration, had a Benthamite view of science as part of its ideology, and found its outlet in organisations such as the Statistical Society, London University, and the Society for the Diffusion of Useful Knowledge. Groups arose with an allegiance to a professional community, in which organised science assumed an important role, as objective knowledge became crucial to the ability of the professional "expert" to maintain the necessary position of social neutrality. Research centres such as the Royal Institution became the necessary tool of these professionals generating the cognitive base on which their expertise and professional solidarity rested.

The Royal Institution thus became a natural centre for controversial issues to be resolved involving technical consultancy, litigation and patent squabbles, government testimony in the courts, and the analysis of pollution. The belief in scientific expertise and its relevance to professional standards was crucial for the reputation and continued development of the Royal Institution which through the work of William Brande and Michael Faraday was at the centre of civic developments such as the introduction of gas illumination. Indeed, Berman has described the volume of commercial and professional work performed by Faraday as "staggering" involving countless professional court testimonies and excise work up until 1835.[84] In addition both Faraday and Brande undertook analytical work for the Admiralty.[85]

The subsequent development of the Royal Institution reflects a familiar pattern. From these early strong utilitarian functions it gradually became more concerned with "pure" science. The role of the professional arbiter and experimenter, however, diffused throughout both central and local public bodies, reinforcing and providing strong internal lobbies for the responsibility of the state to endow the means of production of scientific and technical knowledge. The demand for such social technicians had a more immediate effect of challenging existing educational provisions, expanding the notion of vocational training, and in particular fostering the concept of national educational standards, qualification, and the systematic utilisation of the principle of popular examination. Once the ideology of professional expertise was accepted the state was eventually obliged to become more deeply involved in the maintenance of the regenerative structures involved in professional training and the production of knowledge.

Despite the excellence of Berman's analysis of the social context of the Royal Institution, one must stress important reservations concerning the application of his conclusions to British society in general. Although he quite rightly recognises the significance of the rise of the scientific expert in the context of nineteenth century social administration, it is a mistake to assume that the landed classes were totally eclipsed by the rising bourgeoisie. They remained a significant social force, reflected by their influence on the establishment of a number of nineteenth century institutions such as the British Association for the Advancement of Science, the Royal College of Chemistry, the Geological Survey, and Rothamstead Experimental Station. However, the rise of the professional scientist, particularly in the context of public legislation, and the increasing sophistication of facilities required for the continuity of research, began to eclipse the role of private patronage during the course of the nineteenth century, signalling the transition towards greater formal state patronage for applied research and development which was to further lay the basis for the more comprehensive schemes of state patronage in the twentieth century.

CHAPTER THREE

Science and Public Policy in the Nineteenth Century: the transition from private to public patronage

Introduction

Beneath the dogmas and the ideological and moral strictures of Victorian Britain was a complex struggle to come to terms with the far reaching implications of industrialisation, the contradictions of public and private interests, and the growing threat posed by rival industrial powers in world markets. Despite the familiar elevation of the values of unrestrained individualism, the formal responsibilities of central government multiplied and encroached into various areas of society, legitimated by the persuasive rationale of expediency. To an unprecedented degree scientists and science began to assume an explicit functional role within the regulative and reproductive features of civil society.

Industrial production in the nineteenth century continued to expand with science continuing in a peripheral role, although the demands of quality control and the control of production was increasing the professional requirements of industry for qualified chemists particularly in the chemical trade, the brewing industry, and the textile finishing trades. The world-wide exploitation of mineral resources stimulated a demand for qualified geologists and mining engineers. The establishment of the Geological Survey of Great Britain, the Royal School of Mines, along with geological surveys in the colonies reflected these trends. From mid-century the growth of manufacture based on coal tar products and the rise of the electrical industries, began to emphasise the relevance of organised science to manufacturing industry, and to economic well-being in general.

In the regulative context, science began to hold an important strategic position in the struggle to come to terms with the related problems of pollution and public health, and the social pressures to regulate the anarchic expansion of urban industrialisation and trade whilst holding the sensitive balance between public and private interests.

With the continuing pace of economic growth and as long as Britain continued to dominate world markets, temporary aberrations such as ship-wrecks, mine disasters, boiler explosions, cholera outbreaks along with critical shortages of food, educational skills and civic amenities, could all be tolerated and ameliorated with limited and expedient intervention, with a national confidence based on faith in the virtues of self-help, laissez-faire attitudes, and above all "progress". During the 1860's, however, the first signs of alarm began to show, fostered by an awareness of the technological accomplishments of foreign competitors.[1] Disturbing trends in economic indicators during the following decade, particularly from around 1873 fostered the unease and precipitated a sense of crisis.[2] Contemporaries became alerted to the contrast between Britain and the expanding economies of the United States, and particularly Germany, by a growing army of critics. Inevitably contrasts were made of the institutional provisions of competing countries, not least of the provision for science and technological research and education in Germany. Indeed, Germany became the common reference point for debates within British scientific circles, conscious of the disparity between state provisions and their own professional aspirations.[3] The lack of any coherent scientific community reflected, however, a disparate diffusion of professional expertise into markedly contrasting areas of social life in industry, education and public service. Despite the obvious penetration of scientific investigation into public life, each development remained an isolated occurrence, a pattern which persisted until a more schematic approach to the organisation of public scientific resources in medicine, agriculture and industrial research began to emerge in the twentieth century.

The British Association for the Advancement of Science: From Private to Public Patronage

The British Association for the Advancement of Science (BAAS), founded in 1831 represents probably the last major institutional development dependent on private initiative which took both a comprehensive view of the development of science and technology and an active role in its application before the advent of more formal state mechanisms. Despite retaining a populist image the BAAS was, perhaps, the most influential institution of the nineteenth century for furthering the interests of professional scientists. Nevertheless, the BAAS was itself dependent on patronage beyond the realm of the professional scientist, for its stability and survival. Thus as a recent study has observed that:

> Its members included earls, marquises, and viscounts, while politicians of the calibre of Sir Robert Peel and Lord Palmerston were pleased to accept office within it; the Prince Consort himself was President in 1859.[4]

Aristocratic approval proved central to the success of the British Association, for as the same study has commented: "Creating a powerful agency meant identifying with power; power meant land; land meant aristocracy."[5]

The origins of the BAAS display a richness and complexity comparable to the circumstances which surrounded the founding of the Royal Society and, indeed, there were close parallels.[6] Established as a national institution at a time of political unrest and deep seated social change, the BAAS represented an alliance of moderate interests whose common goal was the non-revolutionary transformation of cultural life in which science was systematically patronised as the instrument of social harmony and a neutral court of appeal to resolve the re-current social conflicts associated with rapid industrialisation.

As with the case of the founding of the Royal Society, the ideas of Francis Bacon were utilised to legitimate its role, not least by William Vernon Harcourt, a leading figure in the creation of the BAAS.[7] In the early 1830's there occurred a widespread revival of interest in Bacon as a philosopher and, indeed, Harcourt saw himself acting with respect to the BAAS, in much the same way that Robert Boyle had done in the Royal Society as Bacon's leading disciple.[8] Nevertheless, any Baconian emphasis was short-lived and from 1833 the BAAS view of what constituted proper science owed more to Newton than to Bacon. The Baconian characteristics,including his inductive methodology and division of labour, were quickly undermined through its invasion by "Cambridge and Metropolitan Savants who preferred the ideology of science derived from Newton than from Bacon."[9]

In fact the establishment of the BAAS reflected widespread discontent with the Royal Society as a vehicle for the systematic patronage of science, and its ability to come to terms with the increasing specialisation, popular appeal, and growing material needs of scientific activity. David Brewster and Charles Babbage, two outspoken critics of the Royal Society, and active in the movement which led to the formation of the BAAS, were both representative of one group of men in the physical sciences increasingly dependent on institutional support to finance the ever larger, more complex instruments they wished and sometimes were able to create.[10] The scale of their thinking and the broad national benefits implicit in the fruition of their plans both indicated that government was the proper source of funds. As Morrell and Thackray further point out, government was also seen as the increasingly necessary support for work in other areas of the physical sciences, not least in paying the people needed to observe, record and order the extended routine series of astronomical, meteorological and magnetic observations that were particularly favoured in this era.[11] To achieve these aims required considerable political weight, and with the Royal Society less aggressive in this respect, the BAAS was to become the focus for a variety of pressures to increase or maintain the effectiveness of state-supported scientific institutions, by alerting Government to their inadequacies. Indeed, the abolition of the Board of Longitude in 1828, one of the few state agencies which sponsored applied research, resulting from financial retrenchment aimed at the Admiralty, and the consternation it caused among certain sections of the scientific community, has been evidenced as one motivating factor in the movement to establish the BAAS.[12]

Although the results of BAAS lobbying in the cause of science had mixed success, and the majority of successful lobbies launched between 1837 and 1844 were concerned with an extension of work already administered by government, its growing authority at dealing with government, and its ability to successfully articulate its arguments in public, continually brought attention to the Government's responsibilities towards the production and utilisation of scientific and technical knowledge. Not that the BAAS threatened the existing boundaries between state-supported institutions and voluntary ones, and indeed George Airy at the 1851 meeting of the BAAS proclaimed that:

> .... the absence of Government science harmonizes well with the peculiarities of our social institutions. In science, as well as in almost everything else, our national genius inclines us to prefer voluntary associations of private persons to organizations of any kind dependent on the State.[13]

Although the promotion of research might require state support, any usurpation of individual privilege was to be resisted. The fact that forty years later the BAAS was to be the platform for a sustained campaign resulting in the establishment of the National Physical Laboratory was indicative of how scientists were to become more ambivalent towards direct State patronage as the century progressed.

Despite a groundswell of antipathy towards direct State support, under the aegis of the BAAS a wide ranging number of activities furthered the development of an explicit interaction between science and public policy by identifying issues of pressing national interest such as ship design and safe operation, as well as providing organisational support to research programmes carried out in private laboratories and educational centres such as Kings College, London.[14] Invention, technological progress, and the mechanical and chemical arts were within the domain of the BAAS from the very start, although admittedly in a subordinate role. Indeed few of the successful early lobbies related directly to technological interests and in the mid-1840's there appeared a distinct decline in technological interest.[15] Nevertheless, the pressure it was able to bring on the Admiralty to extend the study of tides on an international scale and to increase the accumulation of meteorological and magnetic data reflected clear practical interests from the view of public policy.

The establishment of a number of specialist working committees under the organisation of the BAAS in response to pressing issues relevant to both scientific and technological interests is particularly noticeable from around 1860 onwards. Through these committees the BAAS pioneered, for instance, the quest for practical standards of electrical measurement, units of mechanics, and international standards for the analysis of iron and steel. With such active members of the stature of William Thomson (later Lord Kelvin), Thomas Rankine, John Scott Russell and William Froude, the BAAS was prominent in technological changes in ship design and construction, and attempts to solve the problems associated with the introduction of the iron steam ship into regular use.[16]

Whether it was in the setting up of a Parliamentary Science Committee, in being instrumental in pressing for a Royal Commission on scientific questions, or leading the march to the establishment of the National Physical Laboratory, the BAAS was an institution of fundamental importance during the nineteenth century in establishing permanently a closer relationship between science and public policy. However, although private organisations such as the Royal Society and the BAAS provided an important contribution to the development of public policy in relation to scientific and technical matters, pressures for continuity and the needs of routine repetitive services encouraged government departments to develop more permanent scientific support.

The employment of individual experts as consultants to government departments highlighted a transitional phase, as figures such as Lyon Playfair, Michael Faraday, John Tyndall, Edward Frankland and A.W. Hofmann were regularly consulted.[17] Thus Faraday and Tyndall, both based at the Royal Institution, acted as paid advisors on lighthouse illumination to the Board of Trade; Hofmann using the research resources of the Royal College of Chemistry investigated on behalf of public departments in such diverse fields as the adulteration of beer, the deoderization of sewerage and gas illumination; and Frankland acted as the research scientist of the Rivers Commission; while Playfair investigated aspects of public health.[18] The more immediate demands of public administration encouraged first the Admiralty, then the Treasury to support Charles Babbage in his abortive development of a calculating engine. Gradually, however, government departments began to employ scientific expertise directly as part of the civil service itself.

The Growth of Government Research

By the end of the nineteenth century, expertise based on the results of scientific and technological investigation was an essential element of civil service administration, crucial to the ability of government to legislate, regulate and maintain general departmental services. Science and scientists had become permanently and formally linked to the political and administrative functions of central government. The process by which this became established was pragmatic and piecemeal, dictated more by expediency than by conscious design, and dependent on individual enthusiasm and the continued patronage and support from a small group of scientist-administrators. Recognition, in part, of the social role of science and its strategic importance to material progress, encouraged the Government to provide support for fundamental research. A grant-in-aid was administered by the Royal Society, which maintained the traditional advisory role it had occupied since its inception, and the BAAS received some financial support.[19]

At the beginning of the nineteenth century few examples of institutionalised science in the strictly public sphere existed with the exception of the Royal Observatory. The Board of Agriculture, which had supported scientific investigation did not continue beyond the end of the Napoleonic Wars, and agriculture continued to depend on the private patronage of the landed classes for research. Another agency which sponsored research, the Board of Longitude was, as has already been noted, abolished in 1828. In the course of the nineteenth century, however, a number of developments in state involvement in scientific activities occurred in various spheres of public administration which collectively amounted to a steady growth in public support for scientific investigation subordinate to administrative needs, a brief survey of which will now be provided.

(i) Maritime Affairs

In maritime affairs the tradition of close state patronage was maintained, dictated by the strategic economic and political factors involved. The traditional sponsorship role of the Admiralty, despite the abolition of the Board of Longitude, in such areas as hydrography, oceanography and new interests such as geophysics, was complemented by activities sponsored by the Board of Trade in respect to regulative issues. Thus, in conjunction with the Royal Society, the Admiralty continued to sponsor scientific expeditions as the increase of shipping brought demands for more accurate charts and sound hydrographic data.[20]

A recurring theme in early Victorian science was an emphasis on data accumulation and processing, often involving schemes demanding high capital expenditure, prolonged current costs, and the maintenance of routine activities involved with data collection. Such schemes often involved complex organisation and attempts at international co-operation. An example was the Admiralty's participation in geomagnetism in the 1830's and 1840's, when an ambitious programme was mounted to stimulate the growth of a sound theoretical basis.[21] Through the vast accumulation of facts from a widespread system of observatories it was hoped that the variation of the earth's magnetic field could be expressed as simple laws, which could in turn be applied to the art of navigation. In this way the pure and applied aspects were closely linked both scientifically and institutionally.

In this project the Admiralty adopted a major role, stimulated by the hope of eventual economic and political benefits and the indirect accumulation of international prestige. The BAAS acted as a vociferous lobby for this programme aided by such government officers as Sir Francis Beaufort and Edward Sabine. Interest in the project was maintained by the Royal Engineers, and the Government agreed to requests for instruments to enable army observers to make magnetic measurements at colonial stations. By 1840 a whole system of colonial observatories was beginning to develop, with costs jointly borne by the Admiralty, the War Office, and the East India Company, along with foreign support. Although the scheme was ultimately unsuccessful in achieving such ambitious objectives it exemplifies the manner in which science and government were developing a much closer relationship during this period.

A host of new problems were presented to mercantile interests by the introduction of iron into shipbuilding with important consequences for public policy,[22] highlighted by a number of dramatic sinkings and economic uncertainties associated with innovative ship design. The traditional craft basis of ship design gave way to the rapid professionalisation of naval architecture and the subsequent stimulus of a new technical lobby. One particular consequence was a modest research programme, previously referred to, in which William Froude was sponsored by the Admiralty in his investigations into the use of models tested in specially designed ship tanks to develop both the theoretical aspects of applied hydrodynamics and practical methods for assessing the performance characteristics of ship designs.[23]

Magnetic deviation due to the use of iron created additional navigational problems. Investigations in this area were promoted by the Admiralty's Compass Department, and the implications for the mercantile marine were presented to the Board of Trade by the Royal Society.[24] As the Board of Trade's responsibilities in this area grew, including lighthouse management and meteorological forecasting, it became involved increasingly with the employment of scientific expertise and investigation.[25]

(ii) The Meteorological Office

The origins of the Meteorological Office date from the mid-nineteenth century and its establishment and subsequent management indicate the manner in which government departments were assimilating new responsibilities for the direction of experimental investigation, and were then forced into the issues of management and control.

In 1852 correspondence began between the Royal Society and the Foreign Office relating to initiatives taken by the British Government to secure some form of international collaboration in establishing a uniform system for recording meteorological information.[26] Although the Royal Society indicated the practical difficulties involved in a very comprehensive scheme, it stressed the need for more systematic direction of the observations made at sea, a responsibility taken up by the Board of Trade in 1854, in conformity with recommendations made at an international conference the previous year.

Under the direction of Admiral Fitzroy, the new meteorological department began the task of producing forecasts made on the basis of telegrams received from various outstations. Following the Admiral's death in 1865 a flurry of renewed correspondence between the Royal Society and the Board of Trade resulted in the appointment of an advisory Meteorological Committee by the Royal Society, a move which reflected the inability of the Board of Trade to fully superintend matters involving scientific knowledge.[27] Subsequent developments involving meteorological research highlighted the complex problems which arose as the Government began to sponsor research activities on an increased scale. The Director of the Meteorological Office in the 1870's confessed that:

> .... the position is perfectly anomalous; the Government considers us under the Royal Society; and only lately the Secretary of the Royal Society has told me that he always considered us under the Board of Trade; but the Government distinctly disclaims all connexion with us, whilst the Royal Society equally disclaims all control over us, except merely the nomination of the members of the Committee.[28]

Subsequently the advisory Committee was replaced by a paid Council, which operated until 1905 when control passed into the hands of the Treasury.[29]

(iii) Military Research

The Admiralty continued to operate during the nineteenth-century without any formal research organisation despite the promotion of many areas of scientific and technical investigation bearing on operational requirements. The Torpedo School, for instance, began to teach physics and electricity during the 1870's in response to technical needs associated with new devices coming into operation.[30] Research activities began in association with teaching although the lack of any specialist career structure hindered any systematic development.

It was not until 1904 that the War Office formally established a Research Department at Woolwich. Prior to this various fragmentary research and experimental activities were undertaken, particularly in the army colleges which like their naval counterparts provided a location for research activities. A few specialist establishments had, however, been created for chemical and photographic work. In the area of ordnance, Frederick Abel had carried the study of explosives to new theoretical heights. From around 1864, the Royal Engineers began balloon studies which involved scientific aspects of both the chemistry of hydrogen and the physics of levitation. Later, in 1878 a Director of Balloon Design, Construction and Research was appointed at Aldershot[31] and in 1904 the transfer of the Balloon Factory to work on airships at Farnborough laid the basis for the Royal Aircraft Establishment.

(iv) Natural Resources

The exploitation of raw materials was an area where public interest had traditionally focussed, and in which the landed classes had clear commercial interests. The founding of the Geological Survey in 1835 was a particularly important step in direct government assistance for research in this area, established to promote the geological sciences and associated work bearing on agriculture, mining, road building, railroads, canals, and other areas of civil engineering.[32] It continued however the private endeavours of Henry De La Beche who became its first director.

Geological surveys were, in addition established throughout the Empire and constituted a fundamental role in exploiting the cheap raw materials provided by imperial domination. The imperial context of institutional development was also emphasised by the establishment of the Imperial Institute in 1888, as a permanent memorial to honour

Queen Victoria's Jubilee celebrations, not only as a permanent exhibition of raw material products of the Empire but also to conduct research into their properties and suitability for industrial exploitation. The cost of the Institute was primarily met by colonial contributions and work tended to be limited to chemical and technical analyses as well as small scale trials with little scientific research of any note.[33] The Institute later formed the basis for a new public establishment, the Tropical Products Institute.

(v) <u>Chemical Analysis</u>

Issues of public health and safety, environmental protection and the general provision of civic amenities such as sanitation, water supplies and medical facilities were closely associated with urban industrialisation and were usually tackled by both local and central government in a piecemeal and ad-hoc manner.[34] In the context of social administration, individual scientists sought to establish the utility and relevance of their expertise, and were co-opted to provide such services to the many Select Committees and Royal Commissions established to deal with the issues involved, as well as to provide the scientific basis for successful legislative measures. From such disparate means research programmes were often initiated and, indeed, a by-product of attempts to address issues of public health was the first State-aided medical research of any note.[35]

The requirements for supporting legislation through inspectorates brought the advent of full-time civil scientists and particularly chemical analysts whose work was often of a very routine nature. Despite the repetitive tasks involved in much of this work, continual pressure existed for improved techniques of measurement and analysis which encouraged support for auxiliary strategic research of a functional character. Although public analysts had supported State functions since at least the thirteenth century,[36] the expansion of formal government in the nineteenth century established the importance of analytical chemistry in various areas of government service.

In 1842 the Inland Revenue established a chemical department designed to safeguard the revenue from fiscal losses resulting from illegal adulteration of tobacco.[37] From such limited beginnings the new laboratory grew to eventually embrace the analysis of almost every excisable commodity and by 1858 was clearly recognised as an essential and prominent part of the Board of Inland Revenue.[38]

As a result of the 1875 Food and Drugs Act, the laboratory was given the additional responsibility of statutory referee in cases of legal dispute involving official prosecutions. Further consolidation of its work came in 1894 when the analytical facilities of the Inland Revenue were combined organisationally with the laboratories of the Customs and Excise as the Government Laboratory, a conscious policy of centralisation reflecting the degree to which contact had already been established through analytical work for virtually all government departments. As the Treasury explained some years later this was done:

> .... for the express purpose of placing at the disposal of public departments requiring chemical assistance, a more highly skilled and more experienced staff and a more complete equipment for chemical investigation than each department could provide for itself.[39]

This process of centralisation of analytical facilities was continued and consolidated further when the remaining formal ties with the Inland Revenue were broken and the laboratory became autonomous as the Department of the Government Chemist in 1911.[40]

The development of the Laboratory of the Government Chemist in its formative years typifies the way in which scientific investigation, even of only a routine nature, was assimilated into the functions of government administration.[41] During the nineteenth century the gradual expansion of the Government Chemist reflected the slow and uneven growth of government science in general, a process depending on both individual enthusiasm and the immediate demands of administrative and political pressure. Each activity within government science had its own momentum and constraints with no overall commitment to any systematic development in a Baconian sense. During the nineteenth century, however, one individual in particular studied the overall relationship between the art of government and scientific research, and brought the utopian vision of Bacon's New Atlantis into the context of modern public administration. Alexander Strange was one of the few adherents, in Victorian Britain, to the view that science should be systematically developed by specialist government-controlled research institutions.

Alexander Strange: Public Policy and Scientific Institutions

Alexander Strange was born in 1818, the son of Sir Thomas Strange, a distinguished jurist in India and Chief Justice in Madras.[42] After attending school in England he joined the Indian Army, the 7th Madras Light Infantry, at the age of sixteen and immediately began to develop interests in science, especially astronomy. He became a skilled instrument maker and repairer, a background influential in his transfer to the Great Trigonometrical Survey of India, and his subsequent appointment as second assistant to the Survey after a period of study at Simla Observatory. In 1855, after making notable contributions to this great imperial project, he was appointed to the headquarters' staff of the Surveyor-General.

He retired from active service in 1861 and returned to England with the rank of Lieutenant-Colonel. He, nevertheless, maintained his interest in Indian affairs through his association as an advisor to the India Office and in 1862 was successful in persuading the Indian Government to establish a department for the supervision of scientific instruments, a project he took personal responsibility for organising and which included the erection of special premises at Lambeth for the testing, design and construction of instruments, which remained under his supervision.

In England Strange became active in the scientific community and was elected a Fellow of the Royal Society in 1864, later serving on its Council from 1867 to 1869.[43] An enthusiastic supporter of the BAAS, as well as the Royal Astronomical Society, in which he was Foreign Secretary from 1868 to 1873, Strange was also called upon as a juror in the scientific instrument class at both the International Exhibition of 1862 and the Paris Exhibition in 1867.

It was at the 1862 Exhibition that Strange first came into contact with many eminent scientists and from discussions with them became convinced that adequate provisions for scientific research in England were lacking, at a time when science was perceived by him, and others, as vital to efficient government administration and economic progress in general.[44] Attempts by him to raise the issue among his colleagues with a view to soliciting for government support initially proved unsuccessful. As he informed a more receptive audience in 1871: "There were very few men eight years ago who would talk to you five minutes on the subject."[45]

In 1868, however, Strange was persuaded to present a paper on the subject at the annual meeting of the BAAS,[46] by a close associate Dr. R.J. Mann. His views, coming as they did in the wake of the disappointing performance of British entries at the Paris Exhibition the previous year, received serious consideration, and catalysed a series of developments which resulted in an extensive public debate on the issue which centred around a Royal Commission of investigation, the Devonshire Commission.[47]

The essence of Strange's thesis, presented to the BAAS, as subsequently developed in a succession of later papers on the subject rested on a number of central beliefs.[48] His argument was concisely summarised in a letter to The Times in which he stated that:

> I, and many who think with me, maintain that scientific research must be made a national business; ..... the problems presented for solution are such as to need for their adequate treatment permanent well-equipped establishments with competent staffs worked continuously and systematically .... we have tried individual enterprise .... and we are being rapidly outstripped by nations who, though they encourage private excertion - do not rely on it."[49]

Repeatedly in his papers, Strange refers to the need for "system" and "organisation", and for the State to assume responsibility. Thus he asserted that:

.... the State or Government, acting as trustees of the people, should provide for the cultivation of those developments of science which by reason of costliness, either in time or money, or of remoteness or probable porfit [sic] , are beyond the reach of private individuals.[50]

In his arguments he emphasised the previous, if fragmentary, tradition of state intervention and the positive result of substituting organisation for what he saw as "desultory individual effort."[51] A more systematic approach would bring, he argued, investigation in connection with practically the whole of the national economy, in relation to such issues as sanitary improvements, water supply, sewerage treatment, telegraphy, and the improvement of the military. A great national physical laboratory would, thus be created, along with other institutions for the study of metallurgy, chemistry and physiology; observatories for studying astronomy and terrestrial physics; extensions to the Standards Office and the natural history collections; as well as a museum of inventions and scientific instruments.

In addition he proposed radical changes in organisation; a Council for Science, consisting of distinguished scientists, responsible to a Minister of Science, and charged with the duty of advising government departments, through the Minister's office, on scientific issues relevant to their duties, either with respect to the ordinary routine of administration, or on specific issues such as the founding of new research institutions, or the sanctioning of scientific expeditions.[52]

Such a proposed Council would consider, he envisaged, applications for grants, provide opinion on the value of inventions submitted to it, and superintend experimental investigation needed in support of its duties. Strange castigated the existing provisions for answering science-related questions as "desultory", often applied "capriciously, inefficiently, irresponsibly" when such questions were dealt with at all.[53] As for the powers of Parliament, he considered that "no scientific question was ever or will be solved by such an assembly."[54] The press he considered unreliable, whereas commissions and committees had no continuity.

Strange presented his arguments to a variety of audiences, including the Devonshire Commission, advocating a model for the organisation of State science of revolutionary proportions, which was, as his friend John Scott Russell pointed out, quite contrary to all the habits, prejudices, and opinions of the English people and above all contrary to their political doctrines.[55] As Scott Russell observed with obvious satirical intent:

> We do not like science, we like practice. We do not like system, we like leaving to each man to do the best he can for himself. We detest State organisation; we require the fullest possible liberty for every individual to pursue his own interests, and his own whims in any way he likes; not controlled by patriotism or common good, or any of these ideal things.[56]

It is tempting to cast Strange as a classic eccentric Victorian enthusiast with ideas, somewhat ahead of his time. He had, however, his own personal context of experience to draw on, as had Bacon in formulating his own utopia. MacLeod's assertion that Strange was "a little-known elderly ex-Indian army officer and amateur astronomer"[57] needs some qualification. The military after all had a major role in the civil development of India. Strange was, in practice, a very experienced civil scientist-cum-administrator with professional skills developed in a colonial context, where bureaucratic planning was pronounced, skills which he quickly utilised on his return to England. He was very much a "committee" man steeped in a tradition revering organisation and efficiency.

Through his activities on his return, Strange was well known, particularly in the more active circles of the scientific community and acquainted with some of the most illustrious scientific men of the day. From the reaction of the audiences he addressed it is apparent that although his views did not bring universal favour, indeed far from it, he always commanded respect and was never forcibly attacked.

Cardwell has observed that:

> it is a sad commentary on the state of science in England at that time that it was an Indian Army Officer and not an academic, a civil servant, or an industrialist who saw so clearly what the defects were and what the remedies should be.[58]

This comment again misses the vital point that it was undoubtedly Strange's Indian background that was instrumental in shaping his views. As Hobsbawm points out, India was a Victorian "abnormality", the only part of the British Empire to which <u>laissez-faire</u> never applied, a feature reflecting the crucial importance of India to British economic and political interests.[59] During the 1850's, India became the subject of a programme of massive internal development and in this period 1857 to 1865 was responsible for the major movement of British capital, into schemes designed to transform communications, and public works, complementing the direct government promotion of products required by British industry.[60]

Associated with large scale development projects in India were extensive demands for surveying, geological and engineering skills, reflecting the problems posed by harbour developments, inland transport schemes, water supply and irrigation. Through his professional duties, initially in India, and later through his association with the India Council, set up following the establishment of direct Crown administration in 1858, and the Lambeth Observatory, Strange was closely involved in these technical problems. Indeed it is likely that Strange used the India Council as an administrative model and inspiration for his proposed Council for Science. This view is supported by the analogy he drew between the needs of India and the needs of science in his paper to the Royal United Service Institution in 1871, where he referred directly to the role of the India Council.[61] Such a parallel was also drawn by Sir Henry Rawlinson, a member of the India Council, in evidence to the Devonshire Commission.[62] Rawlinson also drew attention to the use to which the hypothetical Council for Science could be put with reference to a number of occasions on which the Indian Government had referred problems to the India Council which they were unable to answer for the lack of any competent and authoritative scientific support.[63] Strange himself had personal experience of this kind of problem. In evidence before the Devonshire Commission he told how, on the Trigonometrical Survey he had been concerned with problems of variation in the coefficient of expansion of standard iron linear measuring bars. On his return to England he was determined to find some solution but was surprised and disappointed to find no suitable institution to adequately deal with such an inquiry, and as he recalled: "It was the discovery of this fact that first directed my attention to our national deficiency with respect to science."[64]

During the extensive evidence presented to the Devonshire Commission, Strange's personal vision of national laboratories, a Council for Science, and a Science Minister, received mixed support and was submerged and distorted in the complex of opinion and interpretation. Whilst the findings of the Commission endorsed his suggestions in principle, there was little indication that many of his contemporaries had any affinity with his comprehensive organisational approach. Many of those who were sympathetic, were also aware of the realities of the period. Thus, as his friend R.J. Mann informed Strange, following his paper to the Royal United Service Institution: ".... the mass of mankind cannot understand such papers",[65] adding to an earlier observation from Scott Russell that: "I am afraid we must wait till these English human beings have got wings, before we can quite attain to the perfection he has seductively pointed to."[66] Much of the emphasis of the debate surrounding the Royal Commission was concerned with the immediate needs of science and scientists, whereas Strange had a more far reaching concept of the mobilisation of science as a function of State activity. Differences of perception influenced the various individual interpretations given to the role of the proposed Science Council as well as the function of hypothetical national laboratories. George Gore, a Birmingham scientist, for instance was a notable supporter of national scientific institutions.[67] Yet he envisaged them devoted to the pursuit of "pure" research without any orientation to material applications directly. The popular conception of the Science Council, proposed to the Commission, was that of an elite representative body which mediated government/science relations, in contrast to what Strange envisaged as more of a government chief scientist's department oriented to State activities.[68]

The disparate response to Strange's support for the establishment of national laboratories reflected the lack of homogeneity in the scientific community if such can be said to have existed at all, and the variety of its institutional context. Although a marked intransigence to any State involvement came from certain academics, it was clear that the pressure to provide adequate facilities for experimental research, particularly in less well endowed provincial settings, brought many to the conclusion that State support was inevitable if opportunities for research were to be pursued. However, to go as far as supporting State-controlled laboratories was a less amenable proposition. Thomas Rankine, for instance, while admitting that scope existed for state institutions to be involved in more routine activities, such as the testing of new materials, was opposed to, "the appointing and paying by Government of a class of men to direct original researches."[69] William Siemens, while accepting that government should endow laboratories, frowned upon the idea of Government departments undertaking research.[70] Support for Strange came mainly from scientists familiar with working in the context of public policy such as William Thomson, Edward Frankland, William Froude and James Joule.

The emphasis Strange placed on the need for systematic organisation, outside a small circle of friends and supporters, was unappreciated and any influence the recommendations of the Devonshire Commission had was piecemeal in the classic manner of _ad hoc_ pragmatism which had characterised the evolution of public administration in Britain. However, the increasing threat of foreign economic competition stimulated various sporadic initiatives although the spirit of laissez-faire lingered. In January 1874, for instance, a Society for the Promotion of Scientific Industry was formally inaugurated with great pomp at Manchester Town Hall by Lord Derby.[71] The initiative came primarily from Manchester chemical manufacturers, in response to growing competition from the German chemical industry. At its launch Lord Derby reaffirmed the faith in private initiative, and a Times editorial, pointing to "the fatal signs" of Britain's disappearing commercial monopoly, greeted the initiative with enthusiasm.[72]

In a following letter to The Times, Alexander Strange scoffed at such an outmoded response.[73] His opinion was soon vindicated. In 1875 an exhibition sponsored by the new Society became a financial disaster, and after a short and ineffectual existence, the Society collapsed, with its last recorded meeting held in January, 1876.[74] Alexander Strange died the same year, leaving his ideas for institutional change still beyond the comprehension of most of his contemporaries. Events which occurred during the first few months of the First World War nearly forty years later were to focus minds on the issue enormously. Nevertheless, between the time of the Devonshire Commission, (the recommendations of which, for a Council of Science and provision for national laboratories, had been largely ignored by the Government of the day), and the First World War, a number of significant moves in the institutionalisation of public science had already occurred. The most significant in the context of the present thesis was the establishment of the National Physical Laboratory in 1900.

The National Physical Laboratory: Public Patronage Institutionalised in a National Laboratory

The establishment and development of the National Physical Laboratory in the years prior to the First World War was the culmination of a series of institutional developments complemented by sustained pressure from the scientific community. Its foundation was symbolic of the passing of an era of private initiative, although its establishment was itself a product of such initiative, and the arrival of government patronage in a particular institutional form. In many respects it represented and institutionalised a nineteenth century approach to scientific activity. Yet it was also an important precedent for twentieth century institutions of government. It centralised a number of functions, particularly work on standards, calibration and testing, which had for many years been carried out in more modest and disparate settings, for instance at Kew Observatory, which at different times had fallen under the management of both the Royal Society and the BAAS.[75] It also, however, marked the first notable government intervention in the realm of industrial research for civil industry, and a considerable expansion in government-supported basic research in applied science.

The need for such a laboratory, as expressed in the organised pressure from the scientific community in the 1890's reflected many of the pressing instrumental needs of the physical sciences at a time when science was being legitimated and utilised by both government and industry.[76] The origins of the National Physical Laboratory should in part, however, also be seen in the context of a number of developments in the institutionalisation of science, particularly connected with the rise of the research laboratory as a recognised form in both industry and academia.

By the end of the nineteenth century the research laboratory was accepted as a social institution crucial to advances in knowledge. At the same time research laboratories, suitably equipped, demanded resources beyond the means of most individuals. Scientific equipment, the means of production of knowledge, was rapidly developing in scale, sophistication and expense.[77] Expanding research programmes were, in addition, associated with an increasing division of labour. The research laboratory was becoming the factory of scientific activity as personal laboratories became overshadowed by large institutions.

The organised research laboratory was largely a product of the nineteenth century. Private laboratories, teaching laboratories attached to universities, and institutions such as Kew Observatory and the Royal Institution, had important roles in support of the work of the BAAS, Royal Commissions, and government departmental work. In industry laboratories developed out of the routine testing associated with production, and gradually became divorced from the production process itself.

By mid-nineteenth century the organised chemical laboratory was established in both teaching and research, while the physical laboratory was also becoming more common.[78] In Glasgow, for instance William Thomson's successful research support for the transatlantic cable gave his laboratory official recognition. In the eight years after 1866 another nine similar laboratories were set up.[79] These were essentially teaching laboratories. Specialist research centres were also established, however, notably the Cavendish Laboratory, founded in 1874, with private endowment.[80] In the same period the Royal Society, again with private financial support, assumed control of the Kew Observatory from the BAAS, to maintain a central magnetic and physical observatory.

In response to pressures from scientists and indirectly from industrial developments, the BAAS co-ordinated a research programme aimed at the standardisation and elucidation of practical electrical units. Much of the early work on this programme was conducted at Kings' College, London, under James Clerk Maxwell and Fleeming Jenkin. Related experiments on electrical resistance formed the first research programme at the Cavendish, which for some time was to remain the major centre for the establishment and maintenance of accurate electrical units until the National Physical Laboratory assumed this task. Indeed, pioneering work on units, measurements, and standardisation occupied some of the most prominent physicists of the day including J.J. Thomson and Lord Rayleigh. In due course, however, this kind of work became increasingly routine, while, nevertheless, remaining vital to both scientific and industrial advance.

At the Cavendish the abstractions of Maxwell's electromagnetic theory provided the continuity for research, forcing more routine work and industrially-related activities into the background. In general scientists working in the fields of chemistry, electrical research and metallurgy became conscious of a lack of suitable facilities for the "rank and file" class of scientist and for a more routine type of research. These needs became legitimated against the technical needs of industry in the economic context of foreign competition, and by drawing comparisons with the provisions for research offered by economic competitors. A further factor of concern was that, following the rapid expansion of the electrical engineering industry, public authorities came under pressure to curb the commercial chaos which existed with regard to practical electrical measurement.[81]

It was in this context that Oliver Lodge, in the familiar arena of the BAAS, at its annual meeting in 1891, raised the issue of a national physical laboratory, emphasising the need for public support for research of a more routine nature. As he observed:

> The quest for the fifth or sixth decimal is a very legitimate, and may become a very absorbing quest, but there are plenty of the rank and file who can undertake it if properly generalled and led; not as isolated individuals, but as workers in a National Laboratory under a competent head and a Governing Committee.[82]

A committee, established under the auspices of the BAAS, to consider the proposal concluded its investigation with some pessimism over the possibility of government support. In 1895, however, following another leading speech on the issue, this time by Sir Douglas Galton, the BAAS Committee was reconvened.

The Committee, reporting in 1896, emphasised the economic arguments for establishing a national laboratory. Strongly worded it claimed that:

> If England is to keep pace with other countries in scientific progress it is essential that such an institution should be provided; and this can scarcely be maintained continuously on an adequate scale, except as a national laboratory, supported mainly by Government.[83]

Lord Salisbury, the Prime Minister, received a deputation of supporters of the proposals and a Treasury Committee of Inquiry was duly formed, and which reported favourably to the idea of a laboratory, aided from public funds, to pursue work on standards, the verification of instruments, testing of materials, determination of physical constants, as well as to undertake special investigations.

Despite this emphasis on routine functional tasks, many saw the new laboratory, established as the National Physical Laboratory in 1900 as fulfilling a much wider, more ambitious role; providing an institutional bridge between abstract research and industrial needs. Richard Glazebrook, for instance, the Laboratory's first director, spoke of its main aim as being; to

> .... assist in promoting a union which is certainly necessary if England is to retain her supremacy in trade and in manufacture, to make the forces of science available for the nation, to break down by every possible means the barrier between theory and practice and to point out plainly the plan which must be followed unless we are prepared to see our rivals take our place.[84]

Despite the zealous and undoubtedly sincere conviction that it should occupy a role between the laboratory of the university and industrial works, the new State laboratory inherited a distinctly academic tradition, with the influence of the Cavendish prevalent, particularly through the appointment of Richard Glazebrook, as well as from other staff trained in an academic context.

Although it was the first major government research establishment in Britain in the modern sense, the nineteenth century tradition of private patronage was to remain important in the formative years of the National Physical Laboratory, emphasising its transitionary character. Although it received a grant-in-aid from the Treasury, substantial support came from private sources, particularly for expensive capital developments. The William Froude National Ship Tank, for instance, was set up with the aid of a private donation from Alfred Yarrow, the shipbuilder. Similar private endowments from Sir Julius Wernher and Sir John Brunner provided for the metallurgical and the electrical laboratory respectively. Numerous smaller subscribers provided both funds and equipment.[85]

In addition much of the early costs of the laboratory were provided for by returns from repayment work, and indeed the Treasury expected the venture to be self-financing. It viewed the work of the laboratory in the functional sense which had hitherto characterised other government scientific activities, and the separation of finance from control of the laboratory heightened the strain between the Treasury and the laboratory in its formative years. Although by placing overall control and management in the hands of the Royal Society, a traditional pattern was being followed with respect to government/science relations, the nature of the laboratory's work and its gradual expansion and continuing dependence on public funds, combined to cause great unease among Treasury officials, particularly as the laboratory moved into areas of longer term research.

The establishment of the Ship Tank, for example, which provided a valuable source of income from routine test work, also encouraged the laboratory into a longer term programme of research in applied hydrodynamics. Similarly government sponsorship of work on aeronautics led to research in more basic areas of applied aerodynamics. Thus work of a functional character was generating programmes of fundamental research, discounting prospects of short-term financial viability and presenting problems which more traditional methods of cost-accounting were incapable of dealing with. While undoubtedly the establishment of the National Physical Laboratory marks the setting up of the first modern government research establishment in Britain, the search for a viable relationship between the Government, and agencies responsible for government-patronized applied research had only just begun.

Conclusion to Section I: Science, Progress and the transition to State patronage

If many scientists in late nineteenth-century Britain found the kind of views which had been expressed by Alexander Strange alien, one thing they were coming to be conscious of was the key role of science in material progress. The results of research programmes, such as those in thermodynamics and electromagnetism, consolidated the belief that all sound useful knowledge had to have a theoretical basis. In consequence, the economic and social development of society was dependent, in the longer term, on the successful elucidation of absolute laws of nature and a comprehensive understanding of the abstract processes underlying the real world, which led in turn to the successful application of new knowledge to existing material conditions. Thus, for instance, George Gore in 1872 declared that:

> Scientific discovery, ... by developing new facts and laws relating to matter and its forces, constitutes not only the basis of new manufactures, but largely, also of the improvements in trades, made by inventors and practical men; and if discoveries are not made, the means of which improvements are effected by such men will become exhausted.[86]

For Gore, and many of his contemporaries, scientific knowledge was seen as the basis for making inventions. Practical inventions led to an increase in trade, and thus economic success depended on original scientific research. Nevertheless, these ideas were in competition with a national consciousness which deified the productive power of the common sense practical man on one hand and the generalist manager and administrator on the other. Thus at the core of debates over educational reform was a conflict over historical interpretation, and its implications for institutional reforms. The debates on education and research became distinctly sharpened by the growing economic competition from overseas, and particularly from Germany.[87] British scientists, in particular, retained a fascination for German institutions lasting until the outbreak of war in 1914.

As the rate of domestic economic growth in Britain began to slow in the 1870's, the German State began a rapid ascendancy to become the leading continental industrial power and presented a severe challenge to British economic interests which reached critical proportions by the 1890's and the early twentieth century. The strength of the German economy was highlighted by the achievements of the new science-based industries such as those founded on the exploitation of organic chemistry and electrical science. The implications drawn by many of the scientific community in Britain were in general two-fold. Firstly the growing success of German industry was attributed, partly, to the generous provisions for both research, and scientific and technical education; and secondly to the ability of the German manufacturers to apply the results of scientific advances. Thus the view of scientists that British manufacturers were failing to take advantage of the work of scientific men, due to the ignorance of potential benefits, contributed to the sustained support for the development of technical education in Britain, and the infusion of scientific education into the universities.

As economic competition intensified science was presented, by scientists and their patrons, as crucial to national strategy, particularly in the early years of the twentieth century prior to the First World War. Endowing science and research institutions was presented as "sowing the seeds of progress", a metaphor common during the Victorian era. Thus in 1859, for example, Prince Albert had referred to the need to exploit as a national resource the "Storehouses of Science .... many a rich harvest is ripe for cutting, but wants for the reaper."[88] Lyon Playfair was another prominent spokesman for science who put great emphasis on its economic role, and the consequent need for long-term investment in such a national resource. As he declared, in a collection of papers published in 1889:

> The crop of truths which we are now harvesting results mainly from seed sown by our forefathers. The seed, which we ourselves may throw upon the waters will assuredly come up into a harvest, though it may not be for many days.[89]

In the years following, an increasing number of scientists rose to assert the need to mobilise science in the economic struggle between nations. In 1903, for example, Sir Norman Lockyer delivered his influential crusading speech entitled "The Influence of Brain Power on History" to the annual meeting of the BAAS, emphasising this theme and declaring that : "The schools, the university, the laboratory and the workshop are the battlefields of this new warfare."[90] Support for his views came particularly from chemists aware of, and alarmed by the rapid ascendancy of the German chemical industry and its growing hold on world markets.[91]

When war finally broke out in 1914 and Britain struggled to maintain supplies of essential products, many derived from the science-based industries, scientists felt their prior warnings vindicated. In 1915 Percy Frankland, a chemist, gave the old metaphor an ironic twist when he claimed that:

> The country is now reaping the harvest of humiliation which it has sown for itself in spite of the warnings repeated ad nauseum by the chemical profession during a whole generation.[92]

If, as the scientists argued, science lay behind material progress, and because the benefits of the application of knowledge ultimately accrued to society in general, then the argument pointed to the duty of the State, acting as a trustee to Society to endow scientific research in the public interest. Once the State accepted this responsibility it then had a direct interest in ensuring that the results of research were applied in practice. The transition from private to public patronage was not sudden, however. As this last chapter has indicated the growth of government research in the nineteenth century was slow and incremental. Much of this work was in support of immediate administrative needs. The degree to which government was slowly increasing its support to science was not immediately obvious at a time when private associations were still of great importance in support of public policy. As late as 1913 Lord Sanderson referred to such private initiatives as:

> .... the cavalry of intellectual advances scouting in front, extending its flanks, procuring supplies and information, and performing various indispensable services for which the infantry and heavy artillery of Public Departments are little adapted.[93]

The irony in these words is particularly striking, coming as they did on the eve of a world war destined to reveal the obsolescence of the traditional military role of the cavalry and limit its future role to more ceremonial occasions. The same war highlighted the inadequacy of private patronage with respect to the promotion of applied science, a context in which a new government department, the Department of Scientific and Industrial Research, was established, which took on many of the functions previously limited to voluntary association and patronage.

Although the First World War did mark an important watershed, nevertheless, important new initiatives in State patronage had occurred earlier. The creation of the National Physical Laboratory had illustrated a distinct transition to public patronage along with a more systematic approach to applied research, not necessarily linked to immediate application, but with more strategic considerations in mind. It also marked the first notable government support for manufacturing industry in the field of research and a move away from a strict *laissez-faire* approach.

Two further pre-war initiatives were indicative of a recognition of the strategic importance of research to political aims and the need for State patronage. These brought more systematic State support for agricultural research and medical research respectively. In 1909 the Development and Road Improvement Act provided for the creation of the Development Commission, a body set up to advise the Treasury in making advances to public agencies for economic development. In particular a sum of £2.9 m. was provided to aid and develop rural agricultural areas including provision for scientific research and instruction.[94] Among plans approved by the Treasury was the creation of a group at the Royal Institution to work on agricultural science. The Development Commission was for many years the major Government agency for funding agricultural research, which it did by supporting a number of institutions, by awarding research grants to individual workers, and by endowing scholarships.

Similarly medical research began to be placed on a more organised basis with the establishment of the Medical Research Committee, the immediate forerunner to the Medical Research Council, in 1913. This was directly related to the provisions of the National Insurance Act, 1911, which established schemes for health and unemployment insurance, and set up a national fund for research purposes. The Act, however, gave no guidance on how to administer the fund, a subject taken up by the Departmental Committee on Tuberculosis, appointed by the Treasury in 1912. The Committee subsequently recommended the creation of an organisation consisting of an advisory council along with an executive committee. A long battle followed between those who wished to departmentalise the scheme, and others who saw the need for a greater degree of independence.

The latter argument won the day and an independent committee with executive functions was established charged with the duty of supervising research.

In both the provisions for agricultural science and medical research a policy emerged supporting the tendency to decentralise research and maintain centres of excellence in different fields in a series of institutes, often associated with colleges and universities. The creation of the Department of Scientific and Industrial Research extended further the scope of public patronage by government to many hitherto unsupported areas. Associated with many of the schemes of applied research promoted by the new department, was the establishment of a series of national laboratories dissociated from the educational system and forming a network of centralised research facilities conforming to the previous visions of both Francis Bacon and Alexander Strange.

SECTION TWO

The Evolution and Development of Government Research Establishments in Britain 1915-1982.

The foundation of a system of central national research laboratories was laid in the inter-war period. Following the end of the Second World War came a period of rapid growth in governmental provisions for applied research and development. Government research establishments remained the central institutional support for such a policy. During the 1960's however confidence in such a policy waned bringing a period of intense debate, reassessment and reform in public provisions for the patronage of applied research and development. In the 1970's the national laboratories in consequence began to suffer from a decline in public commitment typified by extensive manpower reductions and moves to "privatise" a number of institutions.

CHAPTER FOUR

The Establishment of National Laboratories for applied scientific research 1915-1939

The experience of the First World War had a profound impact on all levels of British Society, not least on the relationship between government and industry, and on the form of the response of both to the organisation and scale of applied scientific work. In this respect the most significant initiative of the war was the creation of a new government department, the Department of Scientific and Industrial Research (DSIR), to sponsor applied scientific research in a more systematic manner. Under the auspices of the new department many new national laboratories were founded, and were given the task of developing comprehensive schemes of research in areas considered of national importance. These laboratories were created in response to various pressures such as the immediate strategic demands for food supplies and fuel, as well as in the context of post-war social policies in housing and health.

A crucial factor which influenced the orientation of many of these research initiatives during the inter-war years was Britain's response as an imperial power to the economic threat of world recession.

Established in the context of such externally generated needs, individual laboratories developed distinctive characters moulded by their own internally driven expansion, and conditioned by the uncertainties of finance and manpower, which resulted from official reaction to the turbulent nature of the economy. Nevertheless, by the outbreak of the Second World War, the national laboratories were firmly established as part of the government machinery.

Government and Applied Science: the impact and aftermath of the First World War

In 1914 few countries took the dangers of a prolonged war seriously and no country made serious economic preparations. Britain, as a traditional naval power, by both geographical position and imperial responsibilities, had a comparatively small army, such that from the onset of hostilities the industrial capacity of the nation came under severe pressure both from the cessation of German imports and the rapid escalation in military requirements. Immediate shortages of essential supplies resulted in a prolonged and intense debate on Britain's inadequacies compared with the supposed German ability to utilise scientific knowledge successfully for industrial purposes.[1] This debate continued while the Government made faltering steps towards intervention, which by the summer of 1915 was resulting in increasingly centralised organisation.

For the scientific community the crisis vindicated previous warnings, and scientists interpreted the failure to match the achievements of Germany as largely due to the neglect of science by successive governments. This mood was further inflamed by what was perceived as the inability of the country to mobilise the nation's scientific resources and integrate them into the war effort. This was typified by the indiscriminate recruitment of qualified scientists for front line military service.[2]

In May 1915 a deputation consisting of fellows of both the Royal Society and the Chemical Society was received by W. Runciman and J.G. Pease, Presidents of the Board of Trade, and of Education respectively. In this instance Pease and Runciman succeeded in averting criticism with news that a scheme providing for the encouragement of scientific research had been approved by the Government in principle. The details of this scheme, outlined in a White Paper the following month, represented a notable new initiative in government assistance for the promotion of scientific and industrial research, establishing a committee of the Privy Council responsible for the expenditure of funds placed at its disposal, aided by a small advisory council composed mainly of eminent scientists.[3] The duty of the advisory council was directed to the provision of detailed advice with regard to proposals submitted, whether for instituting specific researches, providing studentships and scholarships, or for establishing or developing special institutions for the scientific study of problems affecting specific industries and trades.

In its first year of operation a modest £25,000 was provided for the new scheme and a number of research proposals, submitted by professional institutions, received support.[4] The Advisory Council for Scientific and Industrial Research, as the advisory committee was titled, while retaining overall control, felt the need to devolve its responsibilities to various specialist standing committees. In addition moves were begun to encourage co-operative research schemes in association with private industry.[5] The success of these initiatives gave rise to the conviction that the Advisory Council should press ahead to support research carried out in direct response to industrial needs.

As the scale of research grew in both bulk and importance it became clear that a separate organisation, having its own Parliamentary estimates, and in the charge of a minister responsible to Parliament was a necessity. Between September and December 1916, plans for the provision of assistance to industrial research were worked out in greater detail, and on December 1st 1916, Lord Crewe, Lord President of the Privy Council, announced the Government's intention of forming a separate Department of Scientific and Industrial Research (DSIR). In addition, with regard to support for particular industries, the Advisory Council persisted in the idea of developing industrial research programmes by subsidising investigations sponsored on a co-operative basis by industry itself, and in 1917 was able to announce the availability of a fund of £1m. to finance the setting up of research associations directly related to the interests of specific industries.[6]

Despite these provisions the Advisory Council was quickly made aware of the existence of a number of large scale problems, considered to be of national urgency, such as the supply and conservation of raw materials, the maintenance and improvement of public services, the processing of materials, and general strategic issues bearing on technology, yet outside the remit of individual industries. Thus, in response to representations made by various professional groups, as well as from executive government departments, the DSIR instituted and became responsible for a number of comprehensive schemes of fundamental research related to such fields as food, fuel, and building materials. Between the two world wars the tendency to centralise research activities connected with these general programmes gave rise to a series of new national laboratories.

In its creation the DSIR reflected the general trend towards collectivism under war-time conditions and the rapid relaxation of _laissez-faire_ principles as the Government was forced to intervene in the affairs of private industry on an unprecedented scale.[7] In a similar fashion events of the war encouraged fundamental changes in attitudes towards research and development. Both during the war, and after, the encouragement of research received a wider, if still relatively limited, support among politicians, civil servants, industrialists, and the public at large. Both the Government and industry began to invest in research on an unprecedented scale,[8] and in particular to create specialised institutions for the pursuit of applied research divorced from immediate day to day needs.[9] Although the collapse of the post-war boom was to expose this growth to the threat of economic retrenchment, important changes in organisational form had occurred, establishing scientific research as a social institution and productive force. Although the war, itself, destroyed any idea that the scientist was an unequivocally benevolent agent of social well-being, for the most part the public welcomed the "marvels and mysteries" of science with enthusiasm.[10]

The war seriously undermined unilateral laissez-faire as an economic and political philosophy. In particular it highlighted the importance of certain industries to national security.[11] In this context the strategic role of scientific investigation began to be realised as of importance, beyond the narrower confines of the scientific community, and especially by the military. The outcome of the war in addition consolidated Britain's position as an imperial power through the acquisition of German territories in East Africa. This consolidation of Empire profoundly influenced the nature of public research in the inter-war period as research programmes became significantly related to imperial development.[12]

This recognition of the strategic role of scientific research, reflected by the increasing resources devoted to it, during and in the immediate years after the war, brought to the fore issues of management and organisation and encouraged the adoption of formal principles of administration. In this context the most influential ideas came from a government committee, reviewing the machinery of government, which published a report on the subject in 1918.[13] This report enunciated three distinct kinds of government research; general administrative intelligence; enquiries and research carried out by government departments directly related to their specific administrative remit; and thirdly longer term general research not falling within the scope of any single department. The identification of the latter category of activity led directly to the managerial guideline, later known as the "Haldane Principle", after the Committee's Chairman Lord Haldane, which was put forward in the report. This stated that, as a principle of operation, that general research should not fall within the direct responsibility of executive departments. Rather it advised, this type of research should be retained within a distinctive organisation, under ministerial responsibility relieved of any immediate pressures of day to day administration. In this way, it was argued, the minister responsible for general research could not fall under suspicion of bias towards the interests of individual executive departments, and any potential hindrance to the application of research results associated with the immediate interests of executive departments would thus be avoided.

A further important argument for having a minister with overall responsibility for research, separate from existing executive departments, was that it could provide a focus for research, not simply in relation to domestic issues but extending in scope to cover the interests of the United Kingdom, Dominions and Colonies.

With respect to the managerial procedures outlined in the report, however, the establishment of the DSIR two years previously was an important precedent, and the report recommended the extension of such arrangements to other areas. In particular it recommended that the Geological Survey and the Medical Research Committee be reconstituted on similar lines. An obvious possibility, however, of which the Committee was aware, was the scope for centralising all aspects of general research activities into a single operational unit. In particular its report suggested that it was not premature to anticipate the formation of a separate "Department of Intelligence and Research" which would assume this role under the authority of a single minister appointed specifically for the task.

Behind such a tentative suggestion was considerable speculation and uncertainty over the future role of the DSIR. Its consolidation, particularly following the transfer of financial and administrative responsibility for both the National Physical Laboratory and the Geological Survey, formally completed in 1918 and 1919 respectively, although negotiations had begun some years previously, seriously raised the possibility of the DSIR forming the nucleus for a larger "Ministry of Science". At the same time, in the immediate aftermath of the First World War, rivalry between different departments of government clouded the future of the Medical Research Committee.[14] With regard to the latter there were suggestions that any new reconstituted body should be placed under direct ministerial control in the proposed Ministry of Health. Tentative moves were also made in official circles to bring medical research under a single research organisation, with the DSIR as the basis.[15] Alternative suggestions included bringing both the DSIR and the Medical Research Committee under the same Privy

Council Committee with the Lord President as chairman. Medical research interests, however, formed a strong lobby and fought to preserve their independence. In January 1919, for instance, Sir Walter Fletcher, Secretary to the Medical Research Committee, made his own opinion on the issue clear in a letter to Sir Frank Heath, Secretary to the DSIR, in which he stated that:

> No doubt you saw the alarming after-dinner remarks of Auckland Geddes (President of the Local Government Board) about a Ministry of Science. They filled me with horror. We might as well have a Ministry of Truthfulness or a Department of Good Manners, to introduce those principles to other Government Departments, and how cordial its relations with them would be![16]

Ironically, Heath was privately and actively promoting the DSIR as a potential basis for a central Ministry and had cultivated an ally in H.A.L. Fisher, President of the Board of Education. In 1918 a memorandum, which had been prepared by Heath, was submitted to the Cabinet Committee on Home Affairs by Fisher advocating the DSIR as the nucleus of a general research and intelligence department.[17] Fisher had the support of both Lord Curzon, Lord President of the Privy Council, and Robert Munro, Secretary of State for Scotland.[18] The establishment of the Medical Research Council as an autonomous body in 1920 effectively ended such speculation, and any ambitions the DSIR had of evolving into a comprehensive general research ministry came to nothing.[19] In 1931 the Agricultural Research Council, was founded, closely modelled on the Medical Research Council. The pattern of public patronage for research was by then firmly set, not least by the rapid expansion of military research in the inter-war period.

In terms of the organisation of research in the military sector the Admiralty led the way by creating a Directorate of Research in 1920.[20] In the same year it created a further notable precedent by establishing the Admiralty Research Laboratory at Teddington, which was to be concerned primarily with fundamental research bearing on naval interests. This complemented a number of institutions maintained by the Admiralty which concentrated on more immediate technical problems such as its engineering facilities at West Drayton, the Haslar Experimental works and the Admiralty Chemists' Laboratory.[21]

In 1924 the Air Ministry followed the Admiralty initiative by appointing both a Director of Scientific Research and a Director of Technical Development. The largest concentration of research facilities under the Air Ministry was still at the Royal Aircraft Establishment. Nevertheless, a number of other establishments had come into being under it including the Aeroplane and Armament Experimental Establishment and the Marine Experimental Establishment. The Ministry also maintained a laboratory at Imperial College, London, and supported an extensive programme in aerodynamics and other subjects related to aircraft performance at the National Physical Laboratory, as well as providing administrative supervision of the work at the Meteorological Office.

The War Office, in contrast, had no central focus for research activities and policy was devolved through a number of independent technical committees. Scientific and technical establishments were still administered by senior military officers. One of the largest was the Woolwich Research Department, financed jointly by the three services which by the mid-1920's had a budget approaching £200,000.[22] A number of smaller technical establishments were maintained, and a large programme on chemical warfare was conducted, mainly at the Porton Down establishment.

In the 1920's with the level of departmental research expenditure reaching an unprecedented height (see Tables 1 and 2) the possibilities of duplication of effort, and consequent waste, became a real fear, particularly with respect to the research programmes of the military research establishments and the DSIR. Indeed, in 1919 a first attempt had been made to overcome such fears with the appointment of a Committee on the Co-ordination of Scientific Research in Government Departments under the chairmanship of the Lord President, A.J. Balfour.[23] The Committee's recommendations resulted in the setting up of three Co-ordinating Boards (for physics, chemistry and engineering) to assist in the interchange of information between different departments and to identify neglected areas of research.[24]

The Boards failed to establish any meaningful role and were later considered redundant.[25] A further attempt at formal co-ordination came with the appointment of an Interdepartmental Conference on the Co-ordination of Scientific Research, set up in 1922, on the instructions of the Cabinet, to bring together the representatives of the DSIR, Medical Research Council and the Development Commission, in formal quarterly meetings. In 1932, however, the formality of the original instructions were waived and it dwindled to periodic meetings of the secretaries of the respective institutions on an informal basis.[26]

In 1925 the issue of effective co-ordination came sharply into public focus, however, when figures provided by the Treasury in response to a Parliamentary question (Table 2) revealed what to many was an astonishing figure for total annual public expenditure on scientific research of £4 m.[27] The implications were taken up by the Commons' Estimates Committee which in turn questioned that adequate measures

TABLE 1

Scientists in the British Civil Service (1920)

Scientific Museums	64
War Office Research Establishments	100
Air Ministry Scientific Establishments	470
D.S.I.R.: National Physical Laboratory	150
D.S.I.R.: Geological Survey	53
D.S.I.R.: Headquarters and other research stations	100
Ministry of Agriculture and Fisheries research establishments	70
Admiralty Scientific Establishments	164

y

SOURCE: James E. Mortimer and Valerie E. Ellis, *The Evolution of the Institution of Professional Civil Servants* (London, 1980), p.5.

TABLE 2

Government Scientific Expenditure in Britain (1925)

	£
Admiralty	983,000
War Office	495,000
Air Ministry	1,373,000
Ministry of Agriculture and Fisheries	348,756
Board of Agriculture for Scotland	51,585
Fishery Board for Scotland	16,910
Forestry Commission	7,057
Mines Department	1,850
D.S.I.R.	380,263
General Scientific Investigations	158,687
Ministry of Health	4,330
Post Office	52,000
Colonial Office	15,000
Office of Works	157,180

SOURCE: Written Answers, H.C. Debs, 187 (1925), July 27.

Notes. The figures include only expenditures explicitly attributed to scientific research in the expenditure estimates. The Treasury, which was responsible for producing the figures, confessed that it was unable to produce a workable definition of research. In consequence such items as inspection costs incurred by the Air Ministry were included. The figures did not include the salaries of administrators (except for D.S.I.R.). In addition a few other significant items of scientific expenditure do not appear in the table notably the Medical Research Council, the Government Chemist, and the Development Commission. The latter for instance allocated £282,492 for research in 1925/26.

were being taken to ensure effective co-ordination.[28] In response the Prime Minister appointed a sub-committee of the Committee of Civil Research to reconsider the question.

The investigation duly carried out was the most comprehensive analysis of government research undertaken during the inter-war period and the evidence presented to it fully confirmed the remarkable expansion in the provisions made by government departments and other public agencies for research. The final recommendations of the appointed committee in turn had a significant impact on the future organisation of government scientific institutions. Despite accepting the ineffectiveness of the Co-ordinating Boards, which were summarily abolished, on the whole the committee dismissed fears that resources were being wasted through ineffective co-ordination. In particular it rejected a suggestion made by the Estimates Committee that the scientific work of the Admiralty, the Air Ministry and the DSIR be concentrated under the control of a single department. The committee was more concerned about the effective deployment of research resources in individual areas of public policy. Considerable concern was expressed, for instance, at the fragmentation of agricultural research and recommendations made by the committee that an Agricultural Research Committee be set up along the lines of the Medical Research Council paved the way for the establishment of the Agricultural Research Council. Similarly its criticisms of the lack of central organisation of research at the War Office resulted in the establishment of central scientific advice.

Thus, a pattern of organisation for research which had emerged piecemeal was consolidated into a recognisable system with research concentrated in central research facilities firmly divided among four major autonomous sectors of public policy; military research, medical research, agricultural research, and general scientific and industrial research. The latter category remained the responsibility of the DSIR. The following section will examine the circumstances surrounding the establishment of a number of major national laboratories set up under the auspices of the DSIR in the inter-war years.

National Laboratories for Applied Research: The DSIR and the origins of central research facilities, 1915-1939.

By 1939 the DSIR had a gross annual expenditure of £934,000 of which £171,000 was provided in grants for industrial research associations.[29] The bulk of the remainder went in supporting research programmes carried out in central research stations, most of which had been established under executive boards created by the DSIR. The National Physical Laboratory had been transferred from the financial and administrative control of the Royal Society in 1918 and by 1939 still accounted for nearly 30% of the total gross expenditure of the DSIR.[30] By pure precedent many of the managerial principles adopted at the National Physical Laboratory were taken up in the new research stations including the salary structures,[31] and by virtue of status it was very much the flagship of the DSIR, developing an outstanding academic reputation in fields far removed from the standards work, which had been a central feature of its *raison d'etre.* Its internal organisation was determined by academic subject boundaries and it retained a great degree of autonomy in the control of its research programmes.

After 1918, however, the National Physical Laboratory did take on more work for industry and continued to undertake pioneering research in fields of strategic importance to sections of British industry. As its work developed in range and quantity, new divisions were formed.[32] The reputation of the laboratory established it as one of the most prestigious research institutions of the British Empire and in terms of the numbers of staff it employed, it was probably the largest single research organisation in Great Britain before the Second World War. Thus its total staff of 676 in 1936 can be revealingly contrasted with what were probably the largest research organisations in private industry. In the same period I.C.I. had a total research staff of 420, including 120 university graduates, G.E.C. employed 150 qualified scientists, and Metropolitan Vickers had 106 graduates and 94 non-graduates on its scientific staff.[33]

The first completely new research laboratory set up under the D.S.I.R. was the Fuel Research Station, opened in 1920. By 1939 this had been joined by new national laboratories working in fields such as food research (the Low Temperature Research Station at Cambridge, the Ditton Laboratory at East Malling, and the Torrey Research Station, Aberdeen), building research (the Building Research Station), forest products research (the Forest Products Research Laboratory), water pollution (the Water Pollution Research Laboratory), chemical research (the Chemical Research Laboratory) and road research (the Road Research Laboratory).

Each had its own particular circumstances of origin and individual factors which determined its development. Nevertheless, with the exception of the Road Research Laboratory, each arose out of the common environment of the DSIR in consequence of the direct recommendations of its advisory council. In its general activities the Advisory Council operated by considering representations made by both invididuals and organisations, often delegating to individual members the task of conducting detailed assessments, before sanctioning new programmes of research.[34]

When it was established in 1915 the Advisory Council immediately adopted the procedure of delegating advisory duties in specialised fields to sub-committees which had no executive powers. Major decisions involved a cumbersome process with the Privy Council Committee the only body explicitly recognised as having executive power. In the context of the war and its likely consequences, however, the immediate importance of work on fuel resources and the scale of effort which was envisaged led to a Fuel Research Board being set up as an executive body answerable directly to the Lord President of the Privy Council, with its own budget, accountable through the presentation of an annual report to the Privy Council. Sir George Beilby, a member of the Advisory Council, and an acknowledged authority on fuel research with extensive industrial experience, became Director of Fuel Research, and subsequently director of the Fuel Research Station. This was a crucial precedent which provided the model for the conduct of research in other areas.

The responsibility of the executive research boards was directed towards the overall management of research programmes. Initially all the research boards sponsored research in existing institutions, particularly university departments. In many cases, however, the very nature of the work, and indeed the reason for State involvement, necessitated expensive capital equipment and support facilities, which in turn encouraged centralisation.[35] Centralisation was attractive to the research boards because it increased their control over research.

By this process national centres of expertise were created which would be visible to potential users of research results and which presented little threat to entrenched interests.

A further important role played by the research boards was to maintain the balance between advisory and ad hoc work and longer term research. The difficulties which such a balance posed for the laboratories highlighted many of the tensions which were from the beginning inherent in the role of the laboratories. The essential role assimilated by the research boards, and hence the laboratories, was to pursue programmes of research in a systematic manner. The Advisory Council was itself against accepting short-term ad hoc investigations distinct from on-going programmes of research, and interpreted its own remit as relating to the establishment of comprehensive programmes of fundamental research related to specific applied objectives. Thus, although the Advisory Council decided to give science as it applied to industry precedence over pure science it did not consider such a distinction unduly problematic, with regard to the way it operated. As an early report from the Advisory Council recorded:

> It has been said that what people call applied science is nothing but the application of pure science to particular classes of problems. And, properly speaking, this no doubt is so; there are not two different kinds of science.[36]

Thus the values which were strongest in work promoted by the Advisory Council, and the DSIR in consequence, values which were assimilated into the work of the research laboratories, were those of science. Investigations were encouraged which formed part of an overall research programme to increase the knowledge base of a particular area.

An example of this approach was the way the Advisory Council refused to become involved in an isolated pollution study, when in 1924 it considered a memorandum on researches aimed at reducing or eliminating the toxicity of effluents from coke ovens. It rejected a suggestion made by the Ministry of Agriculture and Fisheries that the DSIR should undertake such an investigation "on the grounds that the work would not involve scientific research of a nature for which the Department should be responsible."[37] Rather it proposed to inform both the Ministry of Agriculture and Fisheries, and the Ministry of Health that it would "consider favourably ... any comprehensive scheme put forward by them for general research on the purification of water and of industrial effluents."[38]

Despite this emphasis on comprehensive programmes of fundamental research, at the same time the Advisory Council was deeply conscious of the need to demonstrate that the kind of research it was promoting had a "pay-off". This was crucial to the longer-term legitimation of the DSIR as well as to the more short-term pressures from the Treasury which expected research to bring immediate returns. Thus repayment and advisory work, based on existing research programmes, had an important role in the process of legitimation, not least in times of financial retrenchment such as occurred throughout the 1920's and early 1930's. Nevertheless, the more short-term research laboratories performed, the more they were deterred from their major function of long term research. This ambivalence, and resulting tensions, were recurrent in the reports of the National Physical Laboratory in the inter-war period.[39] The manner in which the DSIR assumed greater control of the direction of the laboratory's work reflected the pressures of legitimation particularly from the Treasury. The result was, as Moseley has pointed out, that policy making, as far as the National Physical Laboratory was concerned, became characterised by a struggle between the DSIR, which pressed for work promising an immediate return, and the laboratory's Executive Committee, which advocated a greater commitment to basic research.[40]

The kind of research programmes which the Advisory Council interpreted as falling within its remit belonged to the category of "general research" which was felt unsuitable for co-operative action by research associations and unsuitable for the responsibilities of any single government department. Issues were identified which, rather than relating to a single sectional interest, were considered of "national" importance and thus the results of any research carried out would result in a "public" benefit rather than profit minority groups. This was reflected in the Advisory Council's arguments for the support of fuel research which stated that:

> Every home in the land as well as almost every industry is directly concerned in the economy of fuel and for that reason it is simpler and more just that all should contribute through the taxes to the cost of research.[41]

Initially, research boards were closely involved in the detailed management of research programmes developed in accordance with these general aims, including day-to-day questions such as staffing. As the central laboratories grew in size, however, much of the initiative began to shift from the boards to the establishments.[42] Greater proportions of the budgets of individual boards became concentrated in the central research stations and control shifted away from the boards, which in turn assumed a more noticeably detached advisory role, with nominal authority. As Rendle notes with regard to this change in respect of the Forest Products Research Board:

> With certain exceptions, members did not serve long enough to identify with the Laboratory, and being occupied with their own affairs it is doubtful whether they gave much thought to the Laboratory between Board meetings.[43]

By the Second World War this process whereby the initiative had shifted to the laboratories themselves was virtually complete.

Attention will now move from more general issues to a consideration of the origins and general early institutionalisation of some of the major DSIR laboratories established in the inter-war period.

(i) Fuel Research: The Fuel Research Station

Among the first requests for financial aid received by the Advisory Council following its formation in 1915 were those from university workers and professional institutions, to support investigations relating to fuel resources, and particularly the identification and exploitation of coal supplies.[44] The diversity and range of investigations submitted, associated with the recognised importance of fuel economy to national interests, persuaded the Advisory

TABLE 3

Scientific Staff in D.S.I.R. Laboratories (1936)

	Scientific Staff	Assistants	Total Staff
Building Research Station	35	59	190
Chemical Research Laboratory	25	13	85
Ditton Laboratory	4	7	25
Forest Products Research Laboratory	29	21	142
Fuel Research Station	37	28	225
Geological Survey	54	16	152
National Physical Laboratory	163	155	676
Road Research Laboratory	14	12	60
Torrey Research Station	6	3	29

Source: The Association of Scientific Workers, *Industrial Research Laboratories: A List Compiled by the Association of Scientific Workers* (London, 1936)

TABLE 4

Private Industrial Payments to D.S.I.R. Laboratories

£'s	1933/34	1934/35	1935/36	1936/37	1937/38
National Physical Laboratory	48,000	54,000	66,000	68,000	70,000
Other D.S.I.R. Laboratories	12,000	14,000	14,000	19,000	11,000

Source: D.S.I.R., *Annual Reports*.

Council to press for a comprehensive scheme of research in this area.

The need for accurate assessments of mineral resources, and their successful exploitation was an associated feature of industrial expansion, and as has already been noted was a subject which engaged the attention of many institutions historically from the formative years of the Royal Society onwards. Alarm concerning the continuity of coal supplies came particularly to the fore in the early years of the twentieth century when a Royal Commission was set up to investigate the subject. Its recommendations strongly endorsed the view that attention should be given to keeping records of known national coal deposits up to date; and in particular it lobbied the Treasury in 1905 to increase the staff of the Geological Survey in order to revise geological maps.[45] The Treasury refused, and the issue was not raised in official circles until the events of the war made issues of fuel security more significant.

Before the First World War research resources devoted to questions of coal exploitation and general fuel economy were limited. The Home Office maintained a small experimental station from about 1911 to work on mine explosions. Another small laboratory was maintained by a co-operative of Doncaster Coal Owners. In addition various independent studies were undertaken in university departments and a professional presence was maintained through such bodies as the Institution of Gas Engineers and the Institution of Mining Engineers.

In 1916, as the Advisory Council's attention was being drawn to the related problems surrounding coal, questions of fuel economy were also being considered by a committee of the British Association. Following a preliminary approach by the British Association Committee raising the possibility of funding, the Advisory Council was persuaded to undertake a comprehensive review of the issues involved and a memorandum on the subject of research bearing on coal and its uses was prepared with the assistance of Sir Richard Redmayne, Chief Inspector of Mines to the Home Office.[46] The review was seen as a preliminary move before devising and implementing a comprehensive scheme of research.

Concurrently the issue had raised interest at Cabinet level, and in July 1916 a sub-committee of the Reconstruction Committee was appointed to review the question of coal supplies under the chairmanship of Lord Haldane. Links with the Advisory Council came indirectly through consultations with both Redmayne and Sir George Beilby, a current member of the Advisory Council. In its recommendations the sub-committee emphasised the need for an immediate chemical survey of the coalfields, and for an increase in work on the chemical composition of coal and its behaviour.[47] In correspondence with Sir William McCormick, chairman of the Advisory Committee, Haldane raised the possibility of a joint meeting with the Advisory Council to consider whether to erect a National Coal Laboratory along the lines of the National Physical Laboratory.[48] In consequence an informal meeting took place with representatives from both the sub-committee and the Advisory Council, which recognised that any further initiatives should include representatives from the British Association's Fuel Economy Committee, and suggestions were made for some scheme which would merge the British Association interest into a wider initiative sponsored by the Advisory Council.[49]

A further more formal conference, held on November 2, 1917, which included this time representatives from the British Association committee, came to an agreement that the Advisory Council should establish a Standing Committee on Fuel to take overall responsibility for research proposals.[50] The immediate response of the Advisory Council was to set up a sub-committee consisting of Sir George Beilby, Sir Charles Parsons, and Sir Richard Threlfall to consider the best means of instituting these proposals. Its conclusions, however, stressed the need for machinery which would be both compact and capable of more rapid action than was possible by using the usual procedure of standing-committees.[51] A series of consultations followed between Advisory Council members and Lord Crewe, Lord President of the Privy Council, who in turn consulted other cabinet ministers.[52] These discussions endorsed the findings of the sub-committee of the Advisory Council, and Lord Crewe gave his personal support for the appointment of a full time Director of Fuel Research, assisted by a small Board of Fuel Research, to act in accordance with a scheme approved by the Privy Council, acting on the advice of the Advisory Council. The new Board was to have full executive powers for spending funds and taking action, and report annually to the Committee of the Privy Council.

In 1917 Sir George Beilby became the first Director of Fuel Research and a new Fuel Research Board was created with the duty of organising surveys of the coalfields, conducting investigations into the nature and origins of various types of coal, and into the physical and chemical behaviour of coal constituents under active heat or in the presence of other agents.

From its inception the Fuel Research Board financed a number of individual research projects, including work on economic domestic heating, continuing a long tradition of research interest. In addition a grant was provided to continue work, begun in 1912, under the auspices of a Committee for the Investigation of Atmospheric Pollution.[53] Initially therefore, the effort of the Board was spread across a proliferation of small projects conducted by university departments and professional associations. It was pressure to centralise research, however, and particularly the need to erect facilities for large scale tests which led to proposals to erect a Fuel Research Station as a new national centre, duly approved by the Committee of the Privy Council, at an estimated cost of £120,000.[54]

The new research station built at East Greenwich incorporated facilities for cleaning, drying and pulverizing coal, for the production of coke, coal gas and producer gas, water gas, as well as hydrogen, and research work began in February, 1919. Thus the first major initiative on any scale taken by the DSIR developed firmly in the context of the war and its immediate aftermath. Attention had focussed on such issues as the availability and efficient utilisation of fuel, particularly coal and oil, primarily in terms of national security. Fears that the nation's greatest national asset, coal, was being squandered, became particularly amplified in the war-time environment which emphasised the need for an efficient mobilisation and deployment of resources. The programme of the Fuel Research Board was similarly seen in terms of the strategic means to maintain national and imperial power. This was highlighted by the increasing reliance of the Admiralty on fuel oils, associated with Britain's lack of indigenous oil supplies, reasons which stimulated investigations, for the purposes of national security, on methods for alternative sources, particularly the production of hydro-carbon oils from coal.

The Board's terms of reference allowed it to instigate investigations into the nature, preparation and utilisation of fuel of all kinds, in the laboratory and, where necessary on an industrial scale, and the strategic nature of the work reinforced the need for extensive centralised facilities. The major interest of the Station's work in 1920 and 1921 concerned the economy of steaming in vertical gas retorts, along with low-temperature carbonisation of coals. This was a result of Beilby's personal interest from the angle of Navy fuel. Financial stringency in the years from 1920 to 1923 restricted the scale of work in the laboratory. In 1924, however, the work load began to expand. In particular a programme of work began on the hydrogenation of coals and tars which continued for about fifteen years. The long-term strategic importance of developing methods of procuring oil from coal supplies was at the time obvious in the political and economic context of the period. In 1928 I.C.I. entered the field and within two years had invested £325,000 on developing such techniques.[55] With government support it erected a commercial plant, which continued to produce oil from coal until the end of the Second World War. The method never achieved a competitive advantage over natural petroleum and by the end of the war the strategic importance of maintaining commercial operation had evaporated. In 1935, however, the Fuel Research Station had begun an extensive programme of research into an alternative method of producing hydrocarbon oils known as the Fischer-Tropsch process. Although work was to continue on this until 1960, again it failed to achieve anything in terms of a commercially advantageous process of manufacture.

Further aspects of the research sponsored by the Fuel Research Board at the Fuel Research Station and elsewhere related to the development of imperial resources. In 1920, investigations were carried out on the possibilities of producing alcohol for fuel from such substances as Jerusalem artichokes and molasses. The conclusions did not give any hope of economic success. As the Advisory Council noted:

> Until alcohol can be made from waste materials which can be collected and treated at small cost, it does not seem likely that Empire-produced alcohol can be imported into this country on any considerable scale; it is improbable that it can be produced cheaply enough or in sufficient quantities, to supply home requirements from materials grown for the purpose in those overseas portions of the Empire which will no doubt before long produce it in this way for local consumption.[56]

In addition to these investigations, the Fuel Research Board also sponsored research on behalf of the South African Government into the suitability of certain types of coal for carbonisation and gasification.

With respect to domestic issues, the work of the Fuel Research Board was closely involved in the related aspects of the efficient use of domestic fuels and atmospheric pollution as well as its important coal survey work. In its early years, for instance, it co-operated with Manchester Corporation in supporting work on the effiency of domestic grates, with the Ministry of Health on the efficiency of cooking ranges and worked together with both the Advisory Committee on Atmospheric Pollution of the Meteorological Office and the Smoke Prevention Committee of the Ministry of Health.

Despite the recognition of the Fuel Research Board as a major focus for many aspects of fuel research in the inter-war years, two elements of its work continued to dominate, highlighting the fact that reasons of national security were to the forefront of the raison d'etre for its existence. Its work on methods of producing oil from coals and coal tars mainly carried out at the Fuel Research Station was one, and has been already briefly mentioned. The other took up the recommendation which had originally come from the sub-committee of the Cabinet Reconstruction Committee in 1916 for systematic surveys of the coal fields which became and continued as a major responsibility of the Fuel Research Board until the nationalisation of the coal industry after the Second World War. The relative importance of its work in terms of national political and economic interests was highlighted by the fact that fuel research was the single major category of research expenditure supported under the DSIR, and in terms of institutional support the Fuel Research Station was second only to the National Physical Laboratory in terms of resources committed.[57] Indeed taken in terms of net expenditure it was the highest funded public research institution in the civil sector, in the mid-1920's, before gradually being overhauled by the National Physical Laboratory.[58]

The strategic national importance of fuel resources was highlighted in the context of a major world war and was maintained by events of the following years, particularly with the increasing use of oil as a fuel, not least by the Royal Navy, and the emphasis on industrial efficiency and economy resulting from world trade recession. The General Strike of 1926, and the coal dispute in particular, brought questions relating to the future of coal sharply into focus once again.

The increase in alternative forms of power, the higher efficiency of steam using devices, and the reduced purchasing power of coal-consuming countries all led to a severe reduction in demand. Two lines of recovery emerged; one, the rationalisation of the industry and secondly, finding new uses of utilising coal. It was with respect to the latter that the work of the Fuel Research Station had a strategic importance. Ultimately this role was to be undermined by other developments, firstly the post-war nationalisation of the coal industry absorbed many of the functions previously sponsored through the Fuel Research Board; secondly, Britain established some measure of security for oil supplies through the establishment of major refining facilities; and finally the emphasis in energy research swung dramatically in favour of nuclear power in the post-Second World War period. The subsequent demise of the Fuel Research Station is dealt with in the following chapter.[59]

(ii) Food Research: The Low Temperature Research Station, the Torrey Research Station, and the Ditton Laboratory.

As in the case of fuel research, initiatives resulting in programmes of research into the preservation of foodstuffs were instituted in the context of wartime and the strategic requirements of reconstruction, along with the consolidation of an empire-based economy. The initial approach came from the Council of the Cold Storage and Ice Association which, in February 1917, wrote to the President of the Board of Trade, Sir Albert Henry Stanley, urging the government to take a more active role in developing the engineering and scientific background to mechanical refrigeration as part of technical education.[60]

Following preliminary correspondence between the Board of Trade and the DSIR on the subject, and a further letter from the Association to DSIR's Advisory Council advocating some action, the Association sent a personal delegation to meet with the Advisory Council in June 1917.

Although the general problem of the decay of stored food was the technical issue presented there were strong commercial motives which lay behind the action of the Cold Storage and Ice Association, in particular the growing competition from both Brazil and Argentina in the supply of chilled beef which had been encouraged by improvements in refrigeration techniques. The advantage in quality of chilled beef over frozen beef made the Association anxious to discover suitable methods which would enable chilled meat to be carried on the long voyage from the Dominions, Australia and New Zealand. Indeed during the war it was recognised that only large army orders for frozen meat had kept the Australian meat industry viable, a market which could obviously not be maintained in peace time.

In scientific terms the problem was seen in terms of a lack of adequate knowledge in the biochemistry of food decay rather than one which could be solved by existing engineering techniques. The lack of suitable facilities for research in low temperature work prompted an appeal for government assistance.

The Advisory Council delegated the issue to William Hardy, secretary to the Royal Society, and asked him to prepare a memorandum surveying the field of food preservation.[61] It was on his personal recommendations that the Advisory Council supported the establishment of a Director of Research and an organisation along the lines of the Fuel Research Board. Hardy was again invited to prepare a further report "outlining a definite method of attacking the problems in question and giving an estimate of their probable cost",[62] and following his report the proposed board was established as the Cold Storage Research Board with Hardy himself as director.

The limitations of the scheme were soon apparent, however, when Hardy, at the request of the Ministry of Food, requested permission to investigate the fitness of linseed oil for human consumption, and found that it was outside his terms of reference. As he informed the Advisory Council:

> Preservation by cold is one only of many methods of dealing with food and it has been clear to me for some time that the enquiry must be widened ... to take account of all methods and balance their relative advantages and disadvantages.[63]

In consequence the board was renamed the Food Investigation Board.

For its first half-year's work the Board was given £5,000 to meet its expenses, modest when compared with the provisions for fuel research. Under its immediate supervision a number of working committees were formed dealing with meat, fruit, fish and vegetables and engineering respectively. Early experimental facilities were rudimentary and took advantage of existing facilities. Experiments on the freezing of fish were carried out at North Shields and at an experimental and demonstration plant erected at Billingsgate. Work on the physiology of fruit at low temperatures was conducted in university laboratories at both Cambridge and Imperial College, London, and at the request of the engineering committee the National Physical Laboratory began research on heat insulation and hygrometry.

Nevertheless the Board clearly felt restricted by the existing experimental facilities available and indications of a major new initiative came in 1919 when the Advisory Council in its annual report observed that:

> We feel sure that steps will be necessary in the near future to establish a central research station where experiments on cold storage and other means of food preservation can be conducted on a scale large enough to be a guide to industry, and where scientific control can be continuously secured.[64]

The following year the Advisory Council announced that approval had been obtained to erect at Cambridge a new institute for biochemical and biophysical research at low temperatures at an estimated cost of £30,000.[65]

The new laboratory was to be attached to the university but under the control of the Board. This was in recognition of the pioneering work already under way at Cambridge carried out by Franklin Kidd and Cyril West. Indeed it has been recognised that the subsequent work of Kidd and West at the Cambridge Low Temperature Research Station, as the new laboratory became known, was crucial to the successful introduction of controlled atmospheric storage, a significant innovation in the preservation of horticultural produce.[66] Experimental work and pilot tests continued at Cambridge until 1927 when Kidd and West summarised their findings in Gas Storage of Fruit, issued as a special report of the Food Investigation Board, and identified as a milestone in the development of controlled atmospheric storage that helped draw both scientific and commercial interest.[67] The first commercial "gas" apple storage was erected near Canterbury in 1929 and thereafter a rapid expansion occurred. Similarly the work was taken up by scientists throughout the world.

The establishment of a new experimental facility, the Ditton Laboratory at East Malling, with West in charge, enabled the Food Investigation Board to sponsor large scale tests which enabled the successful commercial application to be fully worked out. By 1938 it was estimated that three million cubic feet of storage facilities using the technique were in operation.[68]

The technique of gas storage was also successfully applied to the problem which had first led to the establishment of food research, the preservation of meat.[69] On June 18, 1933 the Port Fairy, a ship of the Commonwealth and Dominion Line, landed at Southampton with a consignment of chilled beef successfully brought from New Zealand for the first time.[70] As with the preservation of fruit the commercial advantages were quickly exploited.

Early investigations into the preservation of fish were conducted, as has already been noted, in limited conditions. In 1929, however, a new laboratory, the Torrey Research Station was established in Aberdeen, to investigate problems of storage, including studies of the preservation of fish by both cold and smoking along with the fundamental aspects of fish preservation. An early success for the new laboratory was the development of a commercially successful method of brine freezing.

In the inter-war period the overall record of the work of the Food Investigation Board was clearly outstanding and resulted in a transformation of the techniques of food preservation which, by the Second World War, were an accepted and important part of commercial practice. They occurred in the context of a clear policy of opening up the domestic British market to the produce of the dominions, particularly Australia and New Zealand, for both meat and fruit.

In 1926 the imperial orientation of much of the research became more explicit with the formation of the Empire Marketing Board, established with the object of marketing Empire agricultural produce in the United Kingdom. One of the major ways it sought to facilitate this objective was through the funding of research, and a number of government research establishments were assisted from these funds and the Food Investigation Board received considerable financial assistance in this way. It first began to have some impact on the Food Investigation Board's annual expenditure in 1928 when the latter was awarded a grant of £18,500 for a new programme on fisheries research.[71] This essentially was used to establish the Torrey Research Station. In the years up until 1928 the annual gross expenditure of the Food Investigation Board was rising to around £20,000. The continuing grants from the Empire Marketing Board effectively doubled its annual expenditure in the following years. In 1929 a grant of £9,700 was made for an extension of the work of the Cambridge Laboratory, which, it can be assumed was used to set up the Ditton Laboratory.[72] In the year 1931/32 the total gross expenditure of the Food Investigation Board of £47,000 included a grant-in-aid of £30,500 from the Empire Marketing Board,[73] a grant which continued until 1935, when, following the sudden demise of the Board, the major task of maintaining the level of research into food preservation once again became the responsibility of the DSIR.

Nevertheless, the short existence of the Empire Marketing Board had a considerable impact on the development of food research within the DSIR and consolidated its role firmly in the context of imperial economic trade relations between Britain, the Colonies and Dominions.

(iii) Forest Products Research: The Forest Products Research Laboratory

The establishment of the Forest Products Research Laboratory in 1925 was another prime example of the way Britain's imperially oriented economy had a pervasive impact on the nature of the work of public research institutions set up between the two world wars. The concept of government-sponsored forestry research dates from the First World War stimulated by the immediate context of the wholesale felling of woodland for the war effort, rises in prices, and the threat of a world shortage of soft-woods. The urgent position in the immediate post-war period led directly to the creation of the Forestry Commission.

Despite moves to encourage a domestic policy of building existing stocks, Britain was still a major timber-importing country and at the end of the war it was recognised that a national policy was required for developing available timber resources throughout the British Empire. In 1920 the British Empire Forestry Conference made recommendations to various governments throughout the Empire for the organisation of research to meet the needs of growing and utilising forest crops.[74]

For Great Britain the Conference recommended setting up a central forestry research institute along with some organisation to deal with the utilisation of timber. One response was the creation of the Imperial Forestry Institute at Oxford; the second suggestion was referred to the DSIR, which had already undertaken a few sporadic timber investigations at the request of government departments. In 1921 however official permission was given for a more comprehensive organisation and a Forest Products Research Board was established to:

organise and carry on research into the utilisation of timber and other forest products:

(i) wood technology including the testing, seasoning and preservation of timber;

(ii) investigations into forest products other than timber.[75]

It has been pointed out elsewhere that the inclinations of the Forest Products Research Board were towards scientific rather than industrial research, and indeed the composition of the Board, consisting of distinguished scientists, representatives of the forestry profession, and of the Colonial Office, had no representatives from the timber trade or any from the wood using industry.[76] The Board's prejudice towards fundamental research came into question at the 1923 meeting of the British Empire Forestry Conference which although welcoming the formation of the new Board urged;

> that the scope of the Board's work be extended so that, in addition to fundamental research, it may undertake investigations leading to the application of the results of research to commercial practice ... This Conference urges that immediate steps be taken to establish in Great Britain a well-equipped Forest Products Laboratory.[77]

As Rendle notes, the Board now found itself torn by two opposing factions - the scientists, who pinned their faith on fundamental research, and the forestry representatives, who stressed the urgent necessity of testing and publicising the qualities of home-grown and Empire timbers.[78] The DSIR view was that practically oriented applied research ought to be done by a research association, although it conceded that this appeared unlikely to happen. For this reason it agreed to arrange for seasoning trials in commercial-sized kilns.

The pattern of early research under the Forest Products Research Board was the familiar expedient of using existing facilities including university departments, the National Physical Laboratory, as well as the newly established Imperial Forestry Institute. Equally familiar was the subsequent centralisation of research as the decision to go ahead with mechanical testing and large-scale seasoning investigations raised the need for special facilities required for this and other work of an engineering rather than a scientific nature.

Following the provision of accommodation and facilities by the Air Ministry in the Royal Aircraft Establishment at Farnborough, it was decided in principle to locate a central laboratory there permanently. A battery of three experimental kilns and a seasoning research laboratory were built during 1923-24 and accommodation provided for the Timber Mechanics Section and office staff. Rendle, however, considers the appointment of a first full-time Director of Forest Products Research in 1925 as marking the date from which the Forest Products Research Laboratory can be said to have functioned as an operational unit.[79] By this time a decision had been reached to make Princes Risborough, rather than Farnborough, the permanent site for the laboratory.

By 1927 the operations of the laboratory were fully established in its new location and two years later its position as the country's leading centre on scientific aspects of timber and its utilisation was consolidated by the transfer of the programme on mechanical testing at the Imperial Institute to Princes Risborough.[80]

As in the case of food research the setting up of the Empire Marketing Board had a profound impact on the work of the laboratory, facilitating a notable expansion in the years 1929 to 1939 and providing it with a distinct imperial orientation. In 1929 the Empire Marketing

Board made a capital grant of £30,000 along with annual running costs to cover the expansion of existing facilities at the Forest Products Research Laboratory, and consolidate centralisation by reconstituting outlying sections at Princes Risborough.[81]

In order to supervise the laboratory's work on Empire timbers an Empire Timbers Committee was established including representatives from the Colonial Office, the Imperial Forestry Institute, the Royal Botanic Gardens, Kew, and the Empire Marketing Board. During the period prior to the Second World War the laboratory carried out investigations on timbers from throughout the Empire and, as part of the Empire Marketing Board's publicity campaign, compiled a Handbook of Empire Timbers. The heavy programme of work on Empire timbers was in full swing when, in 1932, due to the severe trade depression, the Empire Marketing Board was dissolved and its contributions to the laboratory automatically terminated. Nevertheless the policy of imperial preference was by then deeply ingrained on the work of the laboratory and other arrangements were made for financing work for the Dominions and Colonies. Empire timbers continued to hold an important place in the laboratory programme until 1937-38 when most of the promising species had been investigated and overseas interest was diminishing.

In the period after the end of the Second World War, however, in the immediate context of the physical shortage of timber in Europe, heavy demands of reconstruction, and a shortage of dollar currency, the Laboratory was to become involved in a big new programme of investigations of Colonial timbers. This was the heyday of the Empire however, and from the mid-1950's the role of the Laboratory, in the context of the growth of other domestic institutions with interests in the field of timber research, was to become more problematic.

(iv) Building Research: The Building Research Station[82]

In the context of the formation of the Ministry of Reconstruction in 1917, the question of adequate housing provisions for the nation became a foremost political issue. The immediate demands of the war had resulted in the suspension of building and repair work, which had grave implications for post-war reconstruction, not least with respect to the political jingoism which was reflected in the slogan "Homes fit for Heroes".

The Carmichael Committee, appointed by the Ministry of Reconstruction to consider the position of the building industry after the war included in its recommendations the promotion of modern research in the relevant trades along with the application of research findings. These conclusions were complemented by similar proposals made by another committee, appointed in 1917 by the Local Government Board to consider housing problems. One consequence was that DSIR appointed a Building Materials Research Committee. In addition to these departments a number of investigations into building materials were sponsored by a Building Materials Committee of the Munitions Inventions Department.

Faced with these sporadic and fragmentary initiatives, in 1919 the DSIR submitted a memorandum to its Advisory Council pressing for a more ambitious and comprehensive scheme to be devised, backed by professional interests such as the Royal Institute of British Architects and the Society of Architects. In response, the following year a Building Research Board was set up and research facilities of a temporary nature were secured at East Acton in 1921. These moves coincided with the collapse of the post-war economic boom and in the face of intense economic retrenchment the Advisory Council made it clear that building research did not figure in its priorities and that the building research scheme was not conceived as anything more than a temporary expedient measure. The immediate result was a fall in the provisions for building research and by the end of 1924 the total number of scientific and technical staff at the disposal of the Building Research Board was less than twenty.[83] At this stage the scheme was clearly in a precarious position.

The decisive step towards the permanent establishment of building research resulted from pressure brought by the Ministry of Health, successor to the Local Government Board. A Committee on New Materials for House Construction appointed by the new Ministry found its work seriously handicapped by a lack of adequate technical knowledge in dealing with substantial problems, which had resulted from the introduction of new construction materials. Supported by the Office of Works, the Ministry of Health urged the DSIR to increase the scale of its support for such problems, in the light of the existing housing difficulties. Its response was positive and a decision to expand was taken. In addition, the choice of a site for a new building research laboratory at Garston added to the newly found permanency. From a staff of fewer than twenty in 1924, the number of permanent scientific and technical staff working on building research problems rose to forty by the end of 1925 and to seventy the following year.[84] Thus the concerted pressure from the Ministry of Health had been crucial to the firm establishment of building research as a government activity, and it was to continue to have a major impact on the activities of the newly established Building Research Station.

In its report for 1926 the Building Research Board summarised the dual role the new laboratory was expected to fulfill; firstly the cultivation of fundamental physical and chemical principles underlying the properties of building materials; and secondly to provide assistance to the immediate day-to-day problems of both building trades and government departments. With respect to the latter, indications that the laboratory would meet a need for technical inquiries were confirmed by a steady stream of requests for assistance in the period 1925 to 1939.

The value of the work of the laboratory to the responsibilities of the Ministry of Health proved well founded and was given an additional stimulus in 1935 with the beginning of a new slum clearance programme. Further assistance was provided by the Building Research Station to both the Office of Works and the Ministry of Transport. In 1935 the laboratory began a programme related to fire resistance, a topic which after the war was to become the responsibility of an autonomous laboratory. Inquiries from outside organisations for assistance with technical problems rose from 120 in 1926 to over 3,000 in 1939.[85]

In terms of work of a more fundamental nature the Building Research Station pioneered the development of a number of new areas of applied scientific and technical knowledge. In 1937, for instance, it set up the first soil mechanics laboratory in Britain and was a major influence on the development of the new discipline. As well as being a centre for research the Building Research Station acted as an important training ground with many of its staff moving into important positions in the universities and research associations. Indeed by 1939, after such precarious origins, the Building Research Station was firmly established as one of the major research centres in the country for work in technical and engineering subjects.

(v) Water Pollution: The Water Pollution Research Laboratory

Although the establishment of a central research station did not come until much later the involvement of the DSIR in aspects of water pollution began in 1923. In that year the department offered to assist the Ministry of Agriculture and Fisheries in carrying out research into the possibility of treating harmful effluents in such a way as to recover part or the whole of the costs involved.[86] In reply the Ministry admitted that one of its most urgent problems related to the pollution produced by the effluents from coke oven plants. Although there were doubts concerning the ability of the DSIR to intervene effectively, preliminary talks were held between representatives of the Ministry of Health, the Ministry of Agriculture and Fisheries, and the DSIR, and the Ministry of Health agreed to produce a memorandum on research in connection with methods of reducing the toxicity of the effluents from coke oven plants. This was then expanded by the DSIR and submitted to its advisory Council.

At its meeting on May 21, 1924, however, the Advisory Council rejected the proposals which included plans for the DSIR to carry out experiments at a coke oven works on the grounds that "the work would not involve scientific research of a nature for which the Department should be responsible".[87] Rather that the Ministry of Agriculture and Fisheries and the Ministry of Health should be informed that "any comprehensive scheme put forward by them for general research on the purification of water and of industrial effluents" would be seriously considered.[88]

In 1927 such a scheme was set up with the appointment of the Water Pollution Research Board. Much of its early considerations centred on the problem of sugar beet effluents, supporting the development of a method of biological filtration at Rothamsted.[89] Other early work dealt with the biological and chemical aspects of sewerage effluent and experimental work on plumb-solvency carried out at the DSIR's Chemical Research Laboratory.[90] The Board did not employ permanent staff, however, and sponsored research in various institutions, before a central laboratory, the Water Pollution Laboratory, was finally established in 1938.

(vi) Radio Research: The Radio Research Station

The establishment of a Radio Research Board in 1919 to co-ordinate government-sponsored research on wireless telegraphy reflected the extent to which an interest in the subject had developed in various government departments including the Admiralty, the Air Ministry, the War Office, the DSIR, and also the Post Office. The Board, itself, had no executive functions and was primarily conceived as a convenient channel by which the results of research in pure physics, undertaken at universities and other institutions, could be made accessible to those working on applications in various government research establishments.

Sub-committees of the Radio Research Board were set up to review various aspects including "wireless waves", directional wireless, and thermionic valves, including the physical problems associated with design and manufacture. In addition the Board sponsored some general research including an extensive programme at the National Physical Laboratory on measurement and detection.

It was primarily on the recommendations of another of its sub-committees, the Atmospherics Committee, that an arrangement was made for an extensive investigation into the origins and fundamental nature of "atmospherics" at the Aldershot Wireless Station of the Meteorological Office.[91] Soon afterwards the Aldershot group became the Radio Research Station under the direction of Robert Watson-Watt, and following a request from the War Office for the return of the premises in use the laboratory was moved to a new location at Slough.

Work at the Radio Research Station in the 1920's included the development of a cathode-ray direction finder, studies of the ionosphere (a word originally suggested by the Radio Research Station), and studies of wave propagation, including the direction finding properties of short waves. Work performed at the Radio Research Station provided a fundamental basis for the later development of radar. Its superintendent, Watson-Watt, moved to the new laboratory at Bawdsey in 1936, where crucial developments in radar techniques were developed, and which became the basis for the Telecommunications Research Laboratory during the Second World War. The Radio Research Station meanwhile had been reconstituted as part of a new Radio Department at the National Physical Laboratory. At the end of the Second World War it was again to be reorganised as an autonomous research establishment of the DSIR.

(vii) <u>Chemical Research: The Chemical Research Laboratory</u>

The major initiative leading to the setting up of a Chemical Research Laboratory came from Sir Richard Threlfall. In July 1922 he submitted a memorandum to the Advisory Council pointing to the need for an improvement in facilities available for research in applied chemical problems.[92] He particularly attempted to draw attention to the lack of interest taken by the military and other government departments relative to the efforts which were devoted to physics and engineering.

The Advisory Council's response was to appoint a committee to consider the proposals and as a result of its recommendations a new Chemical Research Laboratory was opened in 1925 at Teddington. Prior to its establishment chemical problems not falling within the scope of existing research stations had been undertaken under the auspices of the Chemical Co-ordinating Board, which delegated investigations to a variety of institutions. Following the abolition of the Co-ordinating Boards in 1927 the Advisory Council appointed a Chemical Research Board to supervise research.

Unlike most of the other DSIR laboratories, the Chemical Research Laboratory never had a central raison d'etre and became a location for a pot-pourri of programmes, both centrally generated by the Chemical Research Board, as well as in response to the requests of other agencies. Work was undertaken in a variety of fields including high pressure gas reactions, synthetic resins, and low temperature distillation of coal for dyestuffs and intermediate products. Without commenting on the quality of the laboratory's work it would be fair to say that it struggled to establish a recognisable identity and it remained the most modest of the DSIR laboratory programmes.

(viii) Road Research: The Road Research Laboratory.

Road research represents the first major area of research which the DSIR "inherited" from another government department. In 1930 the Ministry of Transport established a small experimental station for research into road engineering, soil mechanics, and bituminous and concrete technology. At the same time, however, related investigations were being undertaken at both the Building Research Station and the National Physical Laboratory and in 1932 a report from the Select Committee on Estimates expressed the view that the research work should be centralised and concentrated with other work under the DSIR.[93]

In May 1933 the DSIR duly assumed responsibility for the direction and supervision of road research appointing a Road Research Board along the lines of other research boards and naming the new organisation the Road Research Laboratory. As the Advisory Council noted at the time:

> We assume that the object of the Government in bringing about this transfer was to ensure that the work should be carried out in close association with parallel work in the various laboratories of the Department, thus securing fully the economies to be obtained by co-ordination of effort and experience.[94]

Although engineering problems formed the focus for the laboratory's work in the years prior to the Second World War, after the war it was to become more involved in such general transport issues as road safety programmes.

The National Laboratories: Science, Industry and Imperial Preference

From the outline histories presented in the previous section a number of generalisations can be made. In terms of the origins of the various programmes of research sponsored by the DSIR, the research establishments were set up in response to two dominant external factors; the post-First World War development of social welfare programmes in such areas as housing and health, and the consolidation of an imperial economy along with its strategic political and economic implications.

A number of programmes were initially adopted by the DSIR which had a clear relationship to the specific problems of wartime yet had more long-term strategic overtones bearing upon the economic and political factors likely to prevail in the post-war period; indeed this was the context for the establishment of the DSIR itself. Thus, the provisions for both fuel and food research fall into this category. Concern with security of supply, which was implicitly implied, was also influential in developing a programme of forest products research which later got underway.

The spirit of reconstruction and national renewal, in addition provided a political environment conducive to the instigation of social welfare programmes, highlighted by the post-war public building programmes and the setting up of a Ministry of Health. Such initiatives had a significant impact on the establishment and development of new government laboratories. Nevertheless, once organisations were set up to pursue these various research programmes, the initiative for developing research rested primarily with scientists, within the constraints of available finance.

The legitimation for public expenditure on research rested on the belief that the results of investigations would have "public benefit" for the nation as a whole, and that national progress in economic and social terms was dependent on the elucidation of the fundamental laws and principles governing natural processes. Systematic patronage by the State, however, did not, in itself imply a planned approach. Research discoveries, were seen by a majority as largely fortuitous, although they would, nevertheless, be encouraged by the active and systematic patronage of research. As a report from a government committee, considering the adequacy of facilities for public research noted in 1932, the object of the scientist was;

> .... to increase the body of systematic knowledge in a certain defined field of phenomena .... the more he is animated by the spirit of disinterested scientific curiosity, the more likely he is to hit upon fruitful discoveries. The recognition of this truth is indeed the first principle of the wise direction of scientific research.[95]

This philosophy extended to the laboratories of the DSIR.

Another essential feature which characterised the work of the public laboratories was the particular emphasis on systematic data accumulation and dissemination. This emphasis on empirical procedures and inductive methods was an important factor in the adoption and diffusion of the national laboratory as the recognised institutional vehicle for the public patronage of applied research. In this way a centralised institution was, in part at least, the natural result of data accumulation which depended on either large scale testing facilities, or an extensive system of recording observations over a continuous period of time. In addition, a recognised national, and relatively independent centre, provided an authoritative source for technical information and services. Theoretically the existence of a research programme in a recognised and authoritative national centre increased the visibility of research and encouraged the utilisation of research results.

Centralised research also provided, in principle, advantages in organisational terms for the control of research and expenditure. In Britain these were, at times of economic retrenchment such as recurred in the inter-war period, particularly sensitive issues. The co-ordination of research was an issue which featured strongly in the 1920's, with possible duplication of research effort wasting resources and reducing administrative efficiency. In this context the powerful role of the Treasury and the economic stringencies of the period provided a further advantage of centralisation. Finally it is noticeable that in certain cases professional associations provided important support for national laboratories. A national centre for research provided prestige for aspiring professional groups, particularly scientists and technologists working in fields of applied science denied the prestige of pure science.

These comments suggest that the national laboratory as an institution emerged in response to specific circumstances and demands, the form being determined through an interpretation of function. An argument which requires some thought, however, is that the national laboratories in Britain were merely imitative responses either directly copying foreign initiatives or assimilating into the government context an organisational form which was becoming popular in industry, namely the industrial research laboratory, ostensibly divorced from the day to day needs of production, and devoted to strategic research. Certainly in the case of the National Physical Laboratory the example provided by the Physikalisch-Technische Reichsanstalt was used frequently by those arguing for a similar national laboratory in Britain.

It is important, however, to distinguish real motives and needs from the polemics used by scientists in the debate preceding the setting up of the National Physical Laboratory. The argument used, that a major industrial competitor had an institution which would, it was claimed, benefit industry, while Britain was without such a laboratory, had obvious political advantages. It does not, however, mean that this, in itself, was a major motivation for scientists arguing for a national physical laboratory. Indeed, there were more professional reasons encouraging scientists' demands. In terms of the other national laboratories established after the First World War, the example of a similar overseas initiative was never prevalent, although similar arguments were to be utilised later by the supporters of the Hydraulics Research Station set up after World War Two.

Similarly, although the industrial research laboratory was firmly established as a recognised institution, particularly in the United States and in Germany, before the beginning of public research laboratories in Britain, it was never referred to in discussions surrounding the establishment of particular government establishments. In Britain, particularly, both the industrial laboratory and the public laboratory began to exist in significant numbers from the end of the First World War.

The DSIR, itself, saw an important aspect of its own role, in encouraging private industry to undertake more research. Although the department's own industrial support was primarily carried out through the Research Associations, the research laboratories under the DSIR were also seen to have an important role in this context. In its annual reports the Advisory Council for Scientific and Industrial Research repeatedly emphasised the need to support industry and to encourage private firms to increase their own research commitments by demonstrating the rewards of systematic research. As it declared in 1931:

> The justification of all the expenditure on industrial research carried out in the Department's own laboratories must rest in the essentially practical aim of the work, and their primary purpose must be to secure the application of scientific knowledge in industry.[96]

Concentrating research in national centres was seen as one way to encourage industry to make contact and to apply the results of public research. During the recessionary years of the 1920's the Advisory Council repeatedly called attention to raising the efficiency of production through the application of science as the only escape from national economic difficulties. This was reflected in the motives behind many of the programmes of research undertaken by individual DSIR laboratories, with an emphasis on economy, whether it was in the use of building materials, road materials, or exploiting the resources of the colonies and dominions to reduce the cost of raw materials and foodstuffs.

It is difficult to assess the degree to which close contact with industry was actually maintained by the government laboratories in this (or indeed any other) period when links often occurred at a casual and informal level, although both the Building Research Station and the National Physical Laboratory had close links in terms of the services they provided. Where public research led directly to changes in commercial practice such links were clear however. A particular example was the introduction of effluent controls in beet and milk processing plants. Close co-operation between workers under the Water Pollution

Research Board and individual firms led to the development of filtration technology which combined effectiveness with economy.[97]

It has been noted elsewhere that most food firms used the Low Temperature Research Station for scientific advice.[98] Commercial improvements also came from the work of both the Torrey Research Station and the Ditton Laboratory with respect to new methods of preserving meat, fish, fruit and vegetables. In all these cases, however, the problems were well defined and solutions recognisable. The economic context was clear and the users of the results were a well defined group.

It is, perhaps, notable that the Food Investigation Board was the only major area of government research where the initiative for setting up the scheme came from commercial interests, who were able to define the problems. The technology developed by the work sponsored by the Board, gas cold storage, was in engineering terms relatively simple and the demand was clear. What the laboratories at Cambridge and East Malling achieved with modest resources was to develop the fundamental principles governing food preservation necessary for the optimum design and operation of the technology.

In other areas of industrial support the National Physical Laboratory had a significant role. As the national centre for calibration and standards it provided an important contribution to the national technical and industrial infrastructure. Its ship testing facilities were extensively used by ship designers. Nevertheless in other aspects of its work it is extremely difficult to establish the value of the laboratory's contribution to industrial progress. In scientific terms the laboratory was clearly an outstanding centre for research. Between 1918 and 1939 a total of 14 Fellows of the Royal Society could be counted among its staff.[99] Indeed in 1939 three Fellows were present in one department alone, physics.[100] In two areas at least, metallurgy and aerodynamics the laboratory in its first forty years of existence made outstanding contributions to fundamental knowledge in subjects of obvious practical importance. It pioneered the industrial application of X-ray analysis.

It is clear, however, that throughout the inter-war period the conflicting demands of short-term research and more long-term fundamental research provided a continual tension at the National Physical Laboratory. Ultimately the latter type of research would begin to dominate its work. In the inter-war period the gap between fundamental studies and practical application was never as pronounced as it would become after the Second World War. In addition the problems of relating changes in fundamental knowledge to the improvement of practical industrial methods was greatly underestimated. Practical technique was clearly well in advance of fundamental knowledge, in for instance metallurgy where, despite great advances in understanding, the improvement of metallurgical practice continued to depend on empirical technological advance.

In terms of repayment work for industrial firms, direct financial renumeration was insignificant for most of the research stations apart from the calibration work and ship testing undertaken by the National Physical Laboratory (see table 4). Fees to industry were, however, often deliberately kept low, below the economic cost, to attract industrial interest. In more indirect ways the Building Research Station supported the building trades through the production of specifications for both materials and structures.

Despite these achievements many industrialists remained deeply suspicious or even ignorant of the government stations. In 1920, C.E. Kenneth Mees, the English director of research at Kodak, voiced a familiar complaint when he claimed that there was a tendency for research done under government control to be too academic, needlessly expensive and insufficiently in contact with the practical conditions of industrial life.[101] For him, and many other industrialists the arguments against government organisation of research equated with those against any direct control of industry by the State.[102] Similar criticisms remained in common usage. In 1943, for instance Sir Joseph Barcroft wrote to Sir Edward Appleton, Secretary to the DSIR recounting a conversation he had had with some senior industrialists from the firms Chivers, Glaxo and Lever Brothers. On inquiring how the DSIR impressed them he had been met with "one case of mild hostility .... the DSIR is unacceptable to the trade", another viewed the department with suspicion and a third criticised its remoteness. As Barcroft observed: "They evidently were just unimpressed".[103] Such hostility and indifference illustrates the problems the national research stations experienced in encouraging co-operative relations with industry.

Despite these concerns with domestic industry, as the outline histories demonstrate, the imperial context had a profound impact on the pattern of research. In the period after the First World War, and particularly during the recessionary years of the 1920's there was popular support for developing the resources of the Empire as a viable economic unit to counter foreign competition and provide cheap sources of food and raw materials. Research was seen as important to these aims.

In 1918, for instance, Sir Hugo Hirst, chairman of G.E.C., informed the company's shareholders that:

> If the electrical industry is to rise to the level expected of it, and not to drift back again to a state of industrial dependence, it must make itself independent of foreign importation and develop all its requirements from raw materials and resources which the Empire places at its disposal; in that direction opportunities will be afforded for scientific research and invention.[104]

In the 1920's this spirit was reflected in many government initiatives designed to encourage scientific support for imperial economic development.[105] Both the Forest Products Research Laboratory and the laboratories of the Food Investigation Board were established in the context of imperial trade relationships. Both benefited considerably by the creation of the Empire Marketing Board which provided funds for the establishment of two public laboratories, the Torrey Research Station and the Ditton Laboratory. In turn the British model for the support of research, the DSIR, was replicated throughout the dominions including India, Australia, New Zealand and South Africa.

Despite the unprecedented level of State support for scientific research after the First World War, the overall development of government science during the inter-war years remained slow and uneven. In the early 1920's the DSIR suffered considerably from the implementation of public expenditure cuts, actions which temporarily threatened the survival of a number of research programmes. Nevertheless, reviewing his time as Secretary to the DSIR in this period, Sir Henry Tizard later observed that the Treasury was adopting a more enlightened attitude towards research in the DSIR.[106] If this indeed was the case it did not prevent the DSIR, and indirectly the laboratories, coming under continuing pressure during the depression years to curtail expenditure. Despite the economic situation, research in certain sectors of private industry flourished while government programmes fell victim to retrenchment.[107] In the year 1927-28, for instance, many scientists employed in chemical work in public laboratories resigned to take advantage of expanding opportunities in the chemical industries.[108] Pay for public scientists remained low, deliberately so to encourage industry to employ more scientists.[109] Uneven development in individual laboratories was the inevitable result.

In the early 1930's the Government again curtailed expenditure on scientific activities as part of the attempt to balance the national budget. As the economy gradually moved into recovery, however, expenditure on research began to rise. Between 1932 and 1939 the gross expenditure of the DSIR rose by 34%. At the outbreak of the Second World War the department was firmly established and the laboratories under its patronage were recognised national institutions. At the same time the excitement surrounding their establishment had gone and already some were beginning to appear rather conservative in some of their activities. In the late 1930's, for instance W.L. (later Sir Lawrence) Bragg, in his short period as director of the National Physical Laboratory, is said to have found the work disappointing. As his biographer has noted: "Although some of the research was flourishing, many things were being done that had long since ceased to be useful."[110]

In the context of the Second World War a new generation of public laboratories was to arise, notably those concerned with the development of radar and the release of atomic energy, heralding a tremendous expansion in the post-war years in terms of the resources devoted to both the nuclear and defence fields. Massive new establishments were to be built up in these respective fields dwarfing and overshadowing the research facilities of the DSIR. The latter, nevertheless, benefited considerably from the status which the events of the war bestowed upon scientific research.

Epilogue: The Second World War

Much has already been written concerning the contribution of both scientists and science to the war effort;[111] more than enough to make it unnecessary to comment in any great detail beyond outlining the general way in which science was applied with such success, that it was guaranteed a prominent place in post-war reconstruction plans.

Although scientists had often historically been utilised to good effect during wars, the scale and impact of science during the Second World War was unprecedented as science and scientists were effectively mobilised to develop new weapons, to advise on the deployment of weapons, to advise on the technical aspects of military operations, as well as to deploy scientific skills to the strategic needs in civilian needs such as food policy. It has been noted elsewhere, for instance, that during the Normandy invasion scientists were intimately involved at every level in the planning and execution of the mission.[112]

In Britain the development of radar particularly caught the imagination, a project which, alongside the atomic weapons programme, highlighted the power inherent in the application of the results of basic research associated with a concentration of resources beyond the capacity of individual firms and industries. One feature of both these major projects was the way huge research teams were built up utilising scientists drawn in from university departments. The small team established at Bawdsey under Robert Watson-Watt in 1936 to develop radar was the seed from which grew the Telecommunications Research Establishment, an extensive research complex based finally at Malvern.

Similarly other military establishments such as the Royal Aircraft Establishment, the Admiralty Signals Establishment and the Admiralty Research Establishment expanded to a scale which dwarfed the civil stations of the DSIR. The pre-war existence of such military establishments made it a natural development that they would become the nucleus of the war effort.[113] It has been estimated that the scientific manpower devoted by the military establishments to radar development involved perhaps one third of all the appropriate physicists in the country.[114]

In the public view the development of radar alongside the other major technological achievements of the war, the atomic bomb and penicillin, appeared first and foremost as scientific achievements. The conclusion to be drawn from this was that only through significant State involvement could such technologies be developed and the necessary research and development maintained where this was of a long term nature. As Sir Robert Cockburn notes:

> .... the myth of big science had been born and large research establishments were built up to maintain the momentum of discovery.[115]

Thus as the military application of science and technology caught the public imagination, in the debates from 1943 onwards on post-war development a considerable emphasis was placed on the role of science in social and economic progress.[116]

The DSIR was conscious of the need to build on this wave of enthusiasm and began a campaign to push the idea of "research mindedness". The original "spirit of research in industry" idea was credited to Sir Raymond Streat, a member of the Advisory Council, and a friend of Lord Riverdale, the Advisory Council's chairman.[117] One immediate consequence was a conference arranged jointly by the DSIR and the Manchester Chamber of Commerce.[118] Concurrently the Federation of British Industries began a similar campaign to urge their members to expand their research efforts.[119]

In such a context the civil research establishments of the DSIR appeared likely to benefit in the atmosphere of post-war euphoria for scientific research. During the war they had played a subordinate role to the military establishments. At the outbreak of the war, a major consideration had been the optimum deployment of DSIR personnel. While it was immediately apparent that the military establishments would expand significantly it was decided to maintain the civil units of the DSIR and build up the military laboratories with university scientists.[120] This decision is said to have rested on two influential factors; firstly a belief that modern scientific work was largely team work and secondly that the civil stations had valuable buildings and testing equipment fixed to their existing sites.[121] Retained as working units the DSIR establishments rapidly switched to short term problems related to the war effort. Details of the wartime work of the DSIR laboratories are available elsewhere and only a few aspects will be mentioned here.[122]

The Road Research Laboratory, with the assistance of the Building Research Station, became the centre for the study of civil engineering problems associated with civil defence. Both these laboratories along with the Forest Products Research Laboratory were active in the study of the effects of explosions on structures, work which was related to both civilian and military needs. At the Building Research Station further studies were undertaken on the economic use of materials and the substitution of scarce resources.

The Food Investigation Organisation became completely devoted to support for the policies of the Ministry of Food and the work of the Commissariat Branches of the armed forces. Part of this work included the development of dehydrated foodstuffs. Many novel uses for the large scale testing facilities were found. The massive cold chamber at the Ditton Laboratory, for instance, was used to discover how barrage balloons might behave in the cold upper atmosphere.

The countless problems arising from a state of war involved the civil laboratories in diverse programmes of work. The expertise of the Water Pollution Research Laboratory was applied to the critical problem of effluents from ordnance factories and the difficulties of waste disposal at large military camps. Both the National Physical Laboratory and the Fuel Research Station gave direct support to military requirements. The latter improved incendiary mixtures, for instance, while at Teddington the resources of the Ship Division were used for the design and testing of the "Mulberry Harbour" used in the Normandy invasion.

The work which all the DSIR laboratories undertook during the war was largely in response to the requests from other agencies, usually short term in nature, involving a fairly routine utilisation of the expertise or facilities of individual laboratories. In this way the events of the war undoubtedly strengthened the contacts between the laboratories and other government departments. Payments to the DSIR from other departments rose from £91,000 in 1938/39 to a peak of £428,000 in 1943/44, declining to £162,000 in 1946/47 and thereafter showing a steady increase.[123]

Ironically, however, the Second World War was a water-shed for co-operation between civilian and military research. The expansion of military research facilities, and particularly provision for basic research in the post-war years eliminated the necessity for the continued use of DSIR's facilities and thereby emphasised the separation between the defence and civil research sectors. This was particularly true for the National Physical Laboratory, which, during the inter-war years had had a close relationship with the Aeronautical Research Committee, a relationship which extended to work in the aeronautical, engineering and metallurgical divisions of the laboratory. Although the laboratory continued to undertake aeronautical work in the post-war period and in the years of re-armament undertood a considerable amount of short-term work for the military, the work of the laboratory no longer had any strategic importance to military interests. Aerodynamic work at the National Physical Laboratory was eventually transferred to the Royal Aircraft Establishment.

In contrast the military establishments benefited considerably from the war, from the influx of talented university scholars, as well as from the close involvement of scientists with operational requirements. Such characteristics were particularly prevalent at the Telecommunications Research Establishment where a close collaboration between scientists and military personnel developed. The conditions of wartime also provided encouragement for closer co-operation between industry and the military establishments which was maintained in peacetime. Such a close interaction between the public research establishments, users and industry, did not develop in the DSIR laboratories to the same degree.

The war, nevertheless, consolidated, significantly, the position of the civil research laboratories. Although the increase in laboratory expenditures during the war can be mainly attributed to an increased emphasis on development and testing work, expenditure in each of the civil laboratories continued to increase after the end of the war. The most rapid expansion came at the Road Research Laboratory where gross expenditure rose from £41,000 in 1939/40 to £178,000 in 1947/8.[124] In addition, during and after the war a number of new laboratories came into existence under the auspices of the DSIR, as a period of twenty-five years of steady expansion of central research facilities began.

CHAPTER FIVE

Expansion and Introspection 1945-1964

The Second World War military successes resulted in a considerable expansion of public resources devoted to science and technology which did not falter until the late 1960's. By 1961 the scientific civil service, with a complement of over 15,000 was nearly fifteen times its equivalent strength in 1931.[1] Whereas the total strength of government scientific establishments totalled 8,300 in 1936, by 1945 this figure had risen to 32,500, and ten years later stood at 72,000.[2] As R.V. Jones has pointed out this massive increase in strength, predominantly in the military and nuclear fields, had been achieved at the expense of all other fields of scientific occupation and had occurred almost entirely in mathematics, physics, chemistry and engineering.[3]

Certain individual establishments had grown to unprecedented levels of manpower. By 1960 the Royal Aircraft Establishment had a total scientific and technical professional strength of 1,505; Harwell, the main research facility of the Atomic Energy Authority, had a staff of 1,600 in the same category.[4] In the period under consideration in the present chapter the Admiralty Signals Establishment developed into an organisation with a total staff of 4,700.[5] The major defence and nuclear laboratories had the prestige, high salaries, and the possibilities for pursuing pure research, which attracted many of the best qualified scientists in the country to the potential detriment of universities, industry and probably the less glamorous laboratories of the DSIR. Nevertheless, other government departments and agencies mirrored this steady expansion and, indeed, the DSIR was probably the fastest growing government department in terms of its gross expenditure.[6] Although much of this growth reflected a rapid increase in grants to universities and colleges, the research establishments of the department were steadily expanded and new laboratories came into existence.

A particular feature which had its origins in war-time experience was further moves to centralise scientific advice in the post-war period. During the war a Scientific Advisory Committee to the War Cabinet had been set up,[7] and although it did not contribute to any major wartime developments, the general value to the war effort of scientific advice was recognised. This was reflected in the recommendations of the post-war Barlow Committee which led directly to the establishment of a central Advisory Council on Scientific Policy, (ACSP), complemented by a Defence Research Policy Committee in the military sphere, along with the advice that scientific advisors should be appointed to all government departments.[8]

The ACSP was in existence until 1964 and failed to have any notable impact at the centre of decision making, a view confirmed by Lord Zuckerman, deputy chairman of the ACSP throughout its existence.[9] Its failure was due in part to its inability to break the rigid fastness of individual government departments. Even in individual departments Zuckerman considers that scientists contributed little, if anything, to central policies and that "the job of the scientist was to back up departmental policy, once this was decided".[10]

After 1945, however, several departments began to undertake research virtually for the first time. As Varcoe has noted elsewhere, by the opening years of the post-war period it was apparent that this assumption by executive departments of a more positive role in the organisation and direction of research was undermining the assumed pre-war relationship between government users of research and the "researching" department, the DSIR.[11] Lines of demarcation became confused and the ACSP was unable to provide the central direction which might have clarified the division of responsibility and assisted in the allocation of scientific resources not only between government departments but in the different sectors of society utilising scientists.

With such uncertainty relating to the precise role of the DSIR, its expansion and the growth of public funds devoted to scientific research in general placed an immediate stress on existing institutions heralding a period of intense introspection and re-examination of the role and function of the DSIR's research institutions. Initially this resulted from the needs of long-term departmental planned expansion. Gradually, however, it became part of a much wider mood of dissatisfaction with the organisation and management of the public research effort. In this period the research establishments of the DSIR became subject to what was to become a long running saga of examination and review. The perception of the function of the laboratories began to undergo some modification, from one in which the production of new basic scientific knowledge was paramount, to an increasing emphasis on more narrowly defined projects designed to meet short term needs. For a number of the research stations this implied a movement in the balance of resources away from basic research to more applied work and experimental development.

Perhaps the most important factor which considerably increased concern over the balance of scientific resources, was the dramatic increase in the national expenditure devoted to science and technology, at a time when this was seen as crucial to Britain's ability to retain economic and political power, in a period which saw conclusive shifts in Britain's trading relationships with the rest of the world. Between 1956/7 and 1962/3 national expenditure on research in science and technology rose from £350 m. to £700 m.[12]; whereas in 1955/6 total national research and development expenditure was 1.8% of GNP, by 1958/9 this had risen to 2.35%.[13] Although the largest increase came in the non-governmental sector the public sector continued to dominate the national research and development effort. In 1955/56 around 75% of all research and development expenditure came from government sources with a particular concentration in nuclear and aerospace research.[14]

The problems being generated through internal expansion were put sharply into focus by a mounting public interest in the contribution that science and particularly technology could play in national life and its emergence as a central political issue in the 1960's. Sponsorship of research and development became closely linked to more immediate demands of economic development.

In tandem a more sophisticated view of the relationship between science, technology and industrial innovation began to emerge rejecting more naive views of any direct relationship between spending on research and development, and economic growth, and emphasising the need to relate research expenditure to a more precise knowledge of industrial needs. Thus, in 1959 the Economics Committee of the DSIR, set up in 1956, began a series of detailed studies of the research requirements of several important national industries beginning with the machine tool industry.[15]

In the political and economic context of the period it was inevitable that the functions of the DSIR and its research institutions would come under closer scrutiny than hitherto. The department itself, and most of the research establishments under its control, had origins in a period when Britain had major imperial responsibilities. As was indicated in the previous chapter, laboratories such as the Low Temperature Research Station, the Ditton Laboratory, and the Forest Products Research Laboratory were closely involved in the exploitation of the resources of the Empire. The end of the First World War had consolidated Britain's imperial interests. In contrast the Second World War marked the beginning of Britain's disengagement from imperial responsibilities. By 1960 Britain was looking more towards Europe for economic stability.

In 1955, Alexander King, at the time a member of the DSIR headquarters' staff summarised the social context for his department's role as follows:

> As a densely populated country we have to import nearly half our food. We lack most raw materials other than coal, and we lost most of our foreign investments during the war; consequently our invisible assets have shrunk. We have lost, and are losing, many of our markets for traditional exports because of the general development of secondary industries in countries previously existing on an agricultural economy and which are now making the kind of goods we formerly supplied to them.[16]

As he further pointed out, the one resource Britain has in plenty was "a huge potential of scientific and managerial skills".[17] Thus, the argument followed, it was imperative to increase the rate at which technical and scientific ideas were introduced into industry, to raise productivity in traditional industries in the face of powerful overseas competition, and introduce new products based on technological breakthroughs, in order to maintain Britain's economic position in the world economy.[18] The focus of the DSIR during the 1950's, in consequence, became adjusted towards the more immediate technological requirements of domestic manufacturing industries.

One important result of this attention to domestic industrial problems was a distinct change in attitudes towards selective intervention in industry by Government. Throughout its early history the DSIR saw the role of its establishments as supporting industry as a whole, making its research results and services freely available without discrimination between firms. Indeed the possibility that an individual firm might derive monopoly gains from research financed in the central research stations was frowned upon, and sponsored research carried out for the exclusive benefit of an individual firm was not general DSIR policy. Any deviation from this principle was against the entrenched tradition that public research, in the civil field at least, was public knowledge and the general belief that facilities supported at public expense, for the "national interest", should not produce discriminatory profits for industrial firms. Thus in 1954, Sir Henry Tizard, a former Secretary to the DSIR asserted that:

> It would not be in accord with general policy for Government organisations to accept the responsibility of research and development for particular firms unless there was some very special reason for doing so.[19]

Similarly in 1957, C.H. Cawley, of DSIR headquarters, in evidence to the Parliamentary Select Committee on Estimates declared that the terms under which the research laboratories were prepared to undertake contract work sponsored by industry were such that the results of the work would belong to the DSIR.[20] Indeed, Sir Harry Melville, Secretary to the DSIR, told the committee:

> I might emphasise .... that in the general formulation of our programmes we do not try to do specific problems which might be of interest to particular industries, but more general problems.[21]

Nevertheless, the setting up of the National Research Development Corporation in 1948, charged with the duty of exploiting patentable results from publicly-funded research, had already established the principle of discrimination through the licensing of patents. Indeed its origins reflected the pressures which had surrounded the problems of exploiting the research from public laboratories.[22] Even so, the Corporation had been conscious of pursuing a policy of limited discrimination in its early years which attempted to strike a balance between maximising the financial returns to licensed inventions and attempting to avoid undue monopoly profits accruing to individual firms due to limited licensing. Reviewing the evidence on this issue the Estimates Committee concluded that the DSIR should consider individual approaches to firms and a move away from its principle of general publication of research results.[23] It was indicative of such a change in attitudes within the DSIR that when the new Warren Spring Laboratory was set up in 1959 its terms of reference included the capability of undertaking repayment work for industrial firms.[24]

DSIR and the post-war development of research establishments

During the closing stages of the Second World War special attention was given in the DSIR to what its Advisory Council saw as the "fuller place which it was expected the Department would have to play in post-war affairs".[25] Such confidence was firmly based on war-time experience which had demonstrated the vast scope for the application of science to the solution of national problems. The research laboratories had demonstrated that practical problems could be solved by applying scientific expertise based on the pursuit of fundamental research.

The war had, nevertheless, resulted in the suspension of basic research and post-war developments envisaged by the DSIR combined an emphasis on building up once again programmes of basic research with the need to bring the results of such work to bear on practical problems. A Committee on Post-war Development, appointed by the Advisory Council under the chairmanship of Sir Frank Smith supported the expansion of research activities in both new directions such as mechanical engineering as well as in existing programmes. The Committee also indicated the need to assist in the application of science to small firms with particular emphasis on the dissemination of information.[26]

The Research Boards of the DSIR each put forward ambitious plans for expansion, proposals on the whole endorsed by the Advisory Council on the advice of various committees appointed to survey the post-war plans put forward by individual boards. In building research, for instance, the Advisory Council, agreed with the recommendations of the Building Research Board "for a very substantial extension of the resources and scale of working" and advocated a 50% increase in the staff of the Building Research Station.[27] Similarly it agreed to an increase in the complement of the Fuel Research Station from 300 to 500.[28]

Table 5 indicates the extent of the eventual expansion of the DSIR laboratories. In 1939 the gross expenditure of the DSIR had amounted to £682,000; by 1945 this had risen to £913,000 and to £2.7 m. three years later.[29] The latter figures were, however, influenced by the sharp post-war inflation. Trends in staff provide a more accurate indication of growth. The total staff level of the DSIR rose from 2,153 in 1939 to 2,772 in 1945, and to 3090 in 1948.[30] These figures disguise, however, a significant investment in new capital facilities in the post-war period, in new major laboratories as well as improving the facilities at existing laboratories.

Some of the laboratories began to work in new areas of research. The National Physical Laboratory, for instance began a large programme to continue work pioneered during the war on computer development. The Road Research Laboratory became extensively involved in investigations concerned with road safety, as the work of the station began to move towards considering the whole system of road transport rather than its more limited pre-war emphasis on the engineering problems of road construction. The Building Research Station extended its work on advisory and support services for other government departments regarding building structures. Its position was particularly consolidated in 1950 when the Chief Scientific Advisor's Division of the Ministry of Works was transferred to the DSIR. The immediate impact was to provide a huge increase in the resources devoted to building research and services by the DSIR from £288,000 in 1949/50 to £525,000 for the following year.[31] It also had the effect of shifting the emphasis of the station's work, as much of the Ministry of Works' research programme had involved considering the economic, sociological

TABLE 5

Changes in Scientific Staff* in D.S.I.R. Research Establishments**

1955-1965

Year	National Physical Laboratory	National Engineering Laboratory	Other	Total
1955	151	40	200	391
1956	149	46	205	400
1957	158	46	209	413
1958	160	47	240	447
1959	163	50	255	468
1960	170	51	253	474
1961	191	59	258	508
1962	201	69	274	544
1963	213	78	293	584
1964	236	78	292	606
1965	236	88	295	619

* Scientific Officer class.

** Figures are for 9 laboratories: National Physical Laboratory, National Engineering Laboratory, Building Research Station, Fire Research Station, Hydraulics Research Station, National Chemical Laboratory, Torrey Research Station, Water Pollution Research Laboratory, Forest Products Research Laboratory.

Source: A.V. Cohen and L.N. Ivins, The Sophistication Factor in Science Expenditure (London, 1967).

and productive aspects of the building industry.

Despite the immediate optimism for the role of the DSIR in the post-war years, its plans were soon threatened by the economic crisis of 1951 and the shift of resources towards rearmament. In its report for 1950/51 the Advisory Council expressed its "grave concern" over the delay in implementing plans for development.[32] Of particular concern was the delay in the capital building programme affecting the expansion of two new laboratories, the Mechanical Engineering Research Laboratory and the Hydraulics Research Station. Reductions in non-industrial staff forced on the DSIR were on the whole borne by headquarters staff but also fell heavily on the building research programme.[33]

The immediate impact of the enforced economies and delays highlighted two important and related issues. Firstly it emphasised the need for more continuity in policy, and to this end the Advisory Council pleaded for long-term planning on the basis of "reasonably firm budgeting expectations for several years ahead";[34] and secondly it raised the problems involved in reviewing the relation between the scientific needs of the DSIR and the resources available, and establishing priorities for research.

Throughout the inter-war period the growth of the DSIR had been constrained by the uncertainties and the inflexibility of annual budgeting. Indeed, as Varcoe has noted, the neglect of policy implicit in the separation of administrative responsibility from responsibility for science was sustained by the system of annual budgeting; directors of laboratories were thus encouraged by this arrangement to dispose of unspent funds vigorously, with the result that a flurry of purchasing activity usually took place at the end of the financial year.[35] For their part headquarters' staff considered it to be too difficult to frame general criteria for evaluating particular projects outside the terms of the annual agreements regarding expenditure and staff numbers.[36] A system of frequent review intended to terminate unproductive research was not part of administrative practice leaving the way open for the continuation of such work.

In 1953 the Government accepted the idea of a five year plan for the DSIR beginning in April, 1954. The new plan provided for a total increase in staff of 1,000, a 20% increase in the DSIR vote, and a building programme with a cost estimated at £6 m.[37] This move towards long range planning if anything exacerbated the problems involved in allocating resources and highlighted the inability of the DSIR to establish priorities for research.

Problems of resource allocation affected three broad areas; the distribution of effort between the central research laboratories, the universities and the research associations; the demand for resources between different national laboratories; and the competing attractions of individual research projects. The Advisory Council admitted that the factors relevant to resolving these problems were not readily accessible to detailed analysis, and that it found it a difficult task to produce any quantifiable basis on which to decide in which directions the DSIR should provide an emphasis.[38] A result was that the establishments came under increasing scrutiny and the DSIR strengthened its headquarters' staff to make assessments to provide support for the duties of the Advisory Council. This included the establishment of an economics section which began to investigate the distribution of research expenditure and brought an increased statistical approach to analysing the problems of the department.[39]

The resulting analyses unfortunately tended to be more descriptive than prescriptive and the problems of resource allocation remained unresolved. In its report for 1954/55 the Advisory Council returned to this issue and admitted its continuing inability to come to grips with this underlying problem accepting that:

> There is little we can do at the centre except to comment on the Annual Reports and Programmes of the Establishments and to advise the allocation of future resources in more generous measure to those Establishments which, as it seems to us, have the more urgent objectives to meet, with the better prospects of success.[40]

With the DSIR committed to expansion its continued inability to bring some form of accountability to bear on research expenditure increased the scrutiny under which the programmes of the establishments were placed, and led to a number of attempts to provide assistance, of which the appointment of an economist to work with the Food Investigation Organisation was but one.

In early 1956 the Advisory Council appointed a Committee on Economics and Industrial Operations to review the work of the DSIR's Economics Section and its Industrial Operations Unit, and in addition to undertake a survey of research expenditure in the United Kingdom. The earlier establishment of the ACSP had itself failed to provide any solution to the rational allocation of scientific resources in the public sector. Indeed, beyond broad generalisations there appeared to be no obvious means of achieving this. Sir Henry Tizard at the time identified this as one of the most pressing problems of the period:

> In Government research the broad problem is not simply to secure the services of a fair but not excessive proportion of the best men available, but to use them in the best way at any given time. We must avoid the mistake of rushing into a programme of research to meet a need without studying beforehand the real nature of the need that has to be met. That is why I say that the study of the strategy of science is now of great national importance. It is as easy to waste money on research as on anything else; especially if it is someone else's money.[41]

From 1956 onwards this issue was to dominate the policy questions concerned with government science and bring increasing public attention to the role of the national laboratories.

The New DSIR Laboratories

During the Second World War and its immediate aftermath five new DSIR research establishments were set up; the Pest Infestation Laboratory, the Hydraulics Research Station, the Mechanical Engineering Research Laboratory, the Fire Research Station and a new Radio Research Station. Four of these were based on existing groups, only the Hydraulics Research Station being distinctly novel (even here some previous hydraulics research had been carried out at the National Physical Laboratory). Both the Mechanical Engineering Research

Laboratory and the Radio Research Station were initially based around existing departments of the National Physical Laboratory.

The Pest Infestation Laboratory, set up at Slough in 1940 to investigate attack by insects, mites and fungal pests on foodstuffs during all stages of storage, transport and processing, was established squarely in the context of war-time necessity. The prevention of grain losses through infestation was vitally important due to the necessity for storing huge quantities of grain against the uncertainties of supply, particularly due to losses at sea.

There was already an important precedent for supporting this kind of investigation, however. In the late 1920's a research team had been built up around J.W. Munro at Imperial College, London, financed essentially through the Empire Marketing Board.[42] A further initiative came from industrial interests which set up an informal committee to consider infestation problems in 1938. An approach to the DSIR brought an agreement for a jointly sponsored survey of infestation problems in the United Kingdom. Munro was the natural choice to conduct the survey, and his eventual findings supported the need for control measures. Following further pressure from the Standing Conference and Food (Defence Plans) Department, the Pest Infestation Laboratory was established at Imperial College's Biological Field Station at Slough.

Both the Radio Research Station and the Mechanical Engineering Research Laboratory were set up following recommendations to that effect made by the committee chaired by Sir Frank Smith which had been formed in 1944 to review the policy and activities of the DSIR in relation to post-war needs. Presenting its report in October 1944 its findings singled out a number of areas where it considered that insufficient research effort was being applied including fundamental research on radio and mechanical engineering.[43] Subsequent negotiations with all the public departments with an interest in radio communication led to a decision at the end of the war to establish an autonomous Radio Research Organisation to absorb and develop the work of the Radio Division of the National Physical Laboratory. Economic pressures on the expenditure of the DSIR were such, however, that not until 1957 were new laboratories and a field station at Slough ready for their official opening.

In 1946 the new Hydraulics Research Board was formed with research facilities based at Wallingford, Berkshire, to carry out research in so-called "loose-boundary" hydraulics, and concerned with such practical problems as the study of coastal erosion, river bank erosion, the silting of navigable waterways, and the design of harbour works. Its origins were directly related to a memorandum submitted to the DSIR by the Institute of Civil Engineers which advocated the setting up of a national research facility to deal with the kind of civil engineering problems mentioned above.[44]

It was considered that the absence of such a laboratory placed consulting engineers and contractors at a disadvantage in world markets for civil engineering contracts. In response the DSIR appointed a committee under Sir William Halcrow to make a review of the current facilities available for civil engineering as a whole. The Halcrow committee identified the provision for research on marine works and waterways as the main deficiency and recommended the setting up of a Hydraulics Research Organisation on the scale of a proposed annual budget of around £45,000.[45] These suggestions were duly taken up by the DSIR.

The Fire Research Station was set up under the control of a Joint Fire Research Organisation created in 1946 following a reconsideration, by the DSIR, of a pre-war proposal for the creation of a fire research body. In fact the involvement of the DSIR in fire research dated back well before the Second World War. In 1929 the Royal Institute of British Architects approached the British Engineering Standards Association pressing for the standardisation of fire regulations.[46] The difficulties which a committee, appointed for the task, experienced raised the need for large scale testing facilities. Negotiations between the Building Research Station and the Fire Offices' Committee, representing the interests of insurance companies, explored the possibilities of extending the latter's testing station at Manchester.

Following a conference convened by the DSIR, the Fire Offices' Committee decided to undertake the setting up of an enlarged fire-testing station in the London area. This was eventually sited at Boreham Wood and the programme of research was organised jointly with the Building Research Station. During the war a Fire Research Group was set up within the Ministry of Home Security. The latter, along with the Boreham Wood facility formed the nucleus of the Fire Research Organisation set up in 1946. The capital and running costs of the new organisation were equally shared between the Government and the insurance companies and a programme of research and testing was developed into the causes of fires, their detection and control, and the means for reducing loss of life and property.

The most significant new DSIR station set up immediately after the war was the Mechanical Engineering Research Laboratory. In 1944 the Committee on Post-War Development reported that:

> We are strongly of the opinion that a considerable increase of the facilities for research on the problems of mechanical engineering is essential if this country is to maintain its position in this field after the war.[47]

and recommended that the Advisory Council establish a small committee to investigate the possibility of combining the Engineering Division and the engineering metrology work at the National Physical Laboratory under a single head. A committee was duly appointed under the chairmanship of H.L. Guy.

On a number of occasions during the war concern had been expressed about the current standards of mechanical engineering in Britain. Delays in the production of machine tools along with allegations that Rommel's military successes in North Africa in 1942 were due, in part, to the inferiority of British tanks, encouraged engineers to press the case that insufficient and inefficient use was being made of engineering knowledge in the war effort.[48] The inferior status of engineering compared with the respect given to physics and chemistry fuelled the issue. Pressure from representatives of the engineering profession for their own equivalent of the Cabinet Scientific Advisory Committee led to the creation of an Engineering Advisory Committee in 1941 which soon fell into decline.[49] The subordinate status of engineers was highlighted in 1940 when W.L. Bragg wrote to Lord Hankey, Chairman of the Scientific Advisory Committee, suggesting that:

> .... it would be excellent if the Presidents of the various engineering bodies would come to tell us all they have in mind as to how the application of science could be made in their respective spheres. Perhaps they would be content with that.[50]

The technological achievements of the war glorified the physicists and yet failed to reveal the important contribution of engineers. The moves outlined below to establish a national centre devoted to the mechanical engineering sciences should thus be seen in this context, combining as it did a concerted attempt to bring the fundamental aspects of engineering science to bear on an industry characterised by small firms, wedded to mechanical craft tradition, with the related need to raise the professional status of mechanical engineers.

The Guy Committee reported to the Advisory Council in early 1946 and proposed establishing a "National Mechanical Engineering Sciences Laboratory" for the pursuit of basic and applied research in the engineering sciences allotted to it.[51] It advised that the establishment should concentrate on generic research with tests and _ad hoc_ work maintained at an absolute minimum and that advanced development work should be undertaken only in special circumstances with the consent of its controlling research board. It suggested that the Engineering Division of the National Physical Laboratory along with its engineering metrology work would indeed form an ideal basis for the new engineering laboratory.

The recommendations of the committee were not unanimously welcomed however and the committee itself had been divided. R.V. Southwell was one dissenting voice on the committee who refused to sign the report. He was particularly sceptical about the proposed scope of the laboratory contesting that such aspects as vibration and mechanisms could be studied as academic subjects divorced from problem solving. He also opposed the removal of basic engineering studies from the National Physical Laboratory, fearing the effect it would have on the future of the National Physical Laboratory by removing the more practical aspects of its work.[52] Any move to transfer engineering work away from the National Physical Laboratory was also vigorously opposed by its director Sir Charles Darwin, who had attended the meetings of the Guy Committee as an invited observer.

Before a meeting of the Advisory Council in January 1946, Darwin argued that the loss of engineering at his laboratory would produce a "spiritual divorce" of two aspects of its work between that in the aerodynamics and ship divisions on the one hand and the physical sciences divisions on the other.[53] His view was backed by Arthur Tyndall representing the laboratory's executive committee.

In May 1946 the Advisory Council, despite these protests, accepted the recommendations of the Guy Committee and gave its own backing to the view that a new laboratory should be built up to the order of 500 to 750 staff.[54] The decision incensed Darwin who sent an extremely bitter letter of complaint to Sir Edward Appleton, Secretary to the DSIR. In this Darwin claimed that the report, despite bearing the collective signatures of the committee, had been very much the personal work of Guy;

> .... who by the number of meetings had worn out everybody's attendance (excepting my own!) and many of these signed with the feeling that they were not in a position to form a good judgement.[55]

The Advisory Council had already made some compromise by deciding to retain some engineering facilities at the National Physical Laboratory, and the protests of Darwin were to no avail.

Despite the desire of the Guy Committee to site the new laboratory in or near London, at the insistence of the Lord President, Herbert Morrison, it was directed that the new engineering laboratory should be located in Scotland and in 1949 building began on a site at East Kilbride near Glasgow, with the first buildings coming into use in 1951. At an earlier meeting of the Advisory Council Sir Harold Brown had suggested it might be more appropriate to locate the new establishment in one of the main engineering centres of the north or Midlands. It has been further suggested elsewhere, however, that Morrison was influenced in his decision through his personal friendship with Sir Patrick Dolan, Lord Provost of Glasgow and Chairman of the East Kilbride Development Corporation.[56] The Mechanical Engineering Research Board, set up to supervise the new scheme was undoubtedly opposed to the decision. In its report for 1947-50 it emphasised the "special problems" the decision created, not least the geographical separation from the engineering work retained at the National Physical Laboratory.[57]

Further difficulties for the development of the new laboratory resulted from expenditure cut-backs forced on the DSIR, which brought delays to the building programme. The transfer of staff from the National Physical Laboratory was not completed until well into the 1950's. By 1958 the staff complement had still only reached 493 compared with the three to five years which the original plans had envisaged were required to reach full strength.

Despite such slow expansion the Mechanical Engineering Research Laboratory remained one of the more ambitious initiatives taken by the DSIR in the post-war years. More than any of the other new laboratories it epitomised what can be considered as the "classical" role of the government laboratory. Although it was expected to operate in a very practical field, the guiding principles which governed its initial organisation and function were scientific rather than technological in the commercial sense. Its function was to undertake basic research considered generic to the advancement of engineering knowledge and practice. In retrospect it is clear that the origins of the laboratory reflected moves to enhance the status of the engineering professions by building a national laboratory equivalent to the National Physical Laboratory.

The functions of the laboratory for engineering research remained vague, however, and in comparison to the National Physical Laboratory, with its traditional relationship with the Royal Society, its institutional support was weak. The work of the laboratory was always in danger of falling between two stools; the basic engineering research increasingly being conducted in universities and colleges, and the more applied research undertaken by other research institutions such as the research associations. The problem of identity was similar to that which had afflicted the Chemical Research Laboratory.[58] Although a national centre it never became <u>the</u> national centre in its field of research. Engineering research was already firmly established in other public institutions, including research associations and in other government laboratories such as a number of defence establishments which undertook research in mechanical engineering. Despite demonstrating its utility based on the existence of large test facilities the Mechanical Engineering Research Laboratory could never realistically carry the authority to become a national focus for all public mechanical engineering research which its proposers envisaged. This was due to no fault of its research staff, or even the quality of its work, but rather to an inevitability based upon the realities of existing institutions and over-optimistic, even perhaps naive, expectations.

Particularly true in the case of the Mechanical Engineering Research Laboratory, the problem of retaining a unique and visible role was, nevertheless, a feature of a number of the government research laboratories as applied research began to be undertaken on an increased scale by universities and colleges, research associations, and private research organisations.

Introspection and Reform

The first notable indication of uncertainty regarding the future role of the DSIR and its establishments, came in April 1955 when the Lord President appointed a committee under the chairmanship of Sir Harry Jephcott to examine the Department's organisation and functioning. By October of the same year this committee had submitted an interim report recommending that an executive council be established to replace the Advisory Council.[59] This suggestion was carried through into a Parliamentary Bill introduced into the House of Lords in March 1956, aimed at changing the basis for the Department's administrative and financial arrangements. The measure allowed for the setting up of the proposed executive committee and provided a legislative basis for the Department's expenditure bringing it into line with the existing arrangements for both the Medical Research Council and the Agricultural Research Council.[60]

This constitutional shift in the DSIR's status was a result in part of frequent representations made by the Public Accounts Committee for a specific Act of Parliament to govern the Department's expenditure.[61] When the Jephcott Committee was set up it was informed that such legislation was imminent, and considered it opportune to amend the constitutional position of the DSIR by replacing the Advisory Council with an executive body. Apart from the formal tidying up which was effected by these changes, Varcoe has noted that it was doubtful whether in reality this led to any substantial changes in DSIR policies and procedures.[62]

This did not escape critics who argued that the "ivory tower" role of the central laboratories did little to foster the dissemination of technical information to other administrative departments, or that the DSIR had shown itself capable of assuming more positive responsibilities in the industrial sphere to give effective direction to scientific research in the civilian field.[63]

The publication of the findings of the Jephcott Committee in April 1956 reflected the self-doubts already expressed by the Advisory Council in providing effective central direction. According to the report such direction was;

> .... inevitably inadequate .... headquarters staff do not and cannot exercise effective supervision over priorities in the programmes or over the balance between them.[64]

The report bemoaned the fact that much was started and not enough was stopped. As a result it considered that many of the Department's programmes were too diffuse and too uneven in quality.

The report was confusingly ambiguous, however, when it suggested that this situation could not be otherwise if ministerial control was to be "rightly and necessarily light".[65] It expressed the hope, nevertheless, that the proposed executive council would assist in administering better central direction. In practice the appointment of the executive committee provided little real change in the continuity of the DSIR's programmes, and the Jephcott Committee, while identifying and bringing to a wider audience the problems entailed in the effective use of resources, did not put forward any real solution. As the responsibilities of the DSIR continued to expand, the issue of resource allocation and management reached critical proportions in the early 1960's and was made more pressing by moves to make the work of the stations more directly relevant to industrial needs, and by the fact that science and technology were becoming political issues.

A more immediate consequence of the appointment of the new Research Council, however, was a flurry of reviews of the programmes of the DSIR's research laboratories. In 1956 the DSIR appointed a Stations Committee to work independently of the advisory boards to individual laboratories and to carry out regular programme reviews, before making recommendations to the Research Council. Independently the Select Committee on Estimates also began a review of the DSIR laboratories during the 1957/58 session of Parliament. Initial reforms came with the appointment of new streamlined steering committees, with explicit executive powers replacing the existing boards which had long since become formal advisory bodies, to supervise the annual programmes of the Chemical Research Laboratory, the Fuel Research Station, the Torrey Research Station, the Forest Products Research Laboratory and the

Mechanical Engineering Research Laboratory. By 1959 the internal reviews had been completed and the DSIR began to consider the broad aims and functions of the laboratories as a whole in an attempt to redefine their terms of reference in line with contemporary needs.

Meanwhile evidence of continuing political concern with the conduct of public research programmes was reflected in the appointment by the Lord President of another committee in 1958 under the chairmanship of Sir Claud Gibb:

> .... to inquire into the techniques employed by Government Departments and other bodies wholly financed by the Exchequer for the management and control of research and development carried out by them or on their behalf and to make recommendations.[66]

The subsequent report from this committee threw doubt on the impact of the more recent reforms within the DSIR. The new laboratory steering committees, it noted, had been intended to "bring the user or potential user into contact with all levels of the organisation from the laboratory bench to the Council itself."[67] It considered the new steering committees, however, inadequate for this task, and that the needs of industry for applied research were not brought effectively to the notice of government research organisations. It called instead for more effective linkage between the eventual users of research, whether industry or other government departments, and those institutions responsible for research and development, along with a greater flexibility and "imaginative handling" of scientific manpower through secondment and exchanges.[68]

Despite the reforms within the structure of the DSIR, the responsibility for the planning and direction of scientific programmes in the laboratories remained essentially in the control of individual laboratory directors. As Sir Gordon Sutherland, director of the National Physical Laboratory, informed the Estimates Committee during the 1957/58 sessional hearings: "In general the Research Council does not interfere a great deal in the scientific work of the laboratory."[69] The establishments remained with considerable control over their work including the freedom to follow lines of inquiry purely in terms of scientific or technical interest. Any link with profit was often, indeed usually, tenuous.[70] Nevertheless, the reviews carried out from 1956 onwards brought what one laboratory director later referred to as the first signs of disillusionment with "science for science's sake".[71]

Certain changes appeared merely cosmetic such as changing the titles of the Mechanical Engineering Research Laboratory and the Chemical Research Laboratory to the National Engineering Laboratory and the National Chemical Laboratory, respectively, presumably aimed at making the laboratories more visible as national centres to users of research. Other changes had more profound implications. Despite recommendations from the review committee for a further expansion at the newly named National Engineering Laboratory it was encouraged to strengthen its links with industry and to gear its work more to the immediate practical requirements of industry with less emphasis on basic research. This merely compounded the uncertainty over its precise role as it appeared to be moving into competition with research associations such as the newly established Machine Tool Industry Research Association.[72]

Although an emphasis on basic research continued to be an important element of the work of the DSIR laboratories, official pressure was growing for more work to meet the immediate needs of industry, particularly for research done in partnership with industrial interests. One of the major conclusions drawn from the review by the Estimates Committee of the work of the laboratories in 1957/8 was that the DSIR had failed to adopt a sufficiently "active" role in relation to industry.[73] In the following years the Research Council, in its annual reports, was to put noticeably greater emphasis on the industrial contacts with the work of the laboratories. In 1961, for instance it pointed out that the;

> .... close co-operation with industry and with many national and local organisations is a notable feature of the Stations' activities which increases in importance.[74]

Similarly in the early 1960's the National Engineering Laboratory was giving pride of place in its annual report to paragraphs entitled "Results of Direct Industrial Applications". This change in emphasis was referred to by Sir Harry Roxbee-Cox, chairman of the Research Council, in 1962 when he disclosed that:

> We .... are trying to ensure that in all our Stations the programmes, whether long term or short term, are directed to severely practical ends.[75]

Despite such official posturing it is doubtful if there occurred any immediate radical change in the work of the laboratories. Traditional patterns of operation and attitudes were deeply ingrained, and were set against the equally traditional stance by many industrialists of hostility, at the least indifference, towards the national laboratories. In 1963, an independent report expressed the widespread and long-standing opinion that;

> .... the general consensus of business opinion appears to be that the work of the DSIR stations is often too basic to be of any interest to the practical businessmen.[76]

The next year Aubrey Jones, a former senior government minister, stated that "the more general research stations of the DSIR tend to move in a vacuum undirected by any specific aims".[77] Although a number of the DSIR laboratories were gradually increasing direct repayment work (see Table 6), the National Physical Laboratory, still by far the largest of the department's laboratories was developing a reputation as an academic ivory tower. Certainly in this period the latter was plainly increasing emphasis on basic research and its proportion of income derived from repayment work was actually decreasing. The weight of opinion was that the National Physical Laboratory was becoming increasingly divorced from the realities of industrial needs at a time when the direction of policy was moving in quite the opposite direction.[78] This hardly contributed to public confidence in the ability of the DSIR to fulfill its industrial role at a time when such issues were highlighted by a faltering economy.[79]

The rapidly changing economic and political context of the 1950's was reflected in more notable organisational changes affecting the DSIR and its laboratories. A major decision involved the Food Investigation Organisation, one of the earliest DSIR initiatives, and one which had had considerable success in the inter-war period. During the year 1956/57 the organisation was disbanded with those elements

TABLE 6: DSIR Laboratories. Receipts as a % of Gross Expenditure, 1956-1964.

	1956/7	1957/8	1958/9	1959/60	1960/1	1961/2	1962/3	1963/4
National Physical Laboratory	41	39	38	43	41	36	36	33
Building Research Station	6	6	7	8	7	10	15	8
Chemical Research Laboratory/ National Chemical Laboratory	31	40	45	42	32	26	21	15
Fire Research Station	66	79	79	74	66	65	77	65
Food Laboratories	4	6	4	8	10	11	14	15
Forest Products Research Laboratory	4	4	3	2	2	6	8	9
Fuel Research Station/ Warren Spring Laboratory	5	7	2	7	19	24	14	12
Geological Survey	18	22	22	24	22	18	21	15
Hydraulics Research Station	25	31	41	49	43	49	60	60
Mechanical Engineering Research Laboratory/National Engineering Laboratory	7	6	5	5	6	9	9	9
Pest Infestation Laboratory	8	9	9	15	*	*	*	*
Radio Research Station	1	1	1	1	1	1	2	2
Road Research Laboratory	10	10	14	13	8	15	13	14
Water Pollution Research Laboratory	0	1	14	13	12	10	10	11
Laboratory of the Government Chemist	*	*	*	1	1	4	2	3
Tropical Products Institute	*	*	*	124	10	174	93	137

Source: DSIR Annual Reports

* = not applicable

TABLE 7 Source of Receipts to DSIR Laboratories 1956-1964 (£000's)

	1956/7	1957/8	1958/9	1959/60	1960/1	1961/2	1962/3	1963/4
Receipts From Industry:								
National Physical Laboratory	181	181	200	243	249	214	224	213
All other Laboratories	263	360	426	481	565	644	753	701
Receipts From Government Departments	345	383	406	722	608	1121	960	1159

Source: DSIR Annual Reports

dealing with fruit, vegetables, eggs and meat transferred to the Agricultural Research Council.

Concern regarding the food research conducted under the DSIR was raised by the Research Council which, following an increasingly fashionable indication of "accountability", pointed out the particularly low repayment work sponsored by the Food Investigation Organisation, and concluded that its resources were too thinly spread to be effective.[80] It announced that the organisation best fitted to cope "with the growing scale and diversity of food research" had been considered and a decision reached to bring the control of food research under one body, namely the Agricultural Research Council, including the laboratory facilities at Cambridge (Low Temperature Research Station) and East Malling (Ditton Laboratory).[81]

The decline in Britain's imperial economy made the original rationale for the separation of research dealing with agricultural production from that concerned with distribution and storage obsolete, and as the DSIR food research laboratories had become more oriented to domestic agriculture the re-organisation appeared a logical development.

Another laboratory which had experienced a similar change in its orientation to a more exclusive emphasis on a domestic role from a previously imperial role, was the Forest Products Research Laboratory. Initially a pioneer in its area of applied research, by the late 1950's its role was clouded by the increasingly active role in research taken by the privately sponsored Timber Development Association. To resolve this situation the latter was invited to take responsibility for the supervision of certain sections of the work of the DSIR laboratory.[82]

These changes, however, did not substantially affect the role of the DSIR as the recognised focus for general government-sponsored applied research. Indeed in 1959 its position in this respect was further consolidated when it became responsible for two additional public laboratories, the Laboratory of the Government Chemist and the Tropical Products Institute. The transfer of the latter from the Colonial Office was yet another consequence of the changing shape and nature of Britain's relationship both politically and economically with the rest of the world. Established in the context of colonial development the Tropical Products Institute had assumed a more modern role as part of the general overseas' aid programmes.[83]

Of the many changes which occurred in relation to the operations of the DSIR in the post-war years, perhaps the most illustrative of the changing context and function of public research was the circumstances surrounding the closure of the Fuel Research Station, the first of the public laboratories set up by the DSIR (and indeed the first and only one to date to actually be closed down), and the creation of a new public research facility, Warren Spring Laboratory. A more detailed consideration of the events behind these changes highlights many of the more general changes in policy and emphasis which came in response to both new institutional developments and the changing pattern of the national economic and political situation.

<u>The demise of the Fuel Research Station and the Origins of Warren Spring Laboratory: the changing orientation and nature of government research.</u>

In the years immediately following the end of the Second World War the institutional context of the Fuel Research Station was remarkably different from the circumstances prevailing in its formative years when it was clearly established as _the_ national centre for fuel research problems, and indeed the major public institution devoted to energy research. The first major event which was to create some uncertainty about the future of the Fuel Research Station was the creation of the Ministry of Fuel and Power in 1942. In the same period a number of new research associations with interests related to fuel research were established including the British Coal Utilization Research Association (est. 1938), the Gas Research Board (1941), the British Coke Research Association (1944), and after the war the Coal Tar Research Association and the Heating and Ventilation Research Association. In addition new public utilities, the National Coal Board, the Gas Council and the Electricity Authority were set up with statutory obligations to conduct research, while at the same time private industry was conducting relevant research and development. The position of the Fuel Research Station as a national centre for fuel research in consequence became an anomaly and in 1957 the new executive Research Council concluded that the need for such a centre no longer remained and that it should be replaced by a new laboratory of a similar size but with much wider terms of reference.

In the closing years of the war such a move was never contemplated. The Fuel Research Board was convinced that, even in the light of the new institutional developments, an important role for its research centre remained, and indeed it recommended its expansion from 300 to 500 total staff.[84] With such ambitious plans the existing facilities, still based at an old gas works at Greenwich, suffering from extensive bomb damage, were clearly inadequate, and the Fuel Research Board pressed for a completely new laboratory.

The Board itself found its position consolidated in 1945 when it assumed overall responsibility for work on atmospheric pollution. Nevertheless, the nationalisation of the coal, gas and electricity supply industries forced a reconsideration of the future of the Fuel Research Station. Despite these developments the Fuel Research Board retained its commitment to expansion and the retention of the various functions of the Fuel Research Station. Indeed the transfer of the Coal Survey laboratories to the National Coal Board in 1947 was made in the face of considerable opposition from the Board.[85]

The uncertainties in public expenditure delayed plans for the new Fuel Research Station until 1954 when the DSIR's Advisory Council devoted a considerable part of its annual report, and by implication its deliberations that year, to the issue of a new fuel laboratory.[86] The Advisory Council was under pressure from Sir Cyril Hinshelwood, Chairman of the Fuel Research Board, on what were considered two urgent needs; increases in staff, and the new laboratory, both thought necessary to accelerate work on atmospheric pollution and domestic heating as recommended by the Advisory Council. In its report for 1953/54 the Advisory Council clearly and unambiguously reaffirmed its support for the notion of a national centre which would be recognised as the central organisation in the country for long term basic research on fuel.[87] The following year the Advisory Council further disclosed that the arguments for a national fuel research centre had been accepted by the Privy Council Committee for Scientific and Industrial Research and that the new laboratory was to be built "as a matter of first priority".[88]

With such an emphasis on the needs for a new laboratory the Department's annual report for the year 1955/56 surprisingly provided no reference to the proposed new station, indicative that the whole scheme was being reconsidered by the new Research Council. This was confirmed the following year when it was reported that the original proposals for a new Fuel Research Station had been radically altered.[89] The Research Council announced that a major new laboratory was to be built at Stevenage, near the existing Water Pollution Research Laboratory, retaining as part of its functions only two elements of research carried out by the Fuel Research Station. The continuation of work on atmospheric pollution was essential in view of the recent introduction of the Clean Air Act with the need for scientific and technical support. Work was also to continue on the Fischer-Tropsch process for the synthesis of oil, at the direct request of the Ministry of Fuel and Power. All other programmes were either to be completed at Greenwich or discontinued.

In the space of two years the concept of a national centre for basic research on fuel problems had shifted from "high priority" to obsolescence. The reasons for this are at present unclear. The continuity between the old Advisory Council and the new Research Council was sufficient to make this change alone an unlikely cause. It became usual in later accounts to explain the demise of the Fuel Research Station purely in terms of the rise of other agencies for fuel research.[90] Nevertheless the Advisory Council had been well aware of this context. As its report for 1953/54 declared:

> In our view the presence of various research organisations in the fuel field in no way reduces the necessity for the [Fuel Research] Station to maintain its position as a national centre for the study of fuel problems.[91]

The question arises as to what other factors, if any, influenced the change of decision? Without access to the public records of the period it is difficult to provide any accurate assessment.

What is clear, however, is that in a period when the DSIR was committed to a four year plan, and when manpower was limited, pressures began to build up for the provision of new research facilities in areas which demanded some priority. In all likelihood this became more attractive in prospect than fuel research and, furthermore, provided arguments in favour of a multipurpose laboratory. In addition, as already indicated, from 1956 onwards DSIR policy began to emphasise the pursuit of research of more immediate industrial relevance, including experimental development work rather than more fundamental basic research. A new centre for fundamental research on fuel was thus contrary to the general trend of policy, whereas a centre devoted to more applied aspects of fuel research made little sense considering the existence of other agencies pursuing applied research and development related to fuel problems.

Regarding the need for new research facilities there were important strategic reasons which raised suggestions for setting up facilities for developing methods of exploiting deposits of low grade minerals, along with other aspects of extractive metallurgy which could exploit uncommercial sources. By the mid-1950's there was much interest in exploiting low grade ores in relation to both the needs of the nuclear programme and the importance of rare metals to the aerospace industry.[92] Indications that discussions had taken place between the DSIR and the Advisory Council for Scientific Policy came in the latter's report for 1955/56 in which it was disclosed that it had come under pressure from a number of bodies arguing for the provision of central mineral processing research facilities, and that the DSIR was considering the possibilities.[93]

The security aspects surrounding the vulnerability of mineral resources had already been indicated by a government investigation (the Westwood Committee).[94] In a minority report to the inquiry Peter Thorneycroft, President of the Board of Trade, is said to have supported setting up a centre for studying aspects of mineral processing.[95] On April 2nd, 1957, the Parliamentary Secretary to the Ministry of Works, H. Nicholls, was asked in the Commons whether, in view of the increasing importance of nuclear power, any decision had been reached on establishing a central mineral processing laboratory.[96] In reply it was stated that talks were underway between scientific and industrial interests, along with the DSIR and that "the matter was receiving high priority".[97]

The mixed origins of the new multifunctional laboratory also reflected a further major initiative. This was based around a suggestion that national facilities be provided for the testing of novel industrial pilot plant, an idea which had been mooted since the 1930's. The initiative in the late 1950's, however, related to the narrower needs, stemming from the new development of polymers, for extensive pilot plant facilities for pre-development work. The concept of creating a government centre devoted to the study of pre-development process plant is said to have been principally due to Frank (later Lord) Kearton, chairman of Courtaulds, who himself believed, and convinced the DSIR, that industry would use such a facility.[98]

Thus the decisions were subsequently made that the new research laboratory, initially planned as a replacement for the Fuel Research Station, should be devoted to a wider field of activities including mineral processing, pre-development work on chemical process plant, along with the remnants of the programme retained from the Fuel Research

Station. It was firmly envisaged that its programme of work would provide direct assistance to industry and that the services of the laboratory would be made available on a repayment basis. This was a notable change in official DSIR policy towards discriminatory practices.

Although the main emphasis in the laboratory was to be in applied chemical engineering and process development, it was not intended that the laboratory be confined to any particular science or technology. This was reflected by the name of the new facility, Warren Spring Laboratory, named after a local geographical feature. Initially it was organised in four divisions; mineral processing, atmospheric pollution, chemical engineering, and process development. A movement of staff from the old Greenwich site began in 1958 and was essentially completed, apart from staff still working there on atmospheric pollution, by February 1959.[99] Warren Spring Laboratory had officially replaced the Fuel Research Station the previous month, and been established at a total cost of £620,000.[100] Its research capability was consolidated by the transfer of a small mineral dressing laboratory from AERE, Harwell, along with the Engineering Group from the National Chemical Laboratory.

Warren Spring Laboratory was predominantly technological in its outlook and oriented to provide support for the introduction of new industrial technologies. Difficulties were immediately encountered, however. The original optimism over the potential for industrial interest in the process development work as originally envisaged proved to be unfounded. In 1962, the Laboratory's director, S.H. Clarke noted that:

> It is noteworthy that no use has, as yet, been made of these facilities. Most of the chemical engineering work carried out for industry has been concerned with the design and functions of equipment - not with process development.[101]

Work in this area was further weakened when the recommendations made in 1960 by the Wilson Committee on Coal Derivatives, calling for the work on the Fischer-Tropsch process to be wound up due to its lack of economic potential in the face of continuing cheap oil supplies, were implemented.[102] These factors, coupled with the failure to recruit a suitable head for the process development division, resulted in it being combined with the chemical engineering division.

The immediate lack of success of this aspect of the laboratory's work led to a reassessment of the role of the laboratory as a whole in this sphere, and it was decided to shift the emphasis of its work in process development into the study of the movement and handling of bulk materials.

The new establishment began immediately to develop closer links with industrial firms than was usual for government laboratories, and it particularly attempted to exploit the idea of a "multi-project club" of sponsors. Work on mineral processing attracted the greatest interest in terms of repayment work. In the year 1960/61 repayment work comprised 80% of the mineral processing divisions effort, one half of which was undertaken on a direct contract basis for private industry.[103]

In 1960 Warren Spring Laboratory also became responsible for research into the clearance of oil pollution from beaches, following representations from a deputation from south-coast resorts to the Minister for Science. A few years later it became involved in yet another new area of work, concerned with computer control of plant and processes. Once again the emphasis was technological and industrial, and involved private industrial interests in the work.

The involvement in computer control of manufacturing processes came after a successful project at Warren Spring Laboratory sponsored by Elliott Automation to develop the use of the company's ARCH process control computer for the control of a pilot scale water-gas shift plant, which led to an operational system. A director of the laboratory later observed that:

> There appeared to be a need for a source of independent expertise between the manufacturers of computers and the potential users in the chemical and process industries.[104]

Thus, Warren Spring Laboratory began an explicit policy directed to the users of technology and the implicit recognition that the development and diffusion of new technologies were closely linked. The resulting orientation of the laboratory reflected important changes in attitudes towards government sponsorship of applied research. Indeed the term "applied science" was not particularly appropriate in this case for its interests were more explicitly technological. Implicitly the role assumed by Warren Spring Laboratory reflected a more sophisticated view of the relationship between research, development and the introduction of new technology. Indeed it incorporated a recognition of a process of innovation that went beyond a simple "science-push" model.

The establishment of Warren Spring Laboratory was also one early indication of how successive Governments in Britain were to become more closely involved in industrial development, and of the emergence of a piecemeal industrial policy which accepted as valid public intervention at the level of the firm. These developments had important implications for the public laboratories, particularly as, during the 1960's, science and technology began to assume an important place in political debate.

National Laboratories and the Organisation of Government Research.

Although the various reviews of the laboratories of the DSIR, undertaken by its Research Council between 1956 and 1959, raised problems of control and management, they did not contradict the assumption that a large and growing field of research was appropriate for public patronage in national laboratories. Indeed, in 1958 the Government agreed to a second five-year plan for the DSIR which allowed for an expenditure of £61 m., compared with the £36 m. expended over the period covered by the previous plan.[105] By 1960, however, it was clear that, in association with the perception of an accelerating change of pace in science and technology and severe cost escalation in equipment and facilities, it was becoming difficult, if not impossible to forecast expenditure five years ahead.[106]

Although arrangements were made for annual revisions, by the early 1960's there was every indication that the DSIR was becoming unmanageable, not only in terms of the uncertainties of forecasting expenditure, but also in terms of the difficulties of co-ordinating such diverse activities as post-graduate finance and industrial research and development. In parallel the traditional place of the DSIR as the general research department of government had been continuously undermined by the expansion of civil research in other departments and public agencies (see Tables 8 and 9). Weak control at the centre of government, in particular the inadequacies of the ACSP and the Minister for Science's Office, contributed to the need for a comprehensive review of the total organisation of government science.

In March 1962 a committee under the chairmanship of Sir Burke Trend was appointed to consider whether any changes were needed in the existing functions of the various agencies for which the Minister for

TABLE 8 Distribution of Scientific Officer Class Staff in Public Departments, 1956.

Admiralty	562
Air Ministry	213
Ministry of Defence	38
Ministry of Supply	1432
War Office	30
Ministry of Agriculture, Fisheries & Food	117
British Museum (Natural History)	65
Colonial Office	36
Ministry of Fuel and Power	64
Government Chemist	55
Home Office	37
Post Office	47
Department of Agriculture for Scotland	13
DSIR	626

Source: D.N. Chester and F.M.G. Willson, The Organisation of British Central Government (London, 1957), p.253.

TABLE 9 Distribution of Scientific Officer Class Staff in Public Departments and Agencies, 1965.

Ministry of Aviation	1270
Ministry of Defence	1093
Ministry of Agriculture, Fisheries & Food	181
British Museum (Natural History)	91
Ministry of Power	47
Home Office	43
Post Office	190
Ministry of Technology	807
Medical Research Council	839
Agricultural Research Council	978
Science Research Council	275
Natural Environment Research Council	318
U.K. A.E.A.	1380
Department of Agriculture for Scotland	53

Source: Council for Scientific Policy, Report of the Working Party on Liaison Between Universities and Government Research Establishments (London, 1967), Cmnd. 3222, p.7.

Science was responsible, including such issues as the formulation of civil science policy, the conduct of civil science, priorities for research, finance and accountability, and whether any new agencies should be created. The committee was thus specifically charged with examining the adequacy of existing organisation rather than the policy or the scale and content of research programmes. The role of the departmental laboratories was not directly questioned by the committee. Nevertheless, one particular problem which the Trend Committee considered was the relationship between the laboratories under the control of the DSIR and the government departments which were important "users" of research results from laboratory work.

Traditionally the "Haldane Principle" with its direction towards the separation of the control of research from the immediate executive considerations of departments had dominated organisational principles and this had been consolidated by such examples as the transfer of the Road Research Laboratory to the DSIR in the 1930's, and the rationalisation of building research in 1950. The Haldane Committee, however, had also clearly recognised the necessity of executive departments having strong intelligence support to frame research requirements and integrate the results of research into policy formulation. This had never adequately materialised, and the responsibility for initiating research tended to remain within the research laboratories themselves, isolating them from user departments.

In the post-war period after 1945 the optimum location of research organisations with respect to user departments continued to be an issue of debate. Immediately after the war, for instance, the location of the Fuel Research Station had been an issue of contention in the light of the establishment of a Ministry of Fuel and Power in 1942.[107] Later in 1957/58 the Parliamentary Estimates Committee identified four DSIR laboratories which worked mainly in the context of single executive departments, namely the Pest Infestation Laboratory, the Radio Research Station, the Road Research Laboratory, and the Water Pollution Research Laboratory, and recommended that these laboratories be reviewed to establish the question of departmental control.[108] In particular it strongly felt that the Road Research Laboratory should be under the direct control of the Ministry of Transport with any fundamental research on engineering structures transferred to the Building Research Station.[109]

The issue of the administrative location of the government laboratories was an issue which had also been included in the deliberations of the ACSP. In its very first report it had recommended retaining both the Building Research Station and the Fuel Research Station under the control of the DSIR.[110] A few years later when the ACSP considered in detail the work of the Road Research Laboratory its best administrative location proved to be a more controversial issue.[111]

Much later, in 1964, two economists, Charles Carter and B.R. Williams, both involved at different times as economic advisors to, first the DSIR, and then its successor the Ministry of Technology, advocated the need for strong research divisions to be created in each government department.[112] They envisaged the decentralisation of research stations, the Road Research Laboratory to the Ministry of Transport and the Building Research Station to the Ministry of Public Buildings and Works, as an essential part of such a policy.

The Gibb-Zuckerman Report had also expressed misgivings concerning the position regarding executive departments whose technical interests were primarily served by large research organisations not directly under their control.[113] Although not recommending any organisational changes, which were in any case outside the committee's terms of reference, the Gibb-Zuckerman Report stressed the need for departments to ensure that they possessed the necessary machinery for formulating research requirements, an indication that many were lacking in this respect.[114]

Organisational change did, however, come within the remit of the Trend Committee. With respect to the needs of executive departments it recommended that, as a guiding principle, where a particular research establishment was predominantly concerned with research which was of a relatively immediate and operational nature, and was related to an executive function of government, it was advantageous for the control of the research to be in the hands of executive departments.[115] Where a research station was concerned with long-term or basic research, the Trend Committee concluded that it should be managed by a research council. Nevertheless, it did not feel that the issue was clear in terms of either the Road Research Laboratory or the Building Research Station, and suggested they should continue to operate within an autonomous organisation. On the other hand executive departments, it advised, should be provided with more effective means for associating with the direction and control of the stations. In other words the Trend Committee recognised the dilemma without providing any real guidance as to how to resolve the problem. The issue of the relationship between user departments and research agencies was to remain a difficult and essentially unresolved problem throughout a period of political turmoil which was characterised by distinctive changes in the organisation, management and control of government research and development.

Into the Political Arena

The publication of the Trend Report in 1963 coincided with a period in which science and technology had become an issue of great political significance. A detailed analysis of the way this occurred has been provided elsewhere.[116] Both the major political parties, but particularly the Labour Party, identified science and technology as issues pertinent to an election campaign which emphasised the need to modernise British industry. In such a context the organisation and management of the country's scientific and technological resources emerged as a subject which came under particular public scrutiny, reflected in a wide coverage in the press. Thus the report from the Trend Committee and the Government's response received unprecedented media interest for such issues.

The response of both the Conservative administration and the Labour opposition to the Trend Report committed whichever party won the 1964 General Election to major changes in the organisation of government research and development. The Government accepted the report almost in its entirety. The recommendations of the report, and thus the Government's response, reasserted and consolidated the Haldane Principle as it was embodied in the research council system, by suggesting the replacement of the DSIR by more specialised research councils devoted to basic science and environmental research, along with an Industrial Research and Development Authority - a similarly autonomous body comprising the DSIR research establishments along with the more commercial approach of the National Research Development Corporation.

This new body along with both the new and the existing research councils, it was proposed, would be located in a new government department with functions extending from education to the support of industry. The proposals for industrial research were diluted, however, once it became clear that the National Research Development Corporation vigorously opposed its transfer from the Board of Trade, with the support of the President of the Board of Trade, Edward Heath. Thus when the Government announced its response to the Trend Report it was clear that the National Research Development Corporation was no longer included in the proposals.

In the light of the Conservative defeat at the 1964 General Election the proposals of the Labour Party were of more lasting relevance. Party rhetoric committed it to bringing into being a new ministry for the promotion of technological development in industry, a promise duly honoured following its election victory. Election promises to mobilise the scientific and technical resources of the country to increase the competitiveness of British industry, guaranteed that the national research laboratories would remain under close political and public attention. The divide which separated the euphoria of political promise from the realities of public research and development was, nevertheless, considerable. If the political message was crude and naive, the laboratories were certainly not in a position to have any immediate impact on industrial practices. Indeed in the face of a growing new influence in the Conservative Party, which upheld the sovereignty of market forces, complemented by a waning of the post-war enthusiasm for science, the public laboratories were to become something of a political liability by the latter half of the 1960's. The scene was thus set for a major reconsideration of their place and function.

CHAPTER SIX

The Turning Point 1964-1972

From 1964 onwards the political debates over the role of the government research establishments intensified. Despite the concern expressed in previous years, over managerial and organisational features, a commitment to the laboratories had never appeared seriously in doubt and resources devoted to them had risen continuously since the end of the Second World War. Suddenly, however, confidence in their role seemed to evaporate. Doubts over the large scale of resources devoted to them multiplied and the very relevance of their work came into question. As the Labour Government hesitated over their future, attacks on them became more vehement; in Parliament, in the media, from the Government's own advisors. The laboratories began a period of staunch rearguard action with the Institution of Professional Civil Servants assuming a prominent role as apologist for the role of the laboratories.

Following the victory by the Conservative Party in the 1970 General Election, many of the laboratories ended up caught in the web of Lord Rothschild's "customer-contractor" principle and experienced a relative decline as resources began to shift under political pressure away from the public sector. A few sought a new lease of life, albeit shortlived, in the newly formed Department of the Environment. Harwell, the vast research complex of the Atomic Energy Authority, escaped by an aggressive shift to contract research, while the defence laboratories sought relative anonymity in the Ministry of Defence after the brief glare of the Ministry of Technology. Although all but one of the government's laboratories survived the turbulent period from 1964-1972 intact, the "golden age" of the government laboratory was over; indeed the traditional concept had clearly collapsed.

The Ministry of Technology: rethinking the role of public research

Following the election victory of 1964 the new Labour Government set up a Ministry of Technology charged with the task of guiding and stimulating a major national effort to bring advanced technology and new processes into British industry.[1] As a minister of that period later noted; the idea caught the popular belief that technology was a thing in itself in which the nation could have a special pride and that in spin-off some industrial justification for the high level of public expenditure on research and development would be found.[2]

Leading ideas from the outset included the use of civil development contracts and the mobilisation of the research expertise in the public laboratories, a rather naive formulation which quickly highlighted the need to consider the process of technological innovation as a whole and as a part of the process of economic growth.[3] In order to translate the results of the vast government research and development capability into improved economic performance and to improve the competitive level of industry it was considered necessary, partly as a result of a number of specific industrial case studies, to extend the initial scope of the Ministry's work into the problems of industrial structure and management.[4] The emphasis on industrial policy was reflected in greater intervention at the level of the firm. Indeed it has been recognised that the fundamental importance of the growth of the Ministry was the institutionalisation of the principle of discrimination, and the overturning of the traditional attitude of neutrality, of "holding the ring",[5] an attitude which also characterised the traditional role of the public laboratories. Thus the Ministry of Technology evolved in a direction which posed a distinct threat to the manner in which many of the laboratories operated and brought intense questioning about their future.

By 1967 the centre of gravity of the consolidated Ministry was essentially industrial, a marriage between the Government's long established commitment to research and its sponsorship responsibilities for industry.[6] The Minister of State for Technology, Anthony Wedgewood Benn, in 1967 declared that "our technological policy is an industrial policy".[7] The new corporatist approach involving a "partnership" between government and industrial interests was at the root of conflict with the traditional function of the laboratories. Whereas the majority of laboratories of the Department of Scientific and Industrial Research had operated as relatively autonomous units, as a source of new ideas based on scientific research programmes, within the new orthodoxy they were envisaged as a common resource geared to the more immediate demands of market requirements.[8]

The need for the laboratories to be "reoriented" to meet the demands of this new situation was expressed in various public statements made by both Anthony Wedgewood Benn and Sir Richard Clarke, Permanent Secretary to the Ministry of Technology. In 1967 Benn, for instance, wrote that the job of his ministry was "to orientate the work in our establishments to the objectives of the economy",[9] while the following year Clarke declared that "the establishments' efforts will .... become oriented more effectively to meet industrial needs and to stimulate innovation".[10] This declared intent should be seen in the context of both the problems of the existing balance of resources the Ministry inherited, and the ideology it was attempting to embrace. Because of the rapid growth of the Ministry the management of the research stations was only a minor aspect of its total activities.[11] Nevertheless, after

1967 they collectively represented the largest research organisation in Europe, received a significant proportion of national research funding, and remained a major and unsolved problem throughout the ministry's existence.[12]

From available evidence it appears that the economic and scientific advisors to the Ministry of Technology had an important influence on policy.[13] At Benn's first meeting with his advisory committee on technology B.R. Williams, in his position as economic advisor, presented a paper demonstrating that research and development, *per se* had little direct relationship to economic growth.[14] Indeed the economic realities of the period, in which a poor economic performance contrasted with high expenditure on research and development, negated any positive relationship between these factors. What appeared crucial was the deployment of such resources and their institutional context. It has been suggested that these conclusions particularly influenced the minister's thinking.[15]

Another idea which gained credence was the belief that firm size was related directly to research viability, and hence to its ability to absorb new technologies and innovate.[16] This had been suggested by the Ministry's early industrial studies and had a particular appeal to P.M.S. Blackett, another influential advisor in the early years of the ministry.[17] Blackett's original thinking, before the 1964 election, was that the research resources of the government laboratories could simply be reoriented to meet industry's needs.[18] In the years that followed he became convinced that research and production were intimately linked to market forces such that it was research, and particularly development, carried out in industry, which was of crucial significance and where government financial help was vital. The post-war expansion of public research, he believed, had resulted in a serious imbalance between the public and private sectors. In consequence pressures were exerted to run down the public laboratories in the belief that this would result in a flow to private industry of qualified scientists and engineers.[19]

Additional pressure for the public laboratories to be run down came directly from industrialists, many of whom were being drawn into the policy making process as Ministry officials encouraged government-industry co-operation.[20] In particular it has been argued that industrialists could not be persuaded to develop a programme for the government because they did not approve of the civilian research stations, considering them devoid of commercial sense, and producing little of commercial value to industry.[21]

Yet another factor highlighting the research establishments as a problematic issue was that some of them appeared to have outlived their original purpose. In 1964 Robert Maxwell, for instance, introducing the Government's plans for science, declared a need for: "sharp and independent means for recognizing when the mission of a Government research and development establishment has lost its validity, and practical means for redirecting the establishment into more productive channels".[22] An immediate concern in the Ministry of Technology in this context was the future of AERE Harwell. A similar debate concerned a number of the defence laboratories which became the Ministry's responsibility in 1967 following the transfer of the Ministry of Aviation.[23]

To understand why the laboratories suddenly became the pariahs of the public purse is to understand how the environment in which they had traditionally operated vanished. Under the Department of Scientific and Industrial Research a number of laboratories had operated relatively independently, confident in the utility of their work and convinced that any problems which were experienced related simply to the efficiency of the manner in which results were disseminated. If this dissemination was effective, potential users should exploit the results of research to improve performance in production. Scientific values of worth predominated, with a high regard for publication in reputable journals. The spirit of general availability of research results was matched by the traditional approach of government to the patronage of industry.[24] However, the policy of the Ministry of Technology with its emphasis on selective intervention, the so-called "principle of maximum unfairness" or positive discrimination, was in contradiction to the principles under which many of the laboratories operated. Contract research for instance fitted well into the Ministry's view of the way a public laboratory could relate to industrial needs. Yet traditionally such research had low status and was often considered as a diversion from the main task of the laboratories, accepted merely for the way it maintained contacts outside and because it provided some external legitimation for the utility of scientific work.

Nevertheless it remained subordinate to the major rationale behind the existence of the national laboratories. The appearance in official statements of words such as "reorientate" and the need for "changing attitudes" indicates the existence of this mismatch. Compared to the Ministry's corporatist approach, emphasising commercial needs, the laboratories appeared as old fashioned, too academic, and anachronistic,[25] due not only to the way they had developed, but also to the transformation in the political environment in which they operated. For scientists employed in the laboratories the new situation was both unexpected and incomprehensible. Their work had been accepted as having utility in previous years and was measured in terms of its scientific worth. The relationship of research to practice was problematic only in the sense of communication to the outside world. Accountability was based on comprehensive annual reports demonstrating scientific merit and the general guidance of responsible advisory committees. The sudden burst of criticism which fell on the public laboratories thus came as a shock. It was natural for government scientists to interpret this as a failure on their own part to educate others convincingly of the value of their work.[26]

From the point of view of the Ministry of Technology the problem remained that of overcoming institutional inflexibilities to simultaneously make the work of the laboratories conform to the general strategy of industrial policy, as well as to redress the perceived mismatch between national research resources devoted to the public and private sectors respectively. The problem was exacerbated since, by 1969, the Ministry had grown to enormous proportions with the laboratories dwarfed in its overall organisation. Nevertheless, the problem of their future remained not only unresolved but of great political interest. Two years of intense debate on the issue were to follow.

Political Debate and National Laboratories

Despite concern within the Ministry of Technology over reorienting the laboratories towards immediate industrial needs and diverting research resources from the public to the private sector, not until 1970 did any major indicator of intent emerge. In March of that year a Green (i.e. discussion) Paper was published suggesting that an autonomous corporation be established, consisting of the Ministry's civil research stations, including those of the Atomic Energy Authority, along with the National Research Development Corporation.[27] This met with almost universal disapproval.

The publication of the 1970 Green Paper focussed a debate which had been simmering since the early 1960's. The fact that it appeared not as a white paper and nearly six years following the establishment of the Ministry of Technology reflected the "tremendous battles" which went on internally throughout the Ministry's existence.[28] Plans to hive off the laboratories into a separate corporation had been devised in the Ministry's earliest years principally by P.M.S. Blackett, Maurice Dean (then Permanent Secretary), and John Adams who had responsibilities for the laboratories under the Ministry.[29] Sir Richard Clarke, who replaced Dean in 1966 was open minded on the issue, whereas Benn was "conditioned" to the idea from the time he became Secretary of State.[30] Various proposals were investigated suggesting hiving off individual laboratories or sections of laboratories, involving at least Warren Spring Laboratory, the Royal Aircraft Establishment, the Royal Radar Establishment, and the Water Pollution Research Establishment.[31] In every case arguments were raised revealing the apparent impracticality of such actions.

Alternatively the theoretical possibility existed of inducing individual scientists to leave government employment and take up positions in private industry and thereby gradually run the laboratories down whose roles were in question. It has been claimed that Blackett was particularly convinced that Harwell should be run down.[32] Ironically his leading role in re-shaping its remit to permit it to undertake non-nuclear contract research ensured its survival.[33] In more general terms, as has been argued elsewhere, real contradictions in the belief that laboratories could be allowed to run down existed, for clearly a laboratory had to do something while it was being run down, and conversely could not be run down below a threshold level.[34] In addition, the existence of practical deterrents prevented any firm determination to carry such a policy through. For instance, hopes that scientists would willingly transfer their services to private industry ran counter to their reluctance to leave the low pressure comforts of public laboratories, with the protection of favourable conditions of employment. Individual firms showed no interest in attracting scientists enjoying higher salaries, generous pension provisions, with work attitudes tending to the university rather than having an industrial orientation.[35] Not least it has been recognised that the Institution of Professional Civil Servants conducted an effective campaign on behalf of its membership.[36] As Mencher notes, it ...

> "was and remains a powerful union that reacted vociferously and negatively to any suggestion, however theoretical that the ranks of its members be pruned, whether by transfer of Research Stations, or individual scientists from government to industrial employment."[37]

This observation, while correctly recognizing the effective rearguard action which was conducted, tends to unfairly emphasise the union's negative role. Clearly its prime responsibility was to protect and advance the interests of its membership. Within this remit, however, it succeeded in providing some of the most well argued contributions to the ensuing debate.[38] The Institution's senior officials recognized the threat posed by external pressures yet were faced with both convincing their own sceptical membership that change was inevitable as well as attempting to influence the general debate over whether the research laboratories had an important role to play, even in the context of major redirections in government policy.[39] In particular the Institution conceded the need for "radical changes in "attitude", considerable reorganisation, and the creation of "a new and intimate partnership with industry".[40] To this extent it suggested that representatives of industry should participate fully in the management of research programmes, enabling close attention to industrial needs and relevant advisory services.[41] Furthermore, it accepted that research was probably concentrated too much on long term work and offered proposals for closer links with industry by associating each laboratory with its appropriate industries, perhaps through the "little Neddies",[42] associated with government procurement policies. The need to discriminate between firms to ensure development of new ideas was fully accepted as was the need for close attention to overcoming obstacles to the mobility of staff between the public and private sectors. Nevertheless, any forced reductions in staff were opposed.

If the Ministry of Technology held serious convictions that laboratories, in whole or in part, or individual scientists could be transferred to industry, such hopes never materialised in practical solutions. Neither did a white paper on research and development materialise, as promised from 1967 onwards.[43] The government remained firmly handicapped by continuing uncertainty over the future of the Atomic Energy Authority and the future of defence research facilities. On November 27, 1968, it was announced that the proposed white paper was being deferred on the grounds of both a new defence review and a decision from Parliament's Select Committee on Science and Technology to investigate defence research.[44] Reporting in 1969 the Select Committee put particular emphasis on closer links between defence research establishments and industry.[45] Labour backbenchers were also complaining of the ineffectiveness of government attempts to foster civil research in the defence laboratories.[46] The Select Committee hearings provided an opportunity for some scathing remarks about the laboratories, notably by Sir Solly Zuckerman, the government's Chief Scientific Advisor, who claimed that some of them were "so dreary as to be unbelievable".[47] Zuckerman firmly rejected the notion that defence laboratories should be re-deployed in the civil field once their primary task was completed. In his opinion, if the objective of a laboratory no longer applied it should be closed down: "Institutions should not be kept alive merely for the purpose of keeping them alive".[48] The notable omission from the 1970 green paper of any consideration of defence research was seen as a particular weakness by its critics.

The proposal to establish a British Research and Development Corporation, outlined in the green paper of 1970 was a concerted attempt by the government to find some way out of the seemingly insoluble problems presented by the laboratories. Benn and Clarke made presentations to key groups within and without government and were, it has been recorded, completely unswayed by the considerable opposition generated by the proposals.[49]

The pages of Nature reflected the debate surrounding the green paper.[50] A leading article considered the proposals as "radical, fashionable ... and sensible", and then proceeded to catalogue objections which made them impractical.[51] Firstly, there existed a strong suspicion that it was merely an expedient way of solving the Harwell problem to the detriment of the other participants who would be dominated by Harwell's sheer relative size and hence influence within the new organisation. Secondly the problem of defence research was omitted entirely. Much scepticism existed with regard to claims that the organisation could be self-supporting by 1975 earning one third of its income from industry with the rest contracted from government departments.[52]

If the new organisation could not achieve sufficient outside funding the implications were two-fold. Either it would be a continual drain on public funds or suffer cut-backs in the scale of its operation, perhaps indiscriminately. The Institution of Professional Civil Servants declared it to be a "plan for creating redundancy"[53] if financial limits were adhered to. An unfamiliar ally, the Confederation of British Industry, (CBI), similarly felt it to be a cover for running down laboratories which were uneconomic.[54] The view of the Confederation, a consistent critic of the way the laboratories operated, was that accountability was best pursued by having the closest possible links with departments concerned with the work of individual laboratories. It thus preferred "a modest reshuffling" among government departments along with the redeployment of Harwell staff.[55] These views were later consolidated in the CBI's submission to the Select Committee on Science and Technology two years later, which again stressed the need to integrate research and development with other government activities such that research was directed by known and projected demands.[56] It considered that research for industry was best done by industry itself although it was envisaged that the public laboratories had a continuing role to play as "contractors" to industry on a commercial basis. The philosophy of the CBI was closely attuned to the view of the Conservative Party, which, through its spokesmen on these issues, also supported a strictly functional relationship between government applied research and users of research. The Conservatives reiterated the belief that government laboratories should not do industrial research. David Price, the principal spokesman for party policy on science in the late 1960's expressed these sentiments in an article written in 1967. In this he observed that "the separate departments should be responsible for the research projects closely related to the work of those departments".[57] In Parliament the same year he pressured the Secretary of State for Technology to reveal what steps were being taken to shift the emphasis in government-sponsored work away from the laboratories to industry and the university.[58] Sir Keith Joseph, the party's spokesman on technology, later took up this theme when he said that:

> "we believe that there should be a greater effort by the Government to hive off research wherever possible to private enterprise .... and to reduce the sphere of research covered directly by Ministerial responsibility."[59]

Later, in submissions made by Ministers and their advisors to the Select Committee on Science and Technology in 1972, it was clear that the Conservative Party had carried these views into government and was committed to the strict functional deployment of government research and development. David Price, then Under-Secretary to the Department of Trade and Industry, stated before the committee that: "we see our interest in science and technology as an instrument for achieving our departmental objective .... we do not see a totality of civil research as a whole"[60] - sentiments in sympathy with the evidence of Sir Alan Cottrell, government Chief Scientific Advisor, and Lord Jellicoe, minister with overall responsibility for scientific matters.[61] As a result of these hearings the Select Committee suggested the appointment of a Cabinet Minister with responsibility for research and development, a suggestion clearly completely at odds with current policy and summarily dismissed.[62] Also expressive of the Conservative policy was the government's reaction to another recommendation from the Select Committee, that the independence of the laboratories be increased and that the government should consider setting up a statutory "Research Establishment Authority" to supervise the collective work of the three so-called multifunctional laboratories; the National Physical Laboratory, the National Engineering Laboratory and Warren Spring Laboratory. The suggestion recalled not only Benn's British Research and Development Corporation but also the conclusions of the Trend Committee in 1963. Once again this was dismissed by the Conservative Government, which replied that "fuller integration .... of the research and development in these laboratories with the policy and executive functions of DTI will be of greater benefit".[63]

On assuming power in 1970 the Conservative government had immediately dropped the unpopular proposals of the green paper and begun its own reviews of both the machinery of central government and research and development. Nevertheless, no immediate replacement for the green paper was forthcoming and nearly a year later the columns of Nature were bearing complaints of "persistent uncertainty .... towards the whole principle of how and when Governments should intervene in industrial research".[64] Yet by this time one commissioned report on research and development was complete and unpublished with another nearing completion. The former was written by a committee appointed by the Council for Scientific Policy under the chairmanship of Sir Frederick Dainton and was primarily concerned with the workings of the research councils.[65]

The other report had origins which are not entirely clear. At the end of March 1971, the newly formed Central Policy Review Staff, a body which had been set up to provide direct advice on particular topics of interest to the Cabinet, was asked by the Government to report by October on government research and development.[66] The subsequent report appears to have been prepared chiefly by Lord Rothschild with the assistance of J.F. Mayne, Head and Assistant Secretary respectively of the Central Policy Review Staff, with help from the staff of Sir Alan Cottrell's chief scientific advisor's office.[67] Why Rothschild alone, rather than the Central Policy Review Staff as a whole took responsibility for the report is unclear, but may well reflect the extremely short time available. The Dainton report was completed in May 1971 and remained unpublished until Rothschild's was completed and they were published together.[68] It is unclear what the formal terms of reference provided for Rothschild were, if indeed they were given, for none were provided in the eventual report. On this point we can merely speculate by looking at the context in which the report was commissioned.

The Conservative Party came to power committed, it seems, to the functional deployment of research facilities in line with the programmes of individual departments, to provide a basis for accountability and, more pragmatically, stricter controls on expenditure for public sector research. In general terms this pre-supposed the so-called "customer-contractor" principle implicitly, the principle which Rothschild made explicit. What appears likely is that Rothschild was asked to provide some guidance as to the detailed organisational and administrative framework to implement the concept in reasonably simple explicit principles,[69] so as to provide a framework for its implementation and the legitimation for its use. In the Government's introduction to the Report containing Lord Rothschild's proposal, the "customer/contractor" principle was endorsed, that is, taken as given. Rothschild in a sense "rubber-stamped" a principle which was already present in conservative policy and was being introduced in some areas already, such as in the organisation for commissioning research in the Department of Trade and Industry.

As part of a sweeping review of the functions of departments begun in October 1970, a review of the work of a number of the Ministry of Technology laboratories was undertaken, not starting from an institutional basis, but rather looking at programmes, projects, and above all strategic aims. It has been pointed out elsewhere that this review can be seen as a continuation of a set of reviews dating from 1969.[70] Preliminary moves to reduce the individual institutional power of the laboratories had begun even earlier. It had been recognized that to shift the laboratories towards a functional programmatical basis the balance of power would need to change with less emphasis on advisory boards of scientists institutionally aligned, but with more centralised direction, related if possible to other aspects of the Ministry's industrial policy. Thus the establishments would be linked to broadly defined fields of technological concern or industrial sectors. Within this framework the laboratories could be more easily given a functional remit.

The first action of note along these lines was the severance of the National Physical Laboratory from its traditional ties with the Royal Society, one of the most bitterly contested moves made by the Ministry of Technology, with Blackett as President of the Royal Society crucial in eventually carrying it through.[72] The transfer of control of the National Physical Laboratory was a highly symbolic act highlighting the demise of the traditional role of the public establishments and the shift to functional control.

In 1969 a number of research advisory committees, involving the significant participation of industrialists, were set up to examine research on a programme rather than an institutional basis.[73] At the same time the steering committees and visiting boards for the National

Physical Laboratory, the National Engineering Laboratory and Warren Spring Laboratory were abolished. The programme committees operated for two to three years by which time they had made sufficient progress in assessing the strategic needs of their respective fields, to be disbanded in favour of a more formal structure. By the end of 1970 there was less reliance on the traditional advisory role provided by the scientific community and more emphasis on identifying and involving end users. The concepts developed in the Rothschild Report thus bore some resemblance to existing developments within the Department of Trade and Industry.

In November 1971 the Rothschild Report was published advocating a wider and more systematic application of the customer-contractor principle. Very soon after, the Department of Trade and Industry was able to announce its plans to establish a series of Research Requirements Boards, in accordance with the principles set out in Rothschild's report, with direct "customer" responsibilities for commissioning work within the fields of research for which they were given responsibility, and expected to play a leading role in determining the balance of research programmes within these fields.[74]

Strictly speaking, although closely related to the spirit of the Rothschild Report, new Departmental procedures did not follow its specific suggestions for administrative principles. Rothschild had stated that advice to departmental "customers" should be provided by a Chief Scientist with supporting staff, with the supervision of contracts and overall administration of departmental research establishments undertaken by a hierarchically equivalent but quite distinct Controller of R&D. The Institution of Professional Civil Servants was one group which disagreed with such a split responsibility, although it was particularly enthusiastic about setting up strong Chief Scientist organisations to strengthen the scientific capability of departments.[75] In general this was the pattern adopted by departments, with responsibility for overlooking departments' scientific work vested in a Chief Scientist who also was responsible for inter-departmental co-ordination.

A particular feature of the Rothschild Report was its simplistic distinction between basic and applied research, a distinction which Rothschild considered relevant to the applicability of the customer-contractor principle. Many of the critics of the report, however, focussed on the dangers of adopting such a simplistic classification for the basis of administrative principles. The Institution of Professional Civil Servants, along with other commentators particularly noted the omission of so-called "strategic research",[76] a category used in the Dainton Report and which recalled the category designated "objective basic research" by the Gibb-Zuckerman Report in 1961. The latter had identified "objective basic research" as the characteristic category applicable to government research establishments: indeed, the principle of developing the basic scientific disciplines underlying applied science had been a foundation stone of the traditional role of the laboratories. Rothschild subsumed this into what he called the "general research surcharge", covering research not directly concerned with programmes commissioned by "customers".[77] He suggested this category should not amount to, on average, more than 10% of expenditure sanctioned by customers.

This issue was also raised by the Industrial Activities Committee of the Royal Society which also rejected Rothschild's crude classification and in particular the absence in the Rothschild Report of any analysis of the necessity to organise government research establishments "for the continued maintenance and furthering of a body of expertise in key specialties and sub-specialties within applied science".[78] That in the same report the Industrial Activities Committee should recommend consideration of transferring the National Physical Laboratory to the control of the Science Research Council was clear recognition of the strong institutionalisation of the principle of strategic research in that laboratory and the threat implied from developments in departmental policy.

The Rothschild Report reflected a major shift occurring in the operational framework of the laboratories. It paralleled changes of opinion in the Department of Trade and Industry, and, to a lesser extent, the Department of the Environment.[79] Thus the Rothschild Report catalysed and legitimated changes already underway. Nevertheless the implications for the future of the departmental laboratories were always overshadowed in the debate by the controversial implications of extending the functional control of research to the work of the Research Councils. Political commitment to institutionalising the customer-contractor principle remained resolute, and indeed the Government's response to objections and alternatives was perfunctory and negative.

The publication of its response to the recommendations of the Select Committee on Science and Technology in December 1972 formally marked the end of a debate which had continued in various forms for close on ten years. Effectively the debate had subsided some months earlier for in July of that year a Nature leader reflecting on the Select Committee hearings observed that:

> "In retrospect, the most striking feature of the six-month debate about the re-organisation of civil research and development in Britain is the marvellous silence which has now followed the ending of the debate."[80]

For many of the laboratories the struggle to maintain their position was only beginning. At the start of the long debate in the early sixties they occupied a prominent position in government policy. At the end they were uncertain appendages.

Changes in the deployment of research resources

In contrast to the previous contextual analysis it is possible to note some of the more immediate impacts on both the deployment and function of the government laboratories. Table 10 provides some indication of the relative balance of research manpower between government departments during the period in question. These figures illustrate the prominence of the Ministry of Technology and particularly the high level of support for nuclear and defence research with 14% of total public qualified manpower in the establishments of the Atomic Energy Authority and 46% in defence establishments.

The emphasis on research and development in these sectors is further highlighted when one considers that much of the scientific manpower employed in other departments was concerned with inspectorate duties rather than with research itself. In the Ministry of Public Building and Works, for instance, of the total of 1,183 qualified scientists and engineers only 267 were employed in the Ministry's only major research establishment, the Building Research Station, a pattern evident elsewhere.

The pattern of deployment of research establishments among government departments over the period 1964 to 1972 is shown in Table 11 which concentrates on the departmental centres which figure in the debates in this period. In 1964, apart from the important exception of the establishments of the Atomic Energy Authority, most of the civil

TABLE 10

Qualified Scientists and Engineers employed in Government Departments (January 1970)

Department of Agriculture and Fisheries for Scotland			133
Forestry Commission			287
Home Office			191
Ministry of Agriculture, Fisheries and Food			707
Ministry of Overseas Development			209
Ministry of Public Building and Works			1183
Ministry of Transport			605
Ministry of Technology:	UKAEA	1535	
	Aviation Laboratories	1800	
	Civil Laboratories	1123	
			4458
Ministry of Defence			3384

Source: Hansard, H.C. Debates, Fifth Series, 798 (March 23, 1970), written answers, cols. 307-308; 801 (May 28, 1970), written answers, cols. 567-569.

TABLE 11 Deployment of Major Public Research Laboratories Among Government Departments 1964-1972

1964	1968	1972
Department of Scientific & Industrial Research	Ministry of Technology	Department of Trade and Industry
National Physical Laboratory	National Physical Laboratory	National Physical Laboratory
Warren Spring Laboratory	Warren Spring Laboratory	Warren Spring Laboratory
National Engineering Laboratory	National Engineering Laboratory	National Engineering Laboratory
Laboratory of the Government Chemist	Laboratory of the Government Chemist	Laboratory of the Government Chemist
Torrey Research Station	Torrey Research Station	
Fire Research Station	Fire Research Station	Department of the Environment
National Chemical Laboratory	Forest Products Research Laboratory	Building Research Station
Building Research Station	Hydraulics Research Station	Fire Research Station
Road Research Laboratory	Water Pollution Research Laboratory	Forest Products Research Laboratory
Forest Products Research Laboratory	AEA Laboratories	Hydraulics Research Station
Tropical Products Institute	Aviation Laboratories	Road Research Laboratory
Hydraulics Research Station		Water Pollution Research Laboratory
Water Pollution Research Laboratory	Ministry of Transport	
	Road Research Laboratory	Ministry of Agriculture, Fisheries & Fo
Atomic Energy Authority		Torrey Research Station
Harwell	Ministry of Overseas Development	
Risley		Ministry of Defence
Culham	Tropical Products Institute	Army, Navy and Aviation Laboratories including
Atomic Weapons Research Establishment	Ministry of Public Building and Works	Atomic Weapons Research Establishment
	Building Research Station	
Ministry of Defence		AEA
31 establishments	Ministry of Defence	Harwell
Ministry of Aviation	31 establishments	Risley
8 establishments, including		Culham
Royal Radar Establishment		
National Gas Turbine Establishment		
Royal Aircraft Establishment		

research establishments were under the Department of Scientific and Industrial Research. Defence research was divided between two ministries, Defence and Aviation, the former in control of 31 establishments of varying size and the latter overseeing eight establishments including the giant Royal Aircraft Establishment, which also had responsibilities in the civil aviation field, and the Royal Radar Establishments, the largest centre for electronics research in Britain. At this time the Atomic Weapons Research Establishment was part of the Atomic Energy Authority.

By 1968 this pattern of deployment had changed significantly due mainly to the establishment of the Ministry of Technology. Although this Ministry assumed control of many of the ex-DSIR laboratories a certain degree of functional redeployment occurred when the Road Research Laboratory was transferred to the Ministry of Transport, the Building Research Station to the Ministry of Public Building and Works, and the Tropical Products Institute to the Ministry of Overseas Development. A further consequence of the dismemberment of the DSIR was that the newly formed Science Research Council assumed responsibility for the Radio Research Station and the Royal Observatory with the Natural Environment Research Council taking over the Geological Survey.[81]

In 1967 the Ministry of Technology took charge of the aviation laboratories following the merger with the aviation ministry. Despite pressures to transfer the National Physical Laboratory to the Science Research Council, its industrial responsibilities in the standards field ensured that it remained in the Ministry of Technology. In 1965 the Chemical Research Laboratory effectively became part of the National Physical Laboratory.

The functional deployment of laboratories was even more pronounced by 1972 with the creation of the large federal departments of Trade and Industry, and Environment. The research capability of the Department of Trade and Industry consisted primarily of what by this time were referred to as the "multifunctional" laboratories; National Physical Laboratory, National Engineering Laboratory and Warren Spring Laboratory. The Laboratory of the Government Chemist remained under its brief purely as a matter of convenience. The department had also inherited the Safety in Mines Research Laboratory in consequence of the amalgamation of the Ministry of Power into the Ministry of Technology in 1969. In 1974 this laboratory was to become part of the new Department of Energy and moved again in 1976 following the establishment of the Health and Safety Executive. The process of strict functionalisation adopted after 1970 was also illustrated by the transfer of the Atomic Weapons Research Establishment from the Atomic Energy Authority as recommended by the Rayner report on defence procurement.[82]

Some indication of the changes in relative strength of establishments is given in Tables 12 and 13. Despite concern expressed over the large concentration of manpower in public laboratories there is no evidence of any immediate overall reductions in this period, indeed some laboratories succeeded in expanding significantly. Harwell, under tremendous political pressure suffered a decrease in complement, but not enough to be considered a running down of the laboratory.

In the Ministry of Technology the pressure to reorient laboratories had only limited effects in the short term, and appears to have extended the scope of work rather than changing it dramatically. Repayment work from outside agencies still represented only a small fraction of the overall expenditure (see Table 14). Exceptions were

TABLE 12 Total Staff Numbers in Selected Government Research Establishments 1965-1972

	1964/65	1965/66	1966/67	1967/68	1968/69	1969/70	1970/71	1971/72
Building Research Station	670	690	693	802	850	*	*	*
Fire Research Station	137	141	149	*	164	184	*	*
Forest Products Research Laboratory	175	174	177	*	181	188	*	*
Hydraulics Research Station	222	223	235	*	221	253	*	270
Laboratory of the Government Chemist	383	395	395	*	387	411	400	*
National Engineering Laboratory	739	787	795	*	900	960	1000	*
National Physical Laboratory	1665	1630	1661	*	1665	1720	1600	*
Torrey Research Station	204	196	198	*	210	215	200	*
Warren Spring Laboratory	394	392	398	*	419	449	400	*
Water Pollution Research Laboratory	172	164	171	*	186	203	*	200
Safety in Mines Research Establishment	*	*	404	386	381	407	400	384
Road Research Laboratory	800	*	*	*	*	*	917	985
AERE Harwell	*	*	*	*	4580	*	*	*

Source: Various, including written Parliamentary answers, Select Committee on Science and Technology minutes of evidence, laboratory reports, Nature, personal communication.

Notes:
1. * = not available
2. Due to differences in compilation certain inconsistencies may inadvertently be present. For instance, figures may or may not include the complements of outstations.

TABLE 13 Net Cost[1] of Selected Government Research Establishments 1965-1972[2] (£000's)

	1964/65	1965/66	1966/67	1967/68	1968/69	1969/70	1970/71	1971/72
Building Research Station	979	1040	936	*	2057	*	2140	
Fire Research Station	52	70	187	*	129	226	*	*
Forest Products Research Laboratory	237	260	239	*	331	388	*	*
Hydraulics Research Station	144	43	257	380	117	103	*	*
Laboratory of the Government Chemist	593	596	570	*	743	886	926	1090
National Engineering Laboratory	1120	1409	940	*	2240	2495	2928	3089
National Physical Laboratory	2275	2536	2216	4576	4836	5422	5706	5290
Torrey Research Station	286	331	229	*	415	519	*	*
Warren Spring Laboratory	660	737	505	*	1132	1221	1211	1372
Water Pollution Research Laboratory	231	257	228	*	354	456	*	*
Safety in Mines Research Establishment	*	*	*	*	*	872	906	1079
Road Research Laboratory	1420	1600	2110	2280	2540	2800	*	*
AERE Harwell	*	*	*	*	*	13700	14100	*

Source: Various including Parliamentary written answers, Select Committee on Science and Technology minutes of evidence, laboratory reports etc.

Notes:
1. Net Cost = Gross Cost - Receipts.
2. Problems of comparability exist due to varying standards of assessing gross expenditure of a laboratory not explicit in the usual official sources. Considerable variation can be introduced by including, or not including, depreciation costs and overhead costs incurred by central departmental staff. Inflationary effects also distort the figures.

TABLE 14

Non-Governmental Work Undertaken by Ministry of Technology Research Establishments 1967-1970

(£000's)

	1967/8	1968/9	1969/70
National Physical Laboratory	283	286	268
National Engineering Laboratory	163	113	197
Warren Spring Laboratory	66	125	87
Hydraulics Research Station	390	342	370
Forest Products Research Laboratory	17	21	26
AEA Research Group	1647	2109	2438

Source: Eric Lubbock, "End of a Myth", New Scientist 45 (1970), 498-499, p.498.

the Hydraulics Research Station, which had traditionally undertaken sponsored research and Harwell which was rapidly expanding its non-nuclear work. Nevertheless there is ample evidence in these figures to suggest that the critics of the proposed British Research and Development Corporation were correct in claiming that the assumed level of outside contract work possible for laboratories to undertake was overoptimistic.

Greater emphasis began to be placed in the laboratories on educational functions and the marketing of expertise. In 1967 and 1968 for instance the National Engineering Laboratory held conferences designed to promote a wider understanding of the programme languages used in numerically-controlled machine tools while Warren Spring Laboratory sponsored courses for firms interested in the possibilities of installing process plant control computers to help with running of plant. Similar educational courses began to be a feature at both the Royal Aircraft Establishment and the Atomic Energy Authority, aimed not at scientists but rather at industrialists concerned closely with production. Provision of advice, services, and demonstration facilities was intended to have short term effects and incorporated a steadily increasing element of discrimination between individual firms. The expertise of the public laboratories was also drawn on to advise on a number of general support schemes for industry promoted by the Ministry of Technology.

The impact of such policies is difficult to estimate. It was recognised in one case, however, that circularising the results of research undertaken at the National Engineering Laboratory on the performance of mixed flow fans, resulted directly in production breakthroughs.[83] The increasing element of discrimination was in certain cases problematic. For the National Engineering Laboratory, for instance, the move towards direct sponsorship brought it further into competition with Research Associations reinforcing the uncertainty surrounding its precise role with respect to other agencies.

New initiatives also emerged as a result of government intent to redeploy defence research facilities into civil applications. Industrial Applications Units were set up at both the Royal Aircraft Establishment and the Royal Radar Establishment providing private firms with consultative services and research support. The Royal Aircraft Establishment, in addition, contributed towards a Numerical Control Advisory Service (NCADA) in collaboration with the Production Engineering Research Association and Airmec - AEI. The Atomic Weapons Research Establishment at Aldermarston was a focus for another scheme, the Alderma ston Project for the Application of Computers to Engineering (APACE). When the Conservatives took up office in 1970, however, most of the schemes were dismantled before they had really got started, in line with the view that research should be strictly functional to departmental requirements. In 1971, as a result of the Rayner inquiry, a new defence procurement organisation was set up and following a study of defence research beginning in 1972 the establishments were rationalised in accordance with the new procurement arrangements.

Perhaps the most notable impact of policy changes during this period was the way Harwell successfully engaged upon a major exercise in redeployment of staff and diversification of activities.[84] By 1965 it had become clear that with the beginning of the development of second generation nuclear power stations the scale of research effort at Harwell needed to be drastically reduced. As already indicated, in consequence Harwell figured prominently both explicitly and implicitly in the debates over the future of public research and there existed a strong current of feeling that it should be run down. Staff at the laboratory were vehement in their opposition to either closure or any major reductions in strength.[85] One possibility was to expand work on fusion research. This, however, had already been hived off to Culham and an alternative course was chosen to diversify into non-nuclear contract work based on the existing expertise available at Harwell. It was recognised in the laboratory that such a mission to help industry was likely to receive political support. Politically the proposition was indeed attractive for it forestalled the immediate problem, and provisions were made for it to undertake non-nuclear work in the Science and Technology Act 1965 and this aspect of the laboratory's activities thereafter grew rapidly. Between 1966-7 and 1974-5 staff work for industry and non-nuclear governmental work rose from 5% to 50% of total work undertaken with earnings similarly increased.[86] By 1977 annual earnings from contract and consultancy services had risen to £16.6 m.[87] The ability of the laboratory to increase its work in this area through effective marketing ensured its survival. Indeed Harwell was to emerge as a model against which other laboratories were to be compared, as contract research became a major function expected of government industrial laboratories.

Rothschild Applied

By 1972 "accountability" had become a fashionable catchword. It was to be achieved by a "close relationship" between laboratories and their customers. In this context, and emphasised by the Rothschild

Report, contract research had an obvious economic justification. The traditional manner in which laboratories had previously operated in relative autonomy had given way to a more vigorous functional deployment with Rothschild supplying the operational principles. An account of the manner in which customer-contractor principles were applied in major departments of state already exists,[88] demonstrating how only the Ministry of Agriculture, Fisheries and Food strictly followed the designated procedures, with on the one hand a chief scientist organisation (to advise "customers") and on the other, a Controller of R&D (to oversee the execution of research programmes), with no line relationship between them. The "chief scientist" function within the Department of Trade and Industry in the sense of Rothschild, was supplied by the Requirements Boards which were set up. Similarly in the Department of the Environment, Research Requirements Committees fulfilled this role in association with a Directorate of Research Requirements and Programme Review Committees.

For many of the laboratories these new arrangements had fundamental implications. No longer were programmes drawn up in consultation with institutionally aligned advisory committees and permanent secretaries, but were now to be put together piecemeal from a wider range of interlocking sources, developing a so-called "portfolio" of research programmes. This was a profound change. No longer were laboratories conceived as agents for developing programmes of objective basic research. Now they were expected to respond in an ad hoc fashion to functional requirements even though the initiatives over research programmes remained largely within their responsibility. The following chapter demonstrates that, although the laboratories most immediately affected by the new arrangements, slowly, in some cases painfully, adjusted they became increasingly vulnerable to attacks on resources and manpower in the light of public expenditure cutbacks and to pressures in recent years for privatisation.

CHAPTER SEVEN

Government Research Establishments in the 1970's

As argued in the previous chapter, the years between 1967 and 1972 were marked by distinct changes in the immediate political environment of the public research establishments. Changes in attitudes, however, regarding the value of public research and, equally significant, the manner in which research programmes should be determined, had little immediate impact on the day to day working patterns within the laboratories. Nevertheless, the fundamental shift in the conception of public research which was implied had implications in turn which have since become apparent.

What was referred to in the previous chapter as "the turning point" was in effect the calling into question of the legitimacy of departmental research establishments. The legitimacy of the research establishments related to the public acceptance of the validity of their role. The maintenance of legitimacy is, however, crucial for the semi-autonomy required for institutional stability and continuity. Thus a crisis of legitimacy is related to an erosion of autonomy and uncertainty with respect to role. In the present chapter these issues are examined with respect to the experience of public research laboratories in the period 1972 to 1982.

The Legitimacy of Public Research in Government Laboratories

The historical basis for the legitimacy of the role of the government research establishments, and the manner in which this was incorporated in operational procedures, have been examined in the preceding chapters. Legitimacy was based on an acceptance by government of the role of sponsorship for applied research and development, institutionalised in a way reflecting pre-conceived ideas about the nature of scientific research, its relationship to material progress, and the conditions for its successful incorporation.

The Report on the Machinery of Government, issued in 1918,[1] it may be recalled, specifically demarcated between two distinct types of government research; research carried out at the direction of executive departments to fulfill their immediate operational needs; and general research of a more long-term nature relevant not only to these narrower requirements but also to the needs of other institutions such as industry and local government. In particular it was stressed that some separation should be maintained between the administration of schemes of general research and the short term executive responsibilities of central departments.

This demarcation was reflected in the use made of the constitutional position of the Privy Council to act as a focus for various schemes of general research. Such arrangements, embodied in the so-called "Haldane Principle", ensured that the major responsibility for the elucidation of research programmes rested primarily with scientists. Individual laboratory directors, supported by influential, if increasingly passive, advisory committees assumed considerable powers of negotiation regarding the balance and scale of programmes within an agreed research budget.

The primacy given to scientific value was extended to basic research carried out in the context of defence and nuclear programmes. Traditionally directors of public laboratories were appointed primarily on the basis of scientific credentials. At the National Physical Laboratory the director was appointed through the recommendations of the Royal Society, was a figure of high scientific reputation, given a rank to match the most senior civil servants bar the permanent secretaries, and the position usually resulted in a knighthood.[2] The directors of public laboratories had considerable influence concerning the balance of research programmes and a major role in financial negotiations over expenditure plans. Until the recent institutionalisation of the "customer-contractor" principle, negotiations over the balance of research was conducted between the directors and the permanent secretary of the sponsoring department.

Moves towards programme planning independent of individual establishments fundamentally changed the traditional relationship of management and negotiation with, in the new arrangements, laboratories expected to acquire a "portfolio" of projects, independently negotiated. Greater external determination of research programmes, with a particular emphasis on economic justification rather than scientific excellence posed new problems for senior laboratory management. A number of laboratory directors, particularly those more recently appointed, began to see their role as management administrators rather than scientific leaders. Senior laboratory staff were encouraged to gain managerial experience working within departmental policy divisions, in order to bring greater contact and understanding between individual specialist establishments and general policy. This reflected the spirit of the Fulton Report, published in 1968, which recommended moves to develop "a greater professionalism both among specialists (e.g. scientists and engineers) and administrators", by providing the former with "more training in management, and opportunities for greater responsibility."[3]

Through such changes, and along with a greater emphasis on the need for laboratory staff to justify their research in broader terms than merely scientific value, many public laboratories came under severe pressure to adjust to the more complicated methods for determining research programmes.

The erosion of the traditional basis for the legitimacy of the work of national laboratories was particularly emphasised by the changing function, and indeed the status, of the laboratory directors. In a number of instances the rank of director was formally downgraded, arguably a reflection of the decreasing status of the laboratories themselves, and more pragmatically a limitation on the power the directors traditionally had acquired. Thus the post of Director of the National Physical Laboratory was downgraded in the 1960's, and more recently the same occurred with regard to the National Engineering Laboratory following the early retirement, reportedly under pressure, of its Director, Dennis Mallinson.[4] As Mallinson was reported to comment at the time:

> Inevitably the downgrading of the director's post has been regarded by the staff as a downgrading of the importance of the laboratory in the eyes of the Department of Industry.[5]

The bitterness behind Mallinson's departure was hardly disguised.

Benign patronage as a principle of support gave way to more instrumental procedures of funding, introduced not without opposition from the laboratories, and requiring considerable adjustment. In turn the laboratories became exposed to the more direct impact of fluctuations in departmental policy posing a threat to continuity. In due course the public research establishments became more vulnerable to the effects of short term political expediency. The inability of the laboratories to reassert a convincing role in the face of considerable external pressure was accompanied by continuing reductions in manpower, reductions in funding, and moves towards the privatisation of a number of public laboratories.

Political intervention and national research: the Departments of Transport and of the Environment.

In 1971 the former Permanent Secretary to the Ministry of Technology, Sir Richard Clarke, observed that:

> One characteristic of the next period in machinery of government is the emergence of the "giant" departments, unprecedently large in breadth of business and with large staff and scale of operation. They are unitary departments with one Cabinet Minister in charge, with the full statutory powers and responsibility to Parliament; and a Permanent Secretary responsible to him.[6]

His comments reflected the wide-ranging reorganisation of central government undertaken by the Conservative administration which came to power in 1970. This brought into existence five such notable "giants"; the Foreign and Commonwealth Office, the Department of Health and Social Security, the Ministry of Defence, the Department of Trade and Industry, and the Department of the Environment.

The advantages of such a rationalisation were presented in a White Paper issued in October, 1970.[7] The large rationalised ministry could, in theory, develop its own strategy and decide its own priorities. It incorporated an explicit "functional principle of organisation" in which:

> The basic argument for this functional principle is that the purpose of organisation is to serve policy. And policy issues which are linked should be grouped together in organisational terms. Furthermore, such groupings of related functions clarifies the lines of demarcation between responsibilities and saves duplication of effort between departments. It achieves economies of scale and avoids the diffusion of expert knowledge and the difficulty of co-ordination which organisation by area or by client group would involve.[8]

While the White Paper did not refer directly to the function of the national laboratories within such a reorganisation it clearly complemented the Conservative Party policy of functional deployment of laboratories to serve the direct interests of executive departments.

Similarly the managerial principles outlined in Lord Rothschild's report, issued the following year, complemented the organisation of central government adopted by the Conservative Government. The "customer-contractor" principle as presented by Rothschild, provided a mechanism of management and control which was able to articulate in greater detail how the work of public research facilities could be functionally related to the strategic demands of executive departments. Nevertheless, the resulting functional deployment of research merely continued a process of decentralisation of general research begun by the previous administration. It represented a clear commitment to applied research functionally related to the direct imperatives of executive policy and an explicit rejection of any notion of a centralised "science policy".

Despite the promise of increased efficiency in the machinery of government hoped for by the promoters of these changes, the creation of the giant departments had first to overcome what Clarke referred to as:

> .... the inertia of the system .... you get benefits from doing something new, but are required at the same time to continue the old, and thus make no net savings at all.[9]

As Clarke further noted, to make the giants work put excessive pressure on the detail of organisation and management capable of resulting in clear policy determination and rapid execution. It particularly highlighted the managerial problems of integrating research institutions into the effective determination and execution of departmental policy, while at the same time maintaining the establishments as credible independent scientific institutions.

The problems related not only to the need to establish the effective administrative machinery necessary for the alignment of scientific programmes with departmental needs, but also to have sufficient suitably qualified administrators of a seniority which could ensure the successful utilisation of scientific expertise. It is clear that such problems were not satisfactorily resolved, to the detriment of the necessary continuity and effectiveness of research. A clear example is provided by events which affected the research institutions which were transferred to the Department of the Environment.

The establishment of the Department of the Environment, in name at least, reflected contemporary social concern for environmental issues, which recognised that such factors as housing, transport, urban development and pollution, were intimately connected. As the Government explained in announcing the decision to create the new Department:

> It is increasingly accepted that maintaining a decent environment, improving people's living conditions and providing for adequate transport facilities all come together in the planning of development ...... Because these functions interact, and because they give rise to acute and conflicting requirements, a new form of organisation is needed at the centre of the administrative system.[10]

In practice the new initiative was to comprise four previously distinct areas of administration; Transport, Housing and Local Government, Land and Natural Resources, and Public Building and Works. Similarly the research services for the new Department consisted of a number of previously unconnected research institutions; the Road Research Laboratory, previously under the Ministry of Transport, the Building Research Station which had been under the Ministry of Public Building and Works, along with four Ministry of Technology laboratories; the Fire Research Station, the Forest Products Research Laboratory, the Water Pollution Research Laboratory, and the Hydraulics Research Station. The Water Pollution Research Laboratory was later to be hived off as the Water Research Centre with the status of a research association following the rationalisation of the water supply industry. In 1973 the Building Research Station, the Forest Products Research Laboratory and the Fire Research Station were merged into a single research organisation, the Building Research Establishment.

The rather artificial departmental amalgamation presented obvious difficulties for the clear articulation of a coherent policy. A further handicap was the fact that the declared political directive that the laboratories serve the direct customer interests of their sponsoring departments ran counter to the traditional orientation of the ex-DSIR laboratories, which conducted research not only in the interests of departments but also relevant to external groups.

For a number of the laboratories which came nominally under the control of the Department of the Environment the new mandate was confusing, and in contrast to their links with industrial and commercial interests, links which had been actively promoted by the previous Government. The Building Research Establishment under the new regime was required to sever the informal links which had been established, particularly in the 1960's, with professional institutes and with industry at large, aided by the sophisticated information and advisory services which were developed.

The research programmes of the laboratories forming the Building Research Establishment became concentrated on short-term research of more immediate concern to the Department of the Environment in such areas as codes of practice and regulation. In contrast the manner in which the work of the Hydraulics Research Station could service departmental needs was never clear and it continued to operate serving outside interests with ministerial responsibility appearing more a convenience. Its external sources of income from contract work, however, did serve to provide the laboratory with some measure of protection from political pressures. For the other laboratories in contrast the pressure to conform to departmental policy provided difficulties for long-term continuity.

Problems of continuity were related to the increasing emphasis on short-term projects, but were particularly brought about due to changes in the way programme determination was decentralised as the Department's interpretation of the "customer'contractor" principle was brought into practice.[11] Negotiations between the laboratories and Departmental officials regarding programme funding involved a number of officials of the Department at undersecretary level with responsibilities for particular policy areas. The conscious policy pursued by the Department of frequent changes at undersecretary level handicapped the ability of the laboratories to provide any long-term continuity in support of Departmental policy.

In the first five years of the Department of the Environment, research expenditure grew continuously in real terms. As Gibbons and Gummett have pointed out, until 1974 the greater part of this was devoted to research conducted in the Department's own laboratories.[12] At the same time, however, policy became explicitly geared to increasing the level of extra-mural research which grew from around 40% of the total research budget in 1972 to nearly 60% in 1974-75.[13] More serious problems for the long-term interests of the laboratories began in 1976 when severe restrictions were placed on the level of public expenditure. Proposals for future research had to be reviewed in the context of these constraints and the reductions imposed on civil service manpower. As a result provision was made for a reduction in research expenditure of nearly 25% over two years.[14]

In consequence all the laboratories came under severe pressure to impose rigid and inflexible restrictions on recruitment, as well as to encourage early retirements. Recruitment bans prevented the laboratories from retaining sufficient flexibility to respond to new research opportunities. The Hydraulics Research Station, for instance, was unable to expand to meet the buoyant market induced by the growth of the offshore oil industry.

The pressures became unremitting when, in 1979, a new Conservative administration was elected ideologically committed to reducing the size of the Civil Service and the level of public expenditure. The national laboratories became a prime target. By 1981 the number of scientific civil servants employed in the laboratories of the Departments of the

Environment and Transport was 26% less than the equivalent figure for 1976, compared with a decrease of around 10% in the total number of scientific civil servants in the same period.[15] Component parts of the Building Research Establishment were eroded with work traditionally carried out by the old Forest Products Research Laboratory transferred to the Timber Research and Development Association and fire research work transferred to a new Fire Insurers Organisation.

A further and, arguably, more serious threat to the status of the national laboratories was associated with the new administration's commitment to "privatisation": the transfer of services hitherto performed under public auspices to the private sector. Once again the national laboratories were prime candidates as the Government saw this avenue as both a means of making the laboratories immediately accountable to the "market" for their services, and simultaneously a way to reduce the size of the Civil Service in accordance with election promises.

Ominously for the establishments under the control of the Department of the Environment, the new Secretary of State for the Environment, Michael Heseltine, appeared one of the most vociferous advocates for public expenditure cuts and moves to privatise government agencies. An immediate and abrupt departure from previous policies occurred as the laboratories were given instructions to recover from external sources of funding as much of the cost of support for their work as possible.

The motives behind such moves were only thinly disguised. The greater the financial independence of the laboratories the more powerful the option of transfer to the private sector. In July 1980 Heseltine held out the promise of "exciting changes" in his Department by promoting what he referred to as a "creative tension" between those who spent government money and those who accounted for it.[16] He declared himself to be in favour of his Department having a greater role "in creating and developing private companies", particularly in the fields of direct labour, research and development and procurement.[17] Indications were thus presented of the prospect of moves to privatise both the Building Research Establishment and the Hydraulics Research Station.

Of the two research establishments, the Hydraulics Research Station was the more obvious candidate for such a policy, with its relatively high proportion of income from external contract work. During 1980 it became clear that the Government would press ahead with such a move as soon as the detailed options could be worked out. At that stage the most likely option was for the laboratory to become some form of independent research association.[18]

In the Summer of 1981 a "shadow board" was set up under the chairmanship of Sir Alan Harris to investigate ways of making the transition, and its report was submitted to the Secretary of State for the Environment in January 1982. It recommended that the laboratory should become a private research association with guarantors holding notional shares of around £5, creating a type of limited company status research foundation.[19] Staff of the laboratory were to be considered on secondment for a two years transitionary period. Nevertheless the shadow board also reported that a commercially viable "research foundation" could only be made to work if a 20% cut occurred in its total staff of around 250, a point made also in a submission from the civil service and manual unions.[20] In addition the shadow board specified a number of financial conditions which were needed.[21]

On April 1, 1982, the Hydraulics Research Station became the first public laboratory to be relaunched as a private venture. As one commentator noted:

> .... despite all the polemic, the station's renaming as HRS Ltd. can have only one real consequence - to cut loose from the Treasury purse an institution which is a potential liability in a declining world construction market.[22]

Although Heseltine pledged that at least 26% of the company's turnover would be guaranteed by the Government this was only for the first two or three years. Apart from this, the laboratory was "cut loose" with the board and guarantors, initially the Environment Secretary and the Foreign Secretary, taking responsibility for the staff, their pensions, and redundancy arrangements that would be necessary if the commercial operation failed.[23] In 1982 the Hydraulics Research Station was one of the world's top three centres of expertise in civil engineering hydraulics. To maintain this position it was required to increase its share of project work from overseas construction work in a declining world market by an estimated 60%.[24] As Greeman has noted, exactly how it will achieve this is hard to pin down.[25]

The Building Research Establishment has had a contrasting experience. In 1980 it appeared earmarked for the same fate as the Hydraulics Research Station. Without anywhere near the same level of repayment work the position was, however, more problematic. It was initially given an uncertain remit to recover from industry as much as possible of the costs of the establishment. Heseltine later made apparent the conditions under which he wished to see the organisation operate during a meeting with staff representatives at the Building Research Station. They were reported as including greater autonomy, the requirement to tender for research required by central Government, and other changes which were considered only possible if the Building Research Establishment was no longer part of the civil service.[26]

In summer 1981 concern for the future of the Building Research Establishment was highlighted by three particular factors; the decision to abolish the Department of the Environment's Research Directorate, indications that the Secretary of State for the Environment was intent with pressing ahead with plans to privatise the establishment, and a continuing decline in resources devoted to the work of the establishment. It subsequently became clear that considerable opposition to Heseltine's plans for the Building Research Establishment existed among industrial interests.

An important initiative came in September 1981 when a Working Party of the Building and Civil Engineering Economic Development Committee was set up under the chairmanship of Sir Peter Trench to look at the future and role of the Building Research Establishment. Three months later at the instigation of the Working Party a conference was called to take account of a wider industrial opinion. At the conference attended by over 70 leading industrial figures as well as the Environment Ministers, Heseltine and John Stanley, considerable opposition to any privatisation moves was expressed. Instead some ideas were floated which were favourably received and formally recommended subsequently when the Trench Committee reported in February 1982.

These recommendations proposed setting up a Research Strategy Committee under the auspices of the National Economic Development Office; to play a central co-ordinating role in the planning of building research in the United Kingdom including the determination of priorities.[27] It was emphasised that a strong Building Research Establishment was a pre-requisite for the Strategy Committee to work effectively and the report recommended the establishment of a Board of Management, composed of industrialists and client members, to supervise the work of the research establishment.

The initiative clearly provided Heseltine with a dilemma. Although ideologically favouring privatisation he had been presented with an attractive scheme providing closer association with industry. At the end of April he made the decision in favour of the proposals. The decision was greeted with relief by his erstwhile opponents. Bill Brett, Assistant General Secretary to IPCS, is quoted as calling it:

> .... a considerable victory because it means that by galvanising opinion the value of the BRE has had to be recognised albeit reluctantly by Heseltine.[28]

The decision was also welcomed by the director of the Building Research Establishment, Ivan Dunstan,[29] and a leader in the trade journal <u>Building</u> declared that:

> [it] must be good news. Coupled with an industry research strategy committee, such a board should help give research the direction it has been lacking since the Government started cutting back on the BRE's resources.[30]

The initiative undoubtedly marks an interesting and perhaps important precedent. It remains to be seen how effective it will be in practice. M.A. Smith, Chairman of the Building Research Establishment Non-Industrial Trade Union Side injected a note of realism by reminding that the "inexorable programme of arbitrary cuts that started in 1976 is continuing" with information available suggesting a projected complement of the Establishment of 760 for April 1984, a 40% cut since 1976.[31]

There are also the recommendations of Sir Derek Rayner's general review of efficiency in government departments to contend with. These proposed rationalising the Building Research Establishment by closing the Princes Risborough laboratory along with possibly the old Fire Research Station and transferring staff to the Garston site, with a total saving of 117 support staff.[32] The shape and future of the Building Research Establishment still remains subject to a number of uncertainties.

Another public laboratory which has experienced a traumatic reversal of fortune since 1976 is the Transport and Road Research Laboratory, which as the Road Research Laboratory became part of the Department of the Environment in 1971. During the first years of this department the newly named Transport and Road Research Laboratory began an ambitious programme of expansion to provide, what was hoped would amount to, a comprehensive research support for the determination and implementation of transport policy. A considerable increase occurred in expenditure on transport, traffic and safety studies. In addition, as part of its role as a focus for transport research, the laboratory began to contract out research to universities and colleges.

Between 1971 and 1976 the total non-industrial staff employed at the laboratory rose from 660 to 825, complemented by an increase in total expenditure from £4.2m to £6.35m (at 1972/3 prices) over the same period.[33]

Any hopes, however, that the laboratory would become an integral part of the formulation of transport policy proved over-optimistic. Although the laboratory and its director came more into contact with departmental policy-making machinery the opportunities envisaged for it to play a major role never materialised in practice.[34] Although the expansion of the laboratory had produced an increase in social and environmental studies of transport schemes and road safety, realities of political prejudice, along with entrenched "common sensical" notions among politicians, prevented research results based on "soft" social science work having any noticeable impact.

From 1976 the Transport and Road Research Laboratory began to suffer the severe impact of public expenditure cuts, particularly acute blows following the previous growth in resources. By 1980 its total complement of non-industrial staff had fallen to 670, a decrease of 20% in four years.[35] Its gross annual expenditure, by then at £4.05m (1972/3 prices), was less in real terms than ten years earlier when its brief was more limited.[36] A general decline in engineering research began at the laboratory in 1976 and by the end of the decade significant cuts were severely curtailing its transport and road safety programmes.

In July 1980 it was reported that further cuts in transport research were certain, that existing programmes were being severely examined and that further cuts would bear heavily on individual programmes.[37] Signs of the consternation present within the laboratory were indicated by the laboratory's director in his report for 1979 when he referred to the "uncertainties" and "new problems" facing his establishment following a 25% cut in research funding with transport research taking a 40% cut, from the peak four years earlier.[38] Despite substantial reductions in resources, it was claimed that the problems the laboratory were being asked to deal with had not diminished, and that the range and breadth of its interests had increased.[39]

Research into the environmental impact of heavy lorries was one particular programme affected in a period of widespread public concern over the issue. A claim made by a leading national newspaper that a pilot study on the safety of motor tyres was not being followed up due to expenditure restrictions was strenuously denied by the Department of Transport, which claimed that no part of the laboratory's programme had been "stopped, terminated or not carried out due to staff cuts or shortages of cash".[40] As the newspaper report pointed out the official response was in marked contrast to the laboratory director's admission that the cuts were "beginning to have a noticeable effect on the ability of the laboratory to maintain its position on some topics of long-term importance".[41]

Although by 1980 the laboratory had met its proscribed reductions in staffing, recruitment had not been restored, leading to a further decrease in staff, distorting its existing problems, and reducing the morale of its staff. Further ominous signs for the future of the laboratory came from a report from the Advisory Council for Applied Research and Development (ACARD), which criticised the high concentration of research and development in the public sector in general in support of procurement decisions.[42] It noted pointedly that; "R&D for road construction is dominated by a Government laboratory, the Transport and Road Research Laboratory".[43] The argument pursued by the report was that, where public purchasing was concerned, it doubted the wisdom of having only one source of research advice; that more research should be conducted by private sector interests responsible for marketing products and expertise; and that departmental research requirements should be acquired through competitive tender. As the report further noted "competition generally accelerates progress".[44] In the past, public research had always been envisaged as a unique function, while any competition with private interests was frowned upon. Such a reversal was remarkable, if nevertheless consistent with current Government policy.

By 1981 further reductions in resources had forced the Transport and Road Research Laboratory into plans to sell its expertise on a competitive basis to private industry and local authorities. The plan envisaged setting up a new company to enter into competition with transport consultancies and universities for research contracts.[45] Yet within months rumours were circulating suggesting even greater cuts in the laboratory's size, with a projected figure of 690 total staff by April 1983.[46] This would compare with a total complement of 1100 in 1976, a decrease of nearly 40%. In addition it was reported that the laboratory's scheme to form a shell company to compete for research contracts had run into opposition from the Treasury and, predictably, private consultants worried about the competition.[47] At the end of 1981 the future for the laboratory appeared bleak. Anecdotal evidence reported that at the laboratory's staff Christmas lunch:

.... traditionally the occasion when the research controller bangs the drum to boost staff morale, the more attentive observers failed to discern any mention of the future prospects of the troubled laboratory.[48]

The experience of the research institutions controlled [at present] by the Departments of the Environment and Transport illustrates, not least, the problems which have resulted, in part, from the functional deployment of research laboratories to executive departmental control. In principle a movement away from the traditional autonomy of general research, towards a relationship more integrated with the customer-needs of executive departments reflected changes in the perception of the nature of scientific activity and its relationship to material needs, along with the recognition that the institutional environment in which the establishments operated had changed significantly since the time they were set up. In practice the transition to new working practices failed to establish a significant role based on continuity of purpose. The semi-autonomy necessary for this was eroded and the function of the laboratories distorted by short term political expediency. Confidence in the role of public science was from its origins based partly on faith in the material contribution of research. Demands for accountability based on more than faith have inevitably forced the establishments into more short term work and the use of criteria of cost-effectiveness based upon commercial appeal which reflect immediate interests to the detriment of more long-term work.

The Commercialisation of Public Research: The industrial research establishments of the Department of Industry

Since the late 1950's, as was illustrated in previous chapters, pressures have been evident aimed at bringing the work of public research more to bear on the immediate needs of industry and away from long term basic research. The establishment of Warren Spring Laboratory directly reflected a shift from an emphasis on scientific to technological issues. During the brief existence of the Ministry of Technology, however, any emphasis on the technological function of public establishments began to recede before more direct forms of industrial intervention, and the first moves towards a conscious interventionist industrial policy which legitimated intervention at the level of the firm.

While in the 1970's the research establishments of the Department of Industry continued to have functions within the framework of the Department's sponsorship of industrial research, the dominant trend was in the change in emphasis from internal to external projects. In contrast to the days of the DSIR when all public funds for industrial research and development were provided for the work of either public laboratories or co-operative research associations, in the year 1978/79 private industrial firms received £55m from the Department of Industry in direct sponsorship for research and development compared with £45m spent by it in the public sector on research.[49]

Official figures show a general decline in the scale of funding for the public research laboratories for work in support of industry. The gross funding of the Department of Industry's research establishments[50] fell from £33m in 1973/74 to £28.5m in 1978/79 (at 1978 prices) despite a substantial growth in both contract work funded directly by industry and research funded by other government departments.[51] The latter included work on atmospheric pollution funded by the Department of the Environment at Warren Spring Laboratory and research on offshore structures funded by the Department of Energy at the National Maritime Institute. Overall the net cost of the laboratories to the Department of Industry fell from £28m to £18m (1978 prices).[52] These reductions in expenditure have been complemented by staff reductions from a peak of around 3,370 in 1976 to around 3,000 in 1979, a decrease of around 10%.[53] Scientific staff employed by the laboratories of the Department of Industry fell from 1,737 in 1976 to 1,443 in 1981, a decrease of 17%.[54]

Throughout the 1970's departmental policy encouraged the laboratories to seek to increase external funding, particularly from industry, in order to encourage "relevance" and "applicability" by applying a measure of cost-effectiveness based on direct contract research. From statements made in official reports the establishments were under pressure to do virtually the same amount of work with considerably less staff, and to be more selective so as to do more of what was considered relevant.[55] "Relevant" in this context usually implied work of a short-term interest to industry. Nevertheless, the increase in contract research undertaken for industry was not sufficient to prevent the Chief Scientist and Engineer to the Department of Industry, Duncan Davies, from expressing disappointment with the progress.[56]

Table 15 provides a more detailed indication of how the trend in manpower has affected individual laboratories. It clearly indicates the manner in which the activities of both the National Physical Laboratory, the National Engineering Laboratory, and Warren Spring Laboratory, have been reduced in scale, and have thus borne much of the brunt of political pressure to reduce manpower in the Department of Industry as a whole. In the eighteen months ending November 1980 the numbers of civil servants employed by the Department of Industry fell by 210 of which 120 were staff employed by the research establishments.[57] As indicated in the table the staffing policy of the Computer Aided Design Centre, founded in 1969, established an interesting precedent with staff seconded from a private firm.

The National Physical Laboratory experienced a particular upheaval during the 1970's. Its more narrowly defined remit as the national standards laboratory became re-emphasised through a slimming down of its wider activities. Work on aerodynamics, a subject in which the laboratory had taken a once pioneering role, was transferred to the Royal Aircraft Establishment in 1971, and in 1976 a further core of its traditional activities was removed when the Ship and Maritime Divisions were hived off to form an autonomous institution, the National Maritime Institute.

Later, part of its standards work was curtailed with the elimination or drastic reduction of two areas in the division concerned with chemical standards. This particular action resulted in some bitter correspondence in the press. As one writer ironically pointed out, the decision to cease work in chemical thermodynamic data came merely eighteen months after Duncan Davies, in his official role as Chief Scientist and Engineer to the Department of Industry, had prefaced the proceedings of a conference with the words that: ".... the selection and use of good reliable thermodynamic data is a crucial part of the process of much chemical design".[58] As the same correspondent noted:

TABLE 15

Total Staff in the Industrial Research Establishments 1970-1980

	1970	1975	1977	1978	1979	1980
National Physical Laboratory	1727	1408	1076	993	993	961
National Engineering Laboratory	960	913	930	853	811	761
Warren Spring Laboratory	449	405	393	362	370	358
National Maritime Institute[1]	-	-	265	281	288	286
Computer Aided Design Centre[2]	-	109	101	103	122	147
Laboratory of the Government Chemist	411	500	457	418	419	454

Various Sources

Notes: 1. Established 1976 from the Ship and Maritime Divisions of the National Physical Laboratory.

2. Staffed almost entirely by staff under contract from ICL Dataskill Ltd.

> I cannot take a large enough view to be indifferent to the total decline of chemistry in the NPL. I believe the dispersal of the skilled team in NPL will ultimately be seen as a mistake; it will be hard to rectify.[59]

Soon after the decision to cut work on chemical standards the process plant industry appealed for government help, through the National Economic Development Council. A report submitted to the Council from the Process Plant Economic Development Committee warned that without help the industry would not survive at its existing strength.[60] It particularly requested support through the provision of standards and specifications, and by support for research and development through the research establishments. In a later correspondence the Chairman of the National Physical Laboratory Section of the Institution of the Professional Civil Servants pointed out that the cuts in the Laboratory had specifically affected the provision of basic data for plant design and operation, the conservation of energy and materials, and the provision of certified reference materials used for standards, specifications, and quality control.[61]

Like other establishments the National Physical Laboratory came under severe pressure to increase its level of repayment work. The low proportion of externally funded research in the Laboratory was emphasised after the Ship and Maritime Divisions were hived off. Similarly manpower problems resulted from indiscriminate recruitment checks. Such problems resulted in shortages, particularly in middle to lower grades and especially for people for routine callibration work, and skilled craftsmen.[62]

Similar pressures have been felt at the National Engineering Laboratory. From the mid-1960's efforts were made to change it from being primarily an academic research organisation to being more commercially oriented. Inevitably this was handicapped by the continuing poor competitive position of the mechanical engineering industry. Internal adjustment to the use of more commercial criteria proved to be slow and controversial. The relationship between the National Engineering Laboratory and its main sponsoring Research Requirements Board was not altogether satisfactory in the years following the implementation of "customer-contractor" principles. Towards the end of the 1970's it was having more success with its submissions to the Research Requirements Board. This accompanied adjustments in its senior management structure in an attempt to improve external relationships by having full-time personnel working on the negotiation and submission of research proposals. In addition a marketing division had been formed. Yet despite these changes the future remains uncertain.

Like other public laboratories, the National Engineering Laboratory experienced traumatic cuts in staff numbers. Total staff was expected to be reduced to 720 by 1982 from a peak of 960 in 1970.[63] Further indications of the uncertainty regarding the status of the laboratory in public policy came when the director's post was downgraded, as indicated earlier in the chapter.

The ability of public laboratories to orient their work more towards commercial application has not appeared to have made them immune from staff cuts. At Warren Spring Laboratory, for instance, with well established contacts with users of new technology, in the year 1976/77 alone staff reductions amounted to 6.6% of the total establishment.[64] The same year Warren Spring Laboratory reduced its expenditure by 15.5% and direct funding from the Department of Industry fell from £3m to just over £2m (1977 prices).[65] These cuts fell particularly heavily on certain areas of research including catalysis research and work on marine pollution.

A feature of Warren Spring Laboratory was its dependence on funding from outside the Department of Industry. In 1976/77, for instance, 41.8% of this external funding came from other government departments, principally the Department of the Environment for work on atmospheric pollution.[66] In 1982 it was announced that research into air pollution would be severely curtailed. One report suggested that Britain's ability to influence future directives from the European Community on air pollution was likely to be weakened as a result of reduced government support for the Air Pollution Division at Warren Spring Laboratory.[67] In 1981/82 the contract for this work amounted to just under £1.7m.[68] In contrast the contract for 1982/83 was planned to be £1.3m and it seemed likely that the budget for 1983/84 would be only £1m.[69] Affected would be the laboratory's work on smells, and its National Survey of Air Pollution which was being cut by reducing the number of monitoring stations from 1200 to 150.[70]

In 1976/77 industrial receipts at Warren Spring Laboratory amounted to £0.6m;an increase of 86% in real terms over the previous three years.[71] Its major customers were mainly large multinational and national companies; mining companies, chemical manufacturers, and other industrial operations employing process plant, concentrating particularly on user problems. At a time when renewed concern was evident concerning the continuity and security of mineral supplies, with the Government showing indications of a willingness to promote the development of a national minerals policy which would include a greater emphasis on reclamation, recycling and substitution,[72] areas in which Warren Spring Laboratory had developed considerable expertise, the laboratory experienced the kind of cuts evident in other establishments. Manpower restrictions came at a time when the laboratory was being encouraged to increase returns from externally funded research. As a consequence it was unable to expand to the size of the potential market for its services.[73] Such restrictions placed fundamental constraints on certain areas of activity, reduced time available for forward planning, and raised the need for more selective use of resources through the difficult procedure of establishing an internal consensus.

Despite pressures forcommercialisation of research in the industrial research laboratories of the Department of Industry, only the National Maritime Institute has so far been earmarked for disestablishment from the Civil Service. The National Maritime Institute was set up as a separate national laboratory in July 1976 comprising initially two divisions of the National Physical Laboratory. The setting up of the new laboratory coincided with a number of major national developments including both the dramatic growth of the offshore oil industry based in the North Sea and concern for the hazards associated with the transport of dangerous cargoes by large ocean going vessels. Nevertheless its activities were not to be confined to the marine field but were intended to include areas of civil engineering involving both aerodynamics and hydrodynamics.

In 1972 with the formal introduction of "customer-contractor" procedures the newly formed Ship and Marine Technology Requirements Board had become the major agency for the sponsorship of public research in this area. In this context it was felt desirable to increase the utilisation of valuable capital research facilities. As a consequence of various studies undertaken to devise an organisational scheme to carry through such a policy, a decision was taken to set up the National Maritime Institute and announced to the House of Commons in February 1976.[74]

After its formation the National Maritime Institute steadily increased the proportion of its research performed for private industry. During 1977 work for fee paying customers involved 21.5% of its total resources.[75] The following year this had risen to 29.8%.[76] Nevertheless the bulk of its work still depended on the Department of Industry for funding. Contracts were also placed with the laboratory by the Ship and Marine Technology Requirements Board on behalf of the Department of Trade. Further contracts came from the Department of Energy, associated with its responsibility for leasing offshore oil production facilities, and the Department of Transport, responsible for ports and harbours. Its private customers have included shipowners, shipbuilders, offshore oil producers, and consultants. Private contract work became particularly concentrated in offshore work. In this area of research in 1978/9 52% of orders came from domestic commercial interests and 6.1% from overseas.[77] Like the Hydraulics Research Station, the National Maritime Institute was operating in a competitive international market.

In early December 1979 the Government announced a detailed programme of expenditure cuts which included proposals to convert the National Maritime Institute into a non-governmental research association or some other form of autonomous industrial laboratory.[78] A number of serious problems needed to be overcome however before such a plan could be implemented. Financial viability could only be maintained by a continuing guaranteed public funding. Particularly acute problems arose due to the importance of the large capital facilities, essential to its work, which would depreciate in value. Without government funding the laboratory was clearly not a viable commercial concern. Nevertheless the attractions of reducing the number of civil servants by around 300 were clearly attractive to a government committed to a reduction in the scale of the Civil Service. It was also a natural consequence of the realisation of the accountability of public applied research in terms of commercial cost-effective criteria. In February 1981, Norman Tebbit, Minister of State for Industry, informed the House of Commons that consultants were looking at the viability of a private National Maritime Institute.[79] By 1982 the conclusions had still not been implemented.

Policy for industrial research has thus become related to a model of simple market demand. In such a model the realisation of a positive role for research establishments has been denied and, dependent on direct external funding, they develop an instrumental responsiveness which precludes them acting in any way as agents of long-term change.

The impact of political expediency: defence research laboratories

The post-war expansion of the defence research laboratories provides the most graphic example of faith in the role of centralised public research facilities. With the collapse of such faith in the 1960's the defence research laboratories, particularly those which became part of the Ministry of Technology where they were exposed more to the glare of public scrutiny, came in for hostile criticism from all points on the political spectrum. Following the disbandment of the Ministry of Technology the defence laboratories once again retreated from immediate public scrutiny. Nevertheless the decline of the government research establishment in the 1970's is strikingly reflected by experiences within the defence sector. As a recent assessment of defence research concluded:

> The R&D Establishments have undergone a series of enforced manpower reductions in recent years and these are continuing in an unplanned way. Prospects on current recruitment and financial trends are bleak, and the Establishments are facing a grave shortfall in their resources.[80]

In 1970, in accordance with the declared policy of the new Conservative Government for the rationalisation of government departments and the subordination of applied research to departmental needs, a re-organisation of defence procurement and research began. As a temporary measure the Aviation Group of the Ministry of Technology became the Ministry of Aviation Supply pending the results from a project team asked to report on:

> .... how best to organise the integration of all defence research and development and procurement activities, under the responsibility of the Secretary of State for Defence: among the possibilities to be considered should be the establishment of an agency within Government.[81]

A subsequent White Paper announced the intention to set up a Procurement Executive within the Ministry of Defence to undertake these functions.[82]

Within the operation of the new Procurement Executive detailed research objectives were to be specified individually by the Navy, Army, and Air Force Service Staffs. Complementing this arrangement Chief Scientists were designated as responsible for groups of research establishments related to sea, air, and land respectively. At the same time a major rationalisation of research establishments took place with a number of amalgamations reducing twenty five establishments to twelve major research organisations.[83] Although many of the defence research laboratories were vast establishments, employing in total something of the order of 30,000 people, in 1980 they accounted for only 25% of total defence research and development expenditure.[84]

In past years the defence research establishments have experienced a series of enforced reductions in manpower causing an unplanned and uncontrolled exodus of staff.[85] Between 1974 and 1979 manpower was reduced by 14% resulting in a distortion in the balance of skills and the neglect of longer term research.[86] The situation was made worse with the election of a Conservative Government in 1979 pledged to further drastic cuts in Civil Service numbers and the deployment of services to the private sector including the privatisation of research.

Accordingly the requirement to reduce staff costs led to manpower targets for the defence research laboratories for April 1980 being set roughly 1200 below the January 1980 strength.[87] This duly required further severe restrictions on recruitment and continued unplanned wastage, and although the target could not be reached in the timescale allowed, further drastic reductions were planned for 1980/81. In 1980 the Strathcona Report reflected that:

> On present trends prospects are bleak. The equipment programme as a whole is continuing to grow; the real cost of new developments is increasing; the outflow of staff in the next year or so is bound to be haphazard; and in the next five years an unusually high proportion of the senior scientific manpower in the Establishments will retire.[88]

The Strathcona Committee was, among other things, instructed to consider the implications arising from changing the balance of research performed by the research establishments in comparison with other organisations, by implication private agencies. With respect to changes in function and effort considered by the committee, it was apparent that six developments were envisaged as policy aims; firstly a major devolvement of primary functions of the establishments to private industry; secondly the possibilities of handing over major parts of individual establishments to industry, or other non-defence bodies; thirdly methods of achieving greater efficiency; bringing private contractors into the establishments to provide services currently performed by civil servants such as the running of capital facilities; the devolvement of specific tasks to private contractors operating outside establishments; and finally the transfer of work from the establishments to elsewhere within the Ministry of Defence.

The consideration of these possibilities clearly revealed some strong political preferences. The committee decided that a reduction of manpower engaged on project work of the order of 10 to 15% could be realistically possible through devolving such work to other agencies.[89] It would continue previous trends to reduce the level of project work in a number of laboratories. This appeared modest when compared with previously planned manpower reductions. However, as the committee noted, there was little indication that industry was willing or even able to absorb any significant proportion of the work. Indeed some firms were reported to be apprehensive about the effect of any sudden upsurge in research and development on their overheads.[90] Consultations with industry revealed that few companies had any interest in long term research while industry was itself concerned with the deterioration of of the public effort in this area. In response the committee urged a greater emphasis in the public laboratories on both long term research and concept formulation.[91]

Concurrent with the Strathcona enquiry two military research establishments were the subject of speculation concerning possible privatisation, and both, the National Gas Turbine Establishment and the Propellants, Explosives, and Rocket Motor Establishment, were studied by the committee. The National Gas Turbine Establishment was unusual in that its work related on the whole to the interests of one firm, Rolls Royce. It possessed unique and essential capital research facilities essential to the industry's commercial existence. Although political preference was presumably for privatisation, the Strathcona Report concluded that none of the options it had considered - integration with Rolls Royce, the creation of an autonomous company or research association, or operation of the laboratory's facilities by outside agencies with the rump transferred to the Royal Aircraft Establishment - was without difficulties, and recommended a further in-depth study to consider possible alternatives in more detail.

With respect to the Propellents, Explosives and Rocket Motor Establishments, suggestions of a major devolution of its work to industry had been rejected in the mid-1970's following the setting up of the Rocket Motor Executive at the establishment's Westcott laboratory. In view of the commercial dimension of the work carried out under the Rocket Motor Executive, the Strathcona Report turned once again to the arguments for altering the balance between intra-mural and extra-mural research. It found little agreement on the best course of action and recommended further investigation.[92]

Overall the deliberations of the Strathcona Committee reflected the continuing policy of reducing the scale and functions of the defence research establishments with a greater emphasis on the role of private industry in undertaking project and design work. Nevertheless it was clear from the report that this reduction had occurred in an unplanned manner which restricted the ability of the establishment to perform their existing functions effectively. Short term political intervention, aimed at quick results, had prevented the establishments from instituting longer term evolutionary change in a consciously planned way.

The Decline of Public Research Establishments: Some Observations

An essential ingredient of the Rothschild Report was its explicit negation of the Haldane Principle, i.e. that general research should be administratively distinct from the executive function of government departments. The primary aim of the Haldane Principle was to limit the possibilities of short term expedient interference with the programmes of individual establishments. These provisions were considered to be necessary for the long term continuity of government research, and for the maintenance of the national laboratories as credible sources of independent scientific advice uncompromised by the day to day pressures of executive departments of government.

One factor which undermined this basis was the emergence of a more interventionist industrial policy, particularly in the 1960's, with greater emphasis on intervention at the level of the firm. The traditional autonomy of the research establishments came under threat as ways were examined of reorienting the work of the laboratories towards the immediate needs of industry. Moves towards research management based on programmes rather than institutions emphasised the trend towards the concept of research as a subordinate and integral part of an overall strategy, the basis of the so-called customer-contractor principle for public research, first alluded to in the Green Paper of 1970, but later popularised by Lord Rothschild.

These shifts in the conception of the place of public research ran parallel to changes in the conception of the role of science in material progress. Post-war optimism regarding the contribution of science gave way to more problematic issues whether in the environmental sphere or with respect to technological change in industry. The decline in public research expenditure in national laboratories, which began in Britain in the late 1960's ran parallel to a decline in research and development spending in most sectors of private industry,[93] and similar adjustments in the pattern of post-war growth in the industrial countries world-wide.

Disquiet over the role of public research institutions was not confined to Britain alone, or even to capitalist countries.[94] The decline of a universal model which causally related research and development to material progress and national prosperity was in contrast to national policies which provided significant resources to large relatively autonomous public laboratories. A recognition that research and development had a more problematic relationship to material progress led to concern for a more sophisticated framework for the articulation of research programmes, a framework which Lord Rothschild attempted to supply. For the customer-contractor relationships to be successful, however, depended on a number of serious pre-requisites which arguably have not been fully established with serious implications for the future of public research.

Successful institutionalisation of customer-contractor principles assumed that the Government could articulate a coherent strategy for each area of public policy and co-ordinate its research resources in sympathy with these policies. Such conditions have not been satisfied with the result that the customer-contractor relationships have been interpreted in a particularly narrow way, to the detriment of the long term continuity of public research. The undermining of the relative autonomy of public laboratories, a prerequisite arguably for implementing customer-contractor procedures, has laid the laboratories open to short term political expediency. This has been illustrated by the studies presented earlier in this chapter.

A failure to implement the necessary administrative apparatus which can both incorporate the work of public laboratories into a wider series of policies, at the same time securing long term continuity, is particularly apparent in the performance of the Conservative Government elected in 1979. This administration radically denied a role for centrally co-ordinated strategies in different sectors of public policy and preferred to depend on the operation of market forces for the efficient distribution of resources.

In such a policy framework the customer-contractor relationship becomes interpreted in simplistic market terms. This was reflected in the increasing commercial nature of public research with an emphasis on short term contract work, and moves towards privatisation. Market forces are by their nature dominated by short term needs and susceptible to short term fluctuations. The kind of long-term research pursued traditionally in the public laboratories was previously viewed as a necessary balance against the short sightedness of market forces. It was based implicitly on the Baconian view that research could in turn transform the material basis of life, and that such kinds of research were best pursued away from the immediate pressures of the market, or in terms of public policy, of departmental day to day requirements. The direction of public research by market forces negates automatically the role of long-term research and the need for any continuity of research. Indeed, in its simplest form it negates the need for any public laboratories at all because they can operate as commercial organisations serving the instrumental needs of customers.

Despite the vigour of contemporary policies, the re-orientation of public laboratories towards a "market demand" model was, as has been shown, present throughout the 1970's. The current rejection of central planning in any form is merely an extreme form of the inability of successive administrations to successfully integrate the national research resources into clear national policies relating, for instance, to industrial innovation and environmental development. This failure lies at the centre of the lack of success in re-establishing a clear strategic public role for government research establishments. The weakening of the position of the national laboratories made them vulnerable to political expediency which has meant that after 1976 the national laboratories became a particular target for public expenditure cuts and reductions in staff numbers. The results are seen in a continuous decline of national research resources, the consequences of which are reviewed in the concluding chapter.

CONCLUSIONS

Public Patronage and National Laboratories

It has been argued in this thesis that to fully understand the current position of national research establishments in Britain one needs to study the institutional history of the government research laboratory. A particular model of institutional development was outlined in the introductory chapter. In this it was argued that institutional characteristics evolve through the continual interplay between internal development and environmental factors within a changing economic and political context. Circumstances surrounding the origins of institutions contribute considerably to the early consolidation of institutional role as initial aims become internalised.

The continuous development of a particular institution depends on its ability to adapt to changes in its operational environment. Eventually, if differences become apparent between external imperatives and internal values, the legitimacy of an institution will come into question. Such a crisis leads to a reassessment of role and, dependent on the balance of the power at the time, a transformation takes place, either providing the institution with a reformulated role or bringing about its disintegration. Its functions are either assimilated by new institutional structures or become redundant to contemporary needs.

In brief this is the view of institutional change outlined in the introductory chapter, and which provided some theoretical context for the more descriptive analysis of the emergence and subsequent development of the government research laboratory which has now been presented. A number of relevant observations have already been discussed in the context of previous chapters. It remains to restate some of the more important observations as part of a general summary and final conclusion.

The theoretical structure adopted pointed to the importance of antecedent institutional forms and cultural traditions in forming the context for the emergence of new organisational structures. This theme has now been examined in relation to public patronage for applied research. In particular a number of important institutional precedents for formal government patronage were identified, some of which have been neglected in the traditional accounts of the historical development of the institutions of technology, science and public policy.

A clear example is provided by the role assumed by the Society of Arts in the eighteenth century, in which it attempted to systematically patronise areas of technical knowledge for reasons of national economic and social advancement. It was thus identified as providing institutional continuity between the abortive attempts to patronise technological developments in the early years of the Royal Society and later specialised institutions, both government and "private" formed during the nineteenth century. Complementing such a process of specialisation the notion of collective systematic patronage was reaffirmed and continued during the nineteenth century by the British Association for the Advancement of Science and ultimately brought into the responsibilities of formal government in the twentieth century.

The process of institutionalisation in collective organisation of patronage ran parallel with the development of institutions for the practice of research itself, i.e. the emergence of the organised research laboratory. Both elements were emphasised in Bacon's

New Atlantis which was an influential blueprint for a number of later initiatives. Bacon himself had a number of institutional developments to draw on for his personal inspiration including the artisan's workshop, astronomical observatories, alchemical laboratories and botanical gardens. His concept of systematic patronage went beyond individual endeavour, however, to collective organisation and division of labour. As far as the practice of research was concerned, science was nevertheless to remain an individualistic activity until the nineteenth century when organised research institutions became a more familiar feature.

In the nineteenth century the growth of formal government and the extension of public administration into new areas of responsibility brought the incorporation of technical knowledge into public service. These developments were incremental and pragmatic, reflecting the very nature of the expansion of government administration in general. Although independent scientists were utilised for expert advice and research support, the need for continuous expertise to supervise and maintain day to day activities encouraged the establishment of centralised and permanent public institutions.

Such developments reflected and advanced the newly acquired professional consciousness of scientists. The working laboratory was synonymous with the professional identity, status and aspirations of scientists and a focus for professional activity. Although the pressures for the establishment and expansion of public research facilities came from such professional aspirations and needs, they were usually argued for in terms of national interest. For many scientists and their supporters professional need and national interest were synonymous and sufficient to override any prejudice against State support, and the defence of laissez-faire principles. The advancement of science was identified with national progress, a theme continuously promoted by the propagandists for science in the nineteenth and early twentieth centuries. The economic threat posed by overseas competitors, particularly from Germany, focussed opinion and highlighted international institutional comparisons. National prestige, power and progress became wedded to a belief in large national laboratories.

Despite the important precedent provided by the establishment of the National Physical Laboratory in 1900, the institutionalisation of the government research establishment in Britain belongs essentially to the inter-war period, when at least ten major new national research laboratories were created and the formal ideology of government research firmly established. A feature of the institutional model outlined in this thesis is the way legal and formal changes record and regularise an evolution that has been substantially completed informally. This has been identified with respect to the operational guidelines encompassed by the Haldane Report which indeed reflected previously moulded attitudes towards scientific research and its relation to practice. According to the dominant beliefs of the day the systematic patronage of science did not imply the planning of research with regard to closely defined political aims. Scientific research was rather considered best judged by scientists, and valuable discoveries arose in an unplanned way from research "cultivated" through the patronage of the public purse. Such values were reflected in both the organisation of medical research through the Medical Research Committee (and its successor, the Medical Research Council) and industrial research in the Department of Scientific and Industrial Research (DSIR). The establishment of both organisations preceded the articulation of the "Haldane Principle", which formally advised maintaining the relative autonomy of public applied research of a general nature from the pressures of day to day departmental administration. The "Haldane Principle" thus made explicit and formal, operational guidelines which were already implicitly inherent in public research organisation.

It is evident, nevertheless, that the early programmes of the national laboratories related to immediate practical requirements. Many of the laboratories were, in addition, initially viewed as technical organisations set up as the instrumental research facilities to service the needs of the executive research boards of the DSIR. As the balance of control shifted from the boards to the laboratories the latter began to control the momentum of research with the boards taking a more formal and less active role. In the course of time the more functional character of research programmes began to recede as basic research, more distant from immediate technical problems, demanded long-term continuity which the public laboratories could provide and become a national focus for.

In turn the continuity of basic research, related to applied fields of technical knowledge, was identified with the integrity and continuity of the laboratories themselves, and was to form the basis for their self-maintenance, uniqueness, and hence role. The emphasis for initiating and continuing research rested with scientists, in the laboratories, and external constraints were limited to negotiations concerning overall funding and staffing levels, and the need for new capital facilities. The relative autonomy of the national laboratories was further emphasised by the inability or reluctance of executive departments in public administration to articulate their own longer term scientific requirements and thus to exert any influence on the programmes of the central laboratories.

By the outbreak of the Second World War the institutional role of the national laboratories was firmly established. The character and orientation of individual laboratories reflected wider political and economic circumstances. Two particular influences were identified; firstly the consolidation of the British Empire after the end of the First World War and the continuing economic implications of Empire for Britain's pattern of overseas trade and for domestic industry; and secondly the expansion of social welfare programmes with respect to health and housing. In both these spheres of activity research was seen as having a leading role, and the relationship between research and practice was not considered problematic. Scientific research simply produced new knowledge and discoveries which were then applied in practice. Science was thus a deterministic external influence. This ideal was firmly boosted by the effective role played by scientists during the Second World War. After this investment in scientists and scientific research was regarded throughout the developed world as a key, if not <u>the</u> key, long-term factor in material progress, particularly with respect to economic growth.

From the end of the Second World War to the mid-1960's national resources devoted to research and development grew rapidly, increasing their share of national resources.[1] The national research laboratories remained the major focus for public expenditure on applied research and until the 1960's their operational ideology remained within the traditional lines established during the inter-war period. Thus in 1962 the former Secretary to the DSIR, Sir Harry Melville stated that:

> The essential generic purpose of the DSIR research establishments is to undertake research which is necessary in the interests of the United Kingdom and its citizens, but which cannot appropriately be left or remitted to the control and management of sectional bodies.[2]

The emphasis at this time remained on basic applied research, and indeed in some laboratories, particularly the National Physical Laboratory this emphasis increased. If the operational ideology of the laboratories remained essentially unchallenged, the orientation of their work was in some cases changing dramatically.

The DSIR and its laboratories had originally been conceived as serving the needs of the Empire. The retreat from Empire in the 1950's along with the continuing concern with domestic industry, brought the orientation and role of a number of public laboratories into question. This resulted, as was documented, in some organisational changes and an increasing emphasis on technological questions relevant to more short-term domestic industrial needs, typified by the encouragement given to short-term contract work.

This reconsideration of the orientation, if not the ideology, of the work of the national laboratories, was the result of the various reviews which took place in the latter half of the 1950's in the context of a more general reconsideration of the aims and functions of the DSIR. Attempts were made to redefine the terms of reference of the DSIR laboratories "clearly and in relation to modern needs".[3] The conclusions drawn from this particular exercise did not, however, bring into doubt the established operational role of the laboratories. Indeed the review merely catalogued the various collective activities of the laboratories. Thus in 1959 the "major purposes" of the DSIR research laboratories were listed as being to:[4]

(a) keep their fields of research under constant review in order to define objectives and help the Government, industry, and the public to maintain a lively interest in the value of research;

(b) conduct research which can provide information to central and local Government on matters, such as air and water pollution, road safety, noise and the extinction and prevention of fires in which the Government has a clear responsibility for protecting the health, safety and welfare of the citizen;

(c) carry out research and development in subjects, such as the natural resources of the country and the design and construction of buildings and roads, which affect the efficiency of industry as a whole;

(d) extend the frontiers of knowledge in applied research so that industry can be provided with the basic information required for the solution of particular problems;

(e) pay special regard to the research needs of industries that lack an adequate scientific background, and to research problems that are common to more than one industry;

(f) carry out particular researches, in co-operation with industry, wherever possible, which will enable the Stations to appreciate industry's problems more fully and to recognise those fields in which more basic research is most urgently needed;

(g) provide for industry national and international standards of measurement of various fundamental physical quantities (such as length, mass and time) related secondary standards and reference materials;

(h) conduct research on matters of broad public interest;

(i) disseminate the results of research and secure their application.

Most of these "directives" could have equally been written thirty years previously. In the 1920's, however, they were implicit and required no explicit affirmation, although the various research boards had been provided with terms of reference. In 1959 such guidelines continued to reflect the value placed upon the responsibilities of scientists for deciding on the priorities of research at the "frontiers of knowledge". The national laboratories retained their function as propagandists for the value of research. This redefinition of their role did, however, reflect contemporary fears of a lack of complementarity between the more immediate needs of industry and the work of the public laboratories. One can detect a theme which was to become prominent in later years - calls for the laboratories to co-operate in research with industry in order to make public research scientists more aware of industrial problems and needs. While the directives issued in 1959 reflected the aims and values of the national laboratory which had acquired permanence and stability, they also revealed certain insecurities and pointed to future years of struggle in the face of new problems and altered circumstances.

A period of intense debate on the future of the national laboratories began in the mid-1960's and has continued until the present time. The post-war expansion of the laboratories came to a halt with a reversal of political commitment to large centralised research institutions in the public sector resulting in declining public expenditure in this direction and a pronounced decline in staff numbers. Arguments presented in the present thesis have pointed to the erosion of the legitimacy of the public establishments as national centres for applied research resulting in a threat to their integrity and continuity. A number of major changes in the operational context of the laboratories have been discussed which contributed to this "decline" and these can now be summarised and further developed.

Both long-term and short-term changes in Britain's political and economic circumstances were discussed. Important changes in the traditional economic relationships between Britain, the Colonies and the Commonwealth, brought economic uncertainty and shifts in trading relationships oriented towards European markets. Many of the traditional industries which had formed the backbone of British industrial power were clearly in decline and fared badly in comparison with the performance of overseas competitors. A long history of under-investment was a popular diagnosis although opinion also pointed to an inability to capitalise on national scientific and technological expertise. Obvious casualties in the economy included the engineering industries, shipbuilding and various other traditional elements of manufacturing industry. Recurrent economic crises in the 1960's and 1970's brought pressure on the level of public expenditure which had both direct and indirect effects on public research. The national laboratories suffered directly from expenditure cuts and manpower reductions, particularly from 1976 onwards, and indirectly from reductions in public spending programmes in general.

Short term pressures from the state of the economy, and evidence of technological backwardness in certain sectors, encouraged moves to bring the research resources of the country to bear more on the immediate needs of industry. This was apparent even in the early 1950's, although it became more heavily emphasised a decade later. In parallel a more sophisticated view of the relationship between research and technological progress was gaining ground negating the simple deterministic linear model of the innovation process implicit in the traditional institutionalisation of research. The popularity of the linear model explains why, in the 1950's, a major emphasis of DSIR policy was placed on the methods of disseminating research results. Faults at that time were seen in terms of inadequate linkages between the stages of innovation rather than questioning the very nature of the process of technological change and the implications for the role of public research institutions.

A greater awareness of the more complex relationship between research, technical change, and economic development was promoted by the increasing attention of economists on these issues and the more direct experience derived from the position of the economy. Both these factors stimulated and in turn drew upon an increasing availability of data bearing on such questions. In Britain the work of Charles Carter, B.R. Williams and later Christopher Freeman had a significant impact on the political analysis of the function of research with respect to the economy. The work of Carter and Williams, in particular, along with their influence as economic advisors, highlighted that no automatic relationship existed in macroscopic terms between national expenditure on research and development on one hand and economic growth on the other, conclusions clearly in accordance with the reality of Britain's position. One conclusion drawn from these studies was that Britain as a nation concentrated too much on basic research and not enough on technological development. These studies, including those sponsored by both the DSIR and the Ministry of Technology, along with a number of influential studies sponsored by the National Institute for Economic and Social Research, provided evidence, moreover, that many of the problems faced were of a structural nature which went beyond questions relating to the deployment of research resources to issues of general industrial policy. Nevertheless, with respect to research, an issue was highlighted which had already become of concern for other reasons; the need to be more selective in the use of research resources. This raised problems such as the necessary institutional mechanisms for deciding on priorities, and for ensuring the effective use of resources.

One result of the involvement of economists in these issues, in both the DSIR and its successor the Ministry of Technology, was that it extended the focus of policy beyond research as a semi-autonomous activity, towards the structural problems of industry, and marked the genesis of a more explicit interventionist industrial policy. The development of the Ministry of Technology from 1965 to 1970 epitomised this shift from a focus on science and technology separate from economic policy to an industrial policy in which research was merely one element that had to be integrated into a coherent strategy. Although this was not successfully accomplished during the Ministry's brief existence, nor indeed at any other time, the consequences of this reorientation for the future role of national laboratories were profound. With such a large proportion of national scientific and technological resources deployed in public laboratories, questions bearing on the relationship between the optimum deployment of resources and the more direct benefits of investment in research naturally made the government research laboratories a focus of political debate, a pressing issue for the Government, and an easy target for the opposition.

Influential opinion in both major political parties began questioning the maintenance of large public laboratories when indications were pointing to the importance of research being situated close to the sphere of application. Influenced in addition by the belief that there existed a relationship between firm size and the viability of indigenous research activity, political pressure was exerted in two directions. Firstly it came through intervention to rationalise industrial sectors creating larger industrial units, although the issue of research viability was only one influence on such a policy; and secondly moves began to consider how to shift the balance of research effort away from the public sector.

In the short term the very existence of the public research laboratories with a long established mode of operation, and not easily reduced in scale, fostered moves towards bringing the programmes of the laboratories more to bear on contemporary industrial problems. This was accompanied by a shift towards attempts at planning research on a programme basis, rather than through patronage of individual research institutions. Concurrently the laboratories were encouraged to undertake more work on a repayment basis for industrial firms. In the context of these developments, accountability for the work of the laboratories began to be interpreted not simply in terms of criteria of scientific excellence *per se*, but rather in more commercial terms. These changes were already well underway well before Lord Rothschild outlined his proposals for incorporating the so-called "customer-contractor" principles into the research activities of Government. Once again formal changes in procedure were regularising an evolution which had already to some degree occurred.

The manner in which these changes were introduced, it has been argued in this thesis, significantly undermined the traditional autonomy of the national laboratories - indeed this was one objective. Nevertheless, claims that the establishments have successfully adapted to the new arrangements[5] clearly need close examination on the basis of the evidence presented in chapter seven. While in the Department of Industry the Research Requirements Boards have, in varying degrees maintained some continuity, attempts to provide a coherent research strategy in the Departments of the Environment and Transport have clearly been contradictory over the past decade, and resulted in little continuity of research.

Compounding these problems have been arbitrary manpower restrictions and severe reductions in expenditure, which have been instituted in an unplanned way and have raised serious doubts about the future of a number of the national laboratories. It is clear that unless a more positive commitment to public research is provided, along with more recognisable and effective means of integrating the determination of policy with research, the national laboratories will be unable to re-establish a recognisable role as public institutions beyond being merely instrumental organisations conducting contract research, in which case there would be little point in maintaining them within the public sector.

Successful institutional development requires some degree of permanence and stability along with the ability of institutions to retain sufficient independence to enable them to exploit initiatives to the full. These factors have arguably been absent from the public research laboratories during the past decade. In one sense they are no longer flexible enough, due to the heavy constraints imposed on them, while in another sense the customer-contractor arrangements have not been successfully integrated into the determination of public policy. This raises an important question: if the national laboratories are not playing any role in policy determination will they have any role in implementing public policy? If not, the raison d'etre for their existence is called into serious doubt.

Part of the problem of re-establishing a visible and viable role for government research lies at the general level of the inability of successive governments in Britain to successfully integrate the scientific activities of government into the process of policy determination and implementation. Lack of strong central direction in relation to scientific and technical issues has encouraged research activities to become subordinate to the day-to-day problems and constraints of executive departments.

It would be misleading to infer that there are not deeper and more serious problems entailed in developing coherent policies for public research laboratories. Since their formation dramatic changes have occurred in the institutionalisation of applied research and within the technological infrastructure of society. The complexity of present day institutions and the individual nature of the public laboratories with respect to their fields of operation make it unlikely that a generalised role for government research establishments could be developed. Rather attention must concentrate on each individual institution and the peculiar characteristics of its operational environment. In this sense the all embracing concept of the Government research establishment is no longer valid. Within the peculiarities of their fields of operation,establishments are likely to diverge in their institutional characteristics, a reflection of the variation in the pattern of institutionalisation of applied science in different areas.

When many of the public laboratories were set up they were pioneering institutions in national life. In their respective fields of research they were often clear leaders, particularly in the inter-war period, and pioneered such important areas of research as cold-storage preservation, soil mechanics, fuel science, and acting as an important training ground for specialists in different fields who went on to work in industry, universities and research associations. As unique centres of expertise the self-maintenance of the national laboratories was unproblematic. Along with expertise they possessed unique facilities.

Since the Second World War, with the development of other institutions, the uniqueness of the national laboratories became more tenuous. The commitment of private industry to research increased rapidly. Large multinational enterprises now support research and development facilities which overshadow the scale of public research in individual subject areas. Because of the scale and breadth of the operations of multinationals, research is not necessarily restricted to narrow areas of industrial interest, but serves the broad corporate aims of the enterprise, often including basic research.[6]

A further post-war development in Britain has been the growth of private contract research organisations, some with an international scale of operation. Within the United Kingdom, in contrast to the United States, independent contract research laboratories operated on a very limited scale until comparatively recently, and only since the 1960's have such organisations begun to make a significant contribution.[7] In the United Kingdom in 1971, overall contract research, including that performed in public laboratories, was estimated to be worth £5.6m. per annum, modest in terms of overall national resources devoted to research, but nevertheless more than double the equivalent figure for 1965 and a possible indication of an increasing trend.[8]

Further important changes in the institutionalisation of applied research have come from the rapid expansion of university research activities, particularly since the 1960's. University groups and departments now work in many areas of applied research previously the almost unique preserve of public establishments such as in the fields of transport studies and building methods. The distinction between universities as institutions for the production of knowledge and public laboratories as institutions concerned more with the application of knowledge is no longer valid. With the pressures of economic recession universities have begun to be involved in work of a more immediately utilitarian character to attract funds for continuity. Universities have invested in large capital research facilities once the preserve of public laboratories. In addition they have turned more towards industry for funding and support, not simply in the traditional form of endowment but to bring the work of universities more to bear on industrial practice.

In the latter respect a notable development has been the spread in recent years of the concept of university science parks. The Cambridge Science Park, Britain's first, was opened in 1973 and now has twenty two private companies on a 120 acre site.[9] The movement to set up institutional links between industry and universities does not, according to Levi, owe its impetus to any single type of sponsor.[10] The Cambridge project was sponsored by Trinity College, Cambridge; a similar venture at Herriot-Watt in Edinburgh was started by that university; the West of Scotland Park in Glasgow was largely financed by the Scottish Development Agency and Aztec West at Bristol is a purely commercial enterprise; while science parks at Warrington, Reading, Livingstone (West of Edinburgh) and Birmingham are all financed by local authorities. Other science parks are being considered elsewhere at Liverpool, Leeds, Newcastle, Southampton and Exeter. While most of the parks established to date provide accommodation for small high-technology companies, the Herriot-Watt Research Park is Britain's first "pure" research park which permits only scientific and technological research, the making of prototypes and small batches, but no mass production.[11] The scale of research undertaken is indicated by the fact that one company resident in the Herriot-Watt park, Syntex Pharmaceuticals, has invested £7m. in its research facility there.[12] If such initiatives are envisaged as bringing industry more into contact with university research and support facilities, there are indications that university academics are becoming more willing to partake in industrial projects and commercial activities. Such initiatives, through a reassessment of the function of universities are inevitably changing the context of public applied research. Changes in the institutional pattern of both industrial and university research clearly have important implications for any future public policy for applied research, including the future role of individual public laboratories, and merit detailed study.

Further initiatives which have had some influence on the pattern of institutionalisation of applied research have involved the rationalisation of public service facilities. An early example of this which was presented in this thesis was the undermining of the position of the Fuel Research Station as the national centre for fuel research following the nationalisation of the coal industry along with other institutional developments in the broad field of energy research. The raison d'etre for its existence no longer held in the face of pressures to divert research resources into other areas. More recently the position of two other national laboratories has been affected by rationalisation of public functions. The Safety in Mines Research Establishment became part of the new Health and Safety

Executive. For the other, the Water Research Centre (formerly the Water Pollution Research Laboratory), its change in status from a departmental laboratory to an independent research institution, following the rationalisation of the water supply industry, has clearly been detrimental judging by evidence provided for the House of Lords' Select Committee on Science and Technology currently investigating related issues.[13] It has experienced a sharp cut-back in staff, and has been forced to orient its work towards short-term projects despite criticism suggesting that basic research in its area of expertise is too limited.

In certain cases individual national laboratories have experienced difficulties in establishing a unique and clearly defined role due to institutional complexity of the area in which it operated. This was true of the Chemical Research Laboratory, which despite its change of title to the National Chemical Laboratory, failed to establish a clearly defined role as a national centre and was subsumed within the National Physical Laboratory. Similarly the National Engineering Laboratory has struggled to establish an identity in a field where basic research is often treated with suspicion and where expertise is diffused in many and varied instititutional settings.

The complexity of the existing institutional structure of applied research, coupled with a greater sophistication in the view of the relationship between research and innovation, social and industrial, makes any consideration of the future role of individual public research institutions difficult, not least in the context of an economic recession, and a political environment which provides severe obstacles to new institutional initiatives in public policy. Nevertheless, it is short-sighted to allow the future of the national laboratories to be determined solely by market forces. Government institutions are by their very nature a reflection of the inadequacy of such forces rather than the product of ideological design, and to submit certain institutions to the short-term pressures of the market, particularly in a time of recession, negates any rationale for having public institutions at all.

It was inevitable that the post-war optimism in the automatic benefits from science and technology and the conception of their social function in terms of unproblematic and benevolent external influence, should have waned. Interestingly the down-turn in the national commitment to public laboratories in Britain coincided with a similar pattern in respect to resources devoted to research and development in private industry. Compared with a general and persistent rise in private industrial research and development expenditure effort up to around 1966, an equally persistent fall in effort occurred between the years 1966 and 1975.[14] Indeed it has been calculated that the degree of research and development intensity as measured by research and development expenditure per unit of value added was generally lower in Great Britain in 1975 than in 1958.[15] A pertinent question which could form the basis for further research is whether questions relating to the accountability of research, the balance between technological and more basic research, and the general management and control of research, had a similar impact within the organisation of industrial firms as it did within the public sector.[16]

In both the public and private sectors of national life scientific research, particularly basic research, has suffered from the consequences of a depressed economy. The present need to reassess clearly the future role of individual public research establishments comes at a time of intense restructuring of industry, along with other institutions of national life. Any detailed analysis of the potential of individual laboratories is beyond the scope of this thesis. To achieve this a more detailed study of individual institutions would be required, with internal access, along with a knowledge of their areas of operation both with respect to the general sphere of public policy and their fields of technical expertise. It would probably require expertise beyond the capability of an individual. Such a study could be complemented by a comparative approach, studying the development and role of similar institutions in other countries. In the field of science policy this approach at the level of institutional analysis, rather than at more global levels, is sadly lacking.

With regard to the more general issues relating to the potential role of public research institutions certain points are worthy of further consideration. If the role of individual institutions needs clearer articulation this can only be achieved in the context of a coherent policy into which the work of the research institution can be clearly related to the objectives of such a policy. Despite the enthusiasm expressed in political circles for "customer-contractor" relationships, this has become an excuse for an abdication from the responsibilities of government to provide a more explicit lead in the fields of science and technology. Laboratories have been left susceptible to often arbitrary pressures, confusing their function, and bringing into question the state of the nation's continuing capability in strategic areas of applied scientific research and the mechanisms for successfully integrating such activities into public policy. This weakness within public administration has been apparent for many years and yet still remains.

Another feature, related to the above, which has been of long-standing concern involves the lack of central scientific direction in British public policy. This again has been the subject of considerable debate,[17] yet successive Governments have insisted on decentralising research questions to departmental interests. In this context certain features of the old Haldane Report on the machinery of Government remain valid to this day. The Haldane Report was certainly not antipathetic to executive departments having sound scientific support within their own control. Indeed this was seen as essential for the conduct of day-to-day business, and at the same time to articulate more long term needs. Nevertheless, the report argued for the separation of certain areas of research from the more immediate pressures of executive departments to provide both continuity for longer term research programmes and a credible source of independent advice which was not constrained by departmental interests. By decentralising research to executive departments such advantages have been sacrificed. A major incentive in making departments more responsible for research activities was undoubtedly to encourage them to take a more active interest in, and utilise more effectively, scientific expertise and its part in policy formation. There is little evidence that this has been the case, and the continuing low priority given to research activities is reflected by the pattern of manpower cuts. The consequences for the laboratories have been a decrease in flexibility, a lack of coherence and continuity in research programmes, and a continuing bias towards research of a predominantly short-term nature.

In the aftermath of the publication of the Rothschild Report, fears were expressed in a number of responses, regarding the implications of not providing recognition for so called "objective basic" research or "strategic" research.[18] This arguably was the central focus for the work of the laboratories under the DSIR, having a long-term character, not immediately related to the interests of sectional groups. Admittedly such work need not necessarily be carried out exclusively, or indeed at all, in public laboratories. Nevertheless, it is exactly this kind of work which requires more central public direction and which may be well suited to national laboratories.

From the various conclusions drawn so far it can be seen that two complementary aspects of public policy exist in the context of which the future of individual laboratories can be formulated; with regard to departmental policy and with regard to the more generic needs of scientific and technological development as part of material change. The scope for individual institutions needs to be assessed within these two categories, and the optimum organisational status determined for them to operate effectively as coherent institutions.

In the context of the pervasive changes occurring at present in British society, and with respect to the position of Britain with respect to the rest of the world, the research institutions of the public sector have an important potential for influencing events. Questions relating to inner-city rejuvenation, consumer satisfaction, housing and transport, and industrial renewal cannot be solved by research alone. Yet the national laboratories undoubtedly possess considerable expertise and valuable facilities which could play an important role in presenting options and clarifying technical issues. As Britain becomes a more integrated part of a European community questions will arise in the development of co-operative policies in which an indigenous expertise to provide a meaningful contribution to both the development and implementation of such policies will be necessary, not least to safeguard national interests. The national laboratories already provide valuable support in respect of international questions.

In the past decade much has been made of the "accountability" of public institutions. The meaningful and efficient use of research resources certainly means that users of research should be involved more closely with the elucidation and practice of research programmes. Crude market forces, however, can subdue rather than stimulate research initiative and privatisation is a particularly blunt instrument for achieving accountability to "users". Research, in part remains the art of the possible, the kind of social gamble which market forces rarely condone. It requires protection and an environment conducive to constructive progress. In turn researchers should indeed be accountable for their work and seek to foster links with the community they serve. Indeed, a movement to bring to the attention of the community in general the importance of its own involvement in issues bearing on science and technology, and the need for more democratic participation in the conduct of research and its application, as part of a coherent social and economic policy has hardly begun. The part which individual research institutions would play in future developments remains to be debated. The national investment in skills and facilities present in public research laboratories is, however, considerable enough for their potential to merit serious further examination.

APPENDIX 1 Department of Scientific and Industrial Research: Gross Annual Expenditure in Selected Areas of Applied Research and Development, 1921-1964 (£000's)

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933
National Physical Laboratory	204	190	165	162	173	143	148	194	195	205	209	200	195
Building Research: Building Research Station etc.	6	10	7	9	11	25	35	34	37	41	44	42	42
Chemical Research Laboratory	-	-	-	-	-	-	13	16	19	21	21	20	21
Food Research: Low Temperature Research Station, Ditton Laboratory, Torrey Research Station etc.	27	18	17	10	16	17	22	22	44	39	50	47	45
Forest Products Research: Forest Products Research Laboratory etc.	-	-	3	17	9	17	28	32	35	38	43	42	40
Fuel Research: Fuel Research Station etc.	45	47	41	46	50	79	92	94	85	95	96	89	92
Water Pollution Research	-	-	-	-	-	-	-	4	5	12	10	11	9
Radio Research: Radio Research Station	-	-	-	-	-	-	-	15	12	12	13	14	13

Source: DSIR Annual Reports.

APPENDIX 1 (continued)

	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
National Physical Laboratory	209 [(a)]	219	234	244	252	271	278	307	325	346	378	410
Building Research: Building Research Station etc.	59 [(b)]	70 [(b)]	78 [(b)]	88 [(b)]	97 [(b)]	70	74	84	86	78	87	108
Chemical Research Laboratory	26	26	26	26	27	29	31	32	32	33	36	39
Food Research: Low Temperature Research Station, Ditton Laboratory, Torrey Research Station etc.	44	44	54	55	55	57	59	62	67	79	80	82
Forest Products Research: Forest Products Research Laboratory	40	42	45	45	42	45	43	42	44	44	47	50
Fuel Research: Fuel Research Station etc.	90	92	100	106	103	102	109	130	128	126	131	135
Water Pollution Research: Water Pollution Research Laboratory	12	12	14	11	9	9	8	13	14	15	19	19
Pest Infestation Laboratory	-	-	-	-	-	-	-	-	-	14	16	20
Road Research Laboratory	(c)	(c)	(c)	(c)	(c)	36	41	48	64	79	95	99

Notes:
(a) 1934-1946 includes expenditure on radio research
(b) includes expenditure on road research at the Road Research Laboratory
(c) included in budget for building research

APPENDIX 1 (continued)

	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
National Physical Laboratory	509	620	690	721	721	840	861	831	927	950	1075	1203	1285
Building Research: Building Research Station etc.	166	235	264	288	525	526	457	445	481	529	554	575	600
Chemical Research Laboratory (d)	58	72	101	114	117	148	160	171	188	196	233	260	296
Food Research: Low Temperature Research Station, Ditton Labotatory, Torrey Research Station etc. (e)	103	120	144	189	179	188	223	296	376	365	321	345	342
Forest Products Research: Forest Products Research Laboratory etc.	76	77	89	91	100	102	111	106	120	121	133	141	145
Fuel Research: Fuel Research Station etc. (f)	170	159	162	197	211	239	256	269	291	305	349	352	405
Water Pollution Research: Water Pollution Research Laboratory etc.	28	33	43	46	50	56	62	63	75	77	90	105	117
Pest Infestation Laboratory (a)	22	27	34	40	44	53	60	62	73	80	90	98	106
Road Research Laboratory	142	178	231	242	259	290	313	327	369	415	490	620	619
Fire Research Station	29	26	36	41	44	56	64	69	72	85	112	181	145
Hydraulics Research Station	-	6	10	19	27	55	60	68	85	101	123	145	154
Mechanical Engineering Research Laboratory	-	3	18	83	141	269	356	327	347	455	487	539	637
Radio Research Station	9	85	52	66	30	23	51	99	109	107	137	161	194

Notes:
(d) renamed National Chemical Laboratory in 1959
(e) All research facilities except the Torrey Research Station transferred to the Agricultural Research Council in 1959
(f) Fuel Research Station ceased to exist in 1959; replaced by Warren Spring Laboratory
(g) transferred to the Agricultural Research Council in 1959.

APPENDIX 1 (continued)

	1960	1961	1962	1963	1964
National Physical Laboratory	1439	1788	2033	2165	2484
Building Research Station	657	785	781	858	948
National Chemical Laboratory	316	384	410	431	451
Warren Spring Laboratory	403	454	471	537	557
Forest Products Research Laboratory	155	186	195	216	229
Torrey Research Station	226	215	227	253	279
Water Pollution Research Laboratory	137	165	184	200	219
Road Research Laboratory	718	873	970	1087	1204
Fire Research Station	158	156	164	171	178
Hydraulics Research Station	175	204	233	267	313
National Engineering Laboratory	686	811	925	1007	1086
Radio Research Station	239	240	320	379	479
Laboratory of the Government Chemist	290	460	491	524	542
Tropical Products Institute	164	210	230	230	235

APPENDIX 2

INTERVIEWS: BIOGRAPHICAL NOTES

Ashley Catterall, b.1928 (Interviewed July 23, 1980).

Research physicist at the National Physical Laboratory, 1952-1975; administrator in the Department of Industry 1975-1981, including Head of Research, Technology and Policy Division 1977-1981; at present Head of Energy Technology Division, Department of Energy.

Sir Robert Clayton, b.1915 (Interviewed July 24, 1980).

Associated in various senior positions with research at G.E.C. since 1937, including Technical Director since 1968; member of various government committees including ACARD, 1976-1980; National Enterprise Board, 1978-1981; Advisory Committee on Research and Development for Fuel and Power; Chairman of the Computer Systems and Electronics Requirements Board; Advisory Committee to the Transport and Road Research Laboratory.

B. Copestake (Interviewed July 10, 1980).

Department of Industry, Policy and Perspectives Unit.

Paul Dean, b.1933 (Interviewed July 9, 1980).

Director of the National Physical Laboratory since 1977; research physicist at the National Physical Laboratory since 1957 including Head of Central Computer Unit, 1967-1969; Superintendent of the Quantum Metrology Division 1969-1974; deputy director 1974-1976; Under-Secretary, Department of Industry 1976-1977, including Head of Space and Air Research and Contractors Divisions, Part-time Head of Research Establishments Management Division since 1979; Executive Deputy Chairman of the Council of Research Establishments since 1979.

James Dick, b.1919 (Interviewed August 7, 1980).

Director of the Building Research Station (from 1973, Building Research Establishment) 1969-1979; employed at the Building Research Station 1947-1979, including positions as assistant director 1964-1969; deputy director 1969; retired 1979, and at present working as a private consultant.

Harold Egan, b.1922 (Interviewed July 21, 1980).

Government Chemist (director of the Laboratory of the Government Chemist) 1970-1981; employed at the Laboratory of the Government Chemist 1940-1981; retired 1981.

Norman Frost, b.1923 (Interviewed July 25, 1980).

Deputy director of the National Engineering Laboratory. Employed at the National Engineering Laboratory since 1950 including superintendent of the Structures and Materials Group 1967-1980.

John Lyons, b.1926 (Interviewed July 22, 1980).

Deputy General Secretary of the Institution of Professional Civil Servants 1966-1973; Assistant Secretary 1957-1966; General Secretary of the Electrical Power Engineers' Association since 1973; member of various government committees including ACARD since 1978; National Enterprise Board 1975-1979.

Sir George MacFarlane, b.1916 (Interviewed July 14, 1980).

Controller (Research) Ministry of Technology and Ministry of Aviation Supply 1967-1971; scientific staff of Air Ministry Research Establishment, Dundee and Swanage 1939-1941; Telecommunications Research Establishment 1941-1960; deputy director National Physical Laboratory 1960-1962; director of Royal Radar Establishment 1962-1967; Controller Research and Development, Establishments and Research, Ministry of Defence 1971-1975.

Sir Ieuan Maddock, b.1917 (Interviewed July 8, 1980).

Controller (Industrial Technology), Ministry of Technology, 1965-1971; Chief Scientist, Department of Trade and Industry and Department of Industry, 1971-1977; research career as government scientist since 1940 at Fort Halstead and Atomic Weapons Research Establishment including the direction of the U.K. research programme for the Nuclear Test Ban Treaty 1957-1966; director of the National Physical Laboratory 1976-1977; member of various public committees including ACARD 1977-1980 and ABRC 1973-1977; chairman of the Fulmer Research Institute since 1978; chairman of Sira Institute since 1978.

E.S. Mallett, b.1923 (Interviewed July 21, 1980).

Director National Maritime Institute 1979-1981; employed at the Royal Aircraft Establishment 1950-1976 including head of the Data Transmission and Processing Division, superintendent of the Central Unit for Scientific Photography, and head of the Instrumentation Division; director, Space Division, Department of Industry 1976-1981; undersecretary and head of the Research and Technology Requirements and Space Division, Department of Industry, 1978-1979; at present director of Applications Programmes, European Space Agency, Paris.

A.J. Robinson, b.1925 (Interviewed July 7, 1980).

Director of Warren Spring Laboratory since 1968; employed at Warren Spring Laboratory since 1960; previous career in industry.

R.C.H. Russell, b.1921 (Interviewed July 8, 1980).

Director of the Hydraulics Research Station 1965-1981; employed at the Hydraulics Research Station 1949-1981; retired 1981.

A. Silverleaf, b.1920 (Interviewed July 16, 1980).

Director of the Transport and Road Research Laboratory 1971-1980; employed in the National Physical Laboratory 1951-1971 including superintendent, Ship Division 1962-1967, deputy director 1966-1971; prior to government service employed on ship design in private industry; retired 1980.

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21. G. Basalla, Science and Government in England 1800-1870 (unpublished Ph.D. Thesis, Harvard, 1963); "The Spread of Western Science", Science, 156 (1967), 611-622.

22. Lucile H. Brockway, Science and Colonial Expansion: The Role of the British Royal Botanic Gardens (New York: Academic Press, 1979). The imperial context of Government Science has also been emphasised in R. MacLeod "Scientific Advice for British India: Imperial Perceptions and Administrative Goals 1898-1923", Modern Asian Studies 9 (1975), 343-384.

23. Exceptions include R.M. MacLeod and E.K. Andrews, "The Origins of the DSIR: Reflections on Ideas and Men, 1915-16", Public Administration, 48 (1970), 23-48; "Scientific Advice in the War at Sea 1915-1917: the Board of Invention and Research", Journal of Contemporary History, 6 (1971), 3-40; "The Committee of Civil Research: Scientific Advice for Economic Development 1925-30", Minerva, 7 (1969), 680-705; Ian Varcoe "Scientists Government and Organised Research: the Early History of the DSIR, 1914-16", Minerva, 8 (1970), 192-217; William McGucken, "The Central Organisation of Scientific and Technical Advice in the United Kingdom During the Second World War", Minerva, 17 (1979), 33-69; "The Royal Society and the Genesis of the Scientific Advisory Committee to Britain's War Cabinet 1939-40", Notes and Records of the Royal Society of London, 33 (1978), 87-115; Philip J. Gummett and Geoffrey L. Price, "An Approach to the Central Planning of British Science: The Formation of the Advisory Council on Scientific Policy", Minerva, 15 (1977), 119-143.

24. Some exceptions include P.J. Gummett, Scientists in Whitehall (Manchester: Manchester University Press, 1980); N.J. Vig, Science and Technology in British Politics (London: Pergamon Press, 1968). On scientific advice to British government, see P.J. Gummett, Aspects of recent British Science Policy, with particular reference to the Council for Scientific Policy (Unpublished M.Sc. Thesis, University of Manchester, 1971); British Science Policy and the Advisory Council for Scientific Policy (Unpublished Ph.D. Thesis, University of Manchester, 1973).

25. A view of the state which goes beyond constitutional government has been presented in the writings of the Italian communist Antonio Gramsci. He considers the state as made up of two elements, civil society and political society respectively corresponding to relations based on consent and coertion. Civil society includes so called "private" institutions; Antonio Gramsci, Selections from Prison Notebooks (London: Lawrence and Wishart, 1971), pp.262-263.

26. Basalla has identified elsewhere the rise of government scientific institutions as part of a process of what he calls "institutional formalisation", G. Basalla, Science and Government in England, op. cit.

27. Peter Randman, op. cit., R.M. Pike, The Growth of Scientific Institutions and Employment of Natural Science Graduates in Britain 1900-1960, (Unpublished M.Sc. Thesis, University of London, 1961).

28. Much later in the 1920's the Treasury was faced with an identical problem when a request was made in Parliament for an assessment of total government spending on science. It was found impossible to separate more basic research from experimental testing and other categories particularly for military research; Public Records Office, CAB/107, Treasury Memorandum, Research Expenditure (1926). A similar problem was faced by Musson and Robinson when they attempted to assess the contribution of science to the industrial revolution. As they observed "activities in laboratory and workshop were often hardly distinguishable", A.E. Musson and Eric Robinson, Science and Technology in the Industrial Revolution, (Manchester: Manchester University Press, 1969), p.5.

29. R.M. MacLeod, "Science and the Treasury: Principles, Personalities and Policies, 1870-85", in G. L'E. Turner (ed.), The Patronage of Science in the Nineteenth Century (Leyden: Noordhoff, 1976), p.116.

30. Roger Hahn, The Anatomy of a Scientific Institution: The Paris Academy of Sciences 1666-1803 (London: University of California Press, 1971).

31. *Ibid.*, p.316-317.

32. Joseph Ben-David, "Academy, University and Research Institute in the 19th and 20th Centuries: A Study of Changing Functions and Structures", in Erwin K. Scheuch and Heine v. Alemann (eds.), *Das Forshungsinstitut: Formen der Institutionaliserung von Wissenschaft* (Erlangen: Institut für Gesellschaft und Wissenschaft, 1978).

33. R.M. MacLeod, "Whigs and Savants: The Royal Society of London and Reform 1830-1848", in I. Inkster and J.B. Morrell (eds.), *Metropolis and Province* (London: Hutchinson, 1981).

34. Charles Perrow, Complex Organizations (Glenview, Illinois: Scott, Foreman & Co., 1972), Chapter 5, "The Institutional School", pp.117-204.

35. *Ibid.*, p.178.

36. Philip Selznick, *Leadership in Administration: A Sociological Interpretation* (New York: Harper and Row, 1957), p.6.

37. *Ibid.*

38. See in particular Philip Selznick, "An Approach to a Theory of Bureaucracy", *American Sociological Review*, *8* (1943), 47-54; "Foundations of a Theory of Organizations", *American Sociological Review*, *13* (1948), 25-35. Selznick also produced an influential case-study, *TVA and the Grass Roots* (Berkeley: University of California Press, 1949).

39. Philip Selznick, *Leadership in Administration*, *op. cit.*, p.12.

40. *Ibid.*, p.5.

41. *Ibid.*, pp.20-21.

42. *Ibid.*

43. Philip Selznick, "Foundations of a Theory of Organizations", *op. cit.*, p.29.

44. *Ibid.*

45. *Ibid.*

46. *Ibid.*, p.34.

47. *Ibid.*

1. The emphasis on the use of science for improving human welfare was part of the common descent of both magic and science and had been emphasised by the empiricists of the middle ages, particularly Roger Bacon; see A.R. Hall, _The Scientific Revolution 1500-1800_ (London: Longmans, 1954), p.164-5.

2. Benjamin Farrington, _Francis Bacon: Philosopher of Industrial Science_ (London: Macmillan, 1973, first published 1951), p.13.

3. Newly introduced industries produced sugar, saltpetre, paper, ordnance, copper and brass; see M. Dobb, _Studies in the Development of Capitalism_ (London: Routledge, 1963), p.140; Archibald Clow and Nan L. Clow, _The Chemical Revolution_ (London: Batchworth, 1952), p.5.

4. In 1614 for instance the Duke of Sutherland is said to have spent £16,000 on a single coal works and £2,337 on a saltworks; quoted in Archibald Clow and Nan L. Clow, _ibid._, p.49. The exploitation of large mines entailed high capital investment. Early in the seventeenth century, for instance £4,000 was needed to construct two pumping engines and a new drainage tunnel for Redworth Colliery; J.U. Nef, _The Rise of the British Coal Industry_ (London: Frank Cass, 1966, first published 1932), p.355.

5. J.U. Nef, _The Conquest of the Material World_ (Chicago: The University of Chicago Press, 1964), p.123.

6. Simon Sturtevant and Cornelius Drebbel were two such well known speculative inventors of the period. Drebbel for instance attempted to build a vessel capable of underwater travel but later found a more lucrative venture involving the introduction of a new scarlet dye; J.D. Bernal, _Science in History_ (London: Watts, 1954), p.285.

7. _Ibid._

8. The process of substitution of coal for wood was accelerated by serious fuel crises resulting from severe deforestation; see Nef, _The Rise of the British Coal Industry_, _op. cit._, pp.190-223; William H. TeBrake, "Air Pollution and Fuel Crises in Pre-industrial London, 1250-1650", _Technology and Culture_, _16_ (1975) 337-359.

9. Dobb, _op. cit._, p.140.

10. J.U. Neff, _Cultural Foundations of Industrial Civilization_ (Cambridge: Cambridge University Press, 1958), p.50.

11. Archibald Clows and Nan Clows, _op. cit._, p.32.

12. Nef, Cultural Foundations ....., op. cit., p.56.

13. Te Brake, op. cit.

14. W.H. Price, The English Patents of Monopoly (London: Constable, 1906); see also J.U. Nef, Industry and Government in France and England 1540-1640 (Ithaca: Cornell University Press, 1964, first published 1940).

15. The financial interests of many officials came to be bound up with the development of mines, small factories and large putting out enterprises; Nef, ibid., p.36.

16. Price, op. cit., p.25.

17. James A. Williamson, A Short History of British Expansion: The Old Colonial Empire (London: MacMillan, 1951) p.14.

18. Ibid., p.104.

19. Two serious attempts were made to place a self-supporting colony in Virginia with the aim of providing homes for England's growing unemployed a strong motive. The "rank multitude" of beggars, tramps and general displaced populace had emerged in the wake of the upheavals in English society and had become such a major problem as to inspire numerous writers to view colonisation as a serious solution; see Christopher Hill, Intellectual Origins of the English Revolution (Oxford: Oxford University Press, 1965), p.162; also Williamson, op. cit. p.125.

20. Op. cit., p.205.

21. Raymond Phineas Stearns, Science in the British Colonies of America (Urbana: University of Illinois Press, 1970), p.5.

22. On the early botanical gardens see ibid., pp.46-51.

23. Lord Burghley employed John Gerard (1545-1612) as his superintendent of gardens in the Strand and at Theobald's, Hertfordshire. Gerard, in addition had his own private garden in Holborn. Matthias de Lobel (1538-1616) a Flemish botanist and physician was superintendent of a garden maintained by Lord Zouche at Hackney and later became King's Botanist to James I, ibid.

24. See Bernal, op. cit., p.262.

25. Quoted in Paolo Rossi, Francis Bacon: from Magic to Science (London: Routledge, 1968), p.1.

26. See A.P. Usher, A History of Mechanical Inventions (Cambridge, Mass.: Harvard University Press, 1954, first published 1929), p.215.

27. Farrington, op. cit., pp.39-40.

28. Stearns, op. cit., pp.21-42.

29. Thus the voyages corroborated belief in the sphericity of the Earth and highlighted such fallacies as the burning zone theory and other beliefs relating to the weather and ocean currents.

30. As early as the 1530's a modification of earlier humanist educational ideas becomes apparent with an emphasis on action as the primary end of learning and an appeal to reason and experience; see W.E. Houghton, "The history of trades: its relation to seventeenth century thought", Journal of the History of Ideas, 2 (1941), 33-38.

31. Hariot for instance travelled with Raleigh to Virginia in 1585 as mathematician, surveyor, and astronomer and in particular had the task of recording the various commodities for trade, food, and materials which the country had to offer; Stearns, op. cit., p.67.

32. For a detailed analysis of the association of the new science with merchant capital see Hill, op. cit.

33. See Peter J. French, John Dee, the World of an Elizabethan Magus (London: Routledge, 1972).

34. Ibid., p.180.

35. Ibid., p.176.

36. On Ramism and its influence on English education see Hugh Kearney, Scholars and Gentlemen: Universities and Society in Pre-Industrial Britain 1500-1700 (London: Faber, 1970).

37. See Rossi, op. cit., p.21.

38. J.G. Crowther, Francis Bacon: The First Statesman of Science (London: Cresset, 1960), p.157.

39. Francis Bacon, The Conference of Pleasure (1592), quoted in G.C. Moore Smith (ed.), The New Atlantis (Cambridge: Cambridge University Press, 1900), p.xii.

40. Francis Bacon, Gesta Greyorum (1594), quoted in J.G. Crowther, op. cit., pp.181-182; see also Moore Smith, op. cit., pp.xii-xiii.

41. Quoted in Moore Smith, *ibid.*, p.xiii.

42. *Ibid.*, p.xv. In this memorandum written in 1608 Bacon envisaged his college equipped with "vaults, fornaces, tarraces for Insolacion, woork houses of all sorts".

43. Francis Bacon, *The Advancement of Learning* (1605).

44. The edition used here is, Moore Smith, *op. cit.*

45. Quoted in Moore Smith, *op. cit.*, p.xxvi.

46. Unpublished treatise *Interpretation of Nature* written in the first year of the reign of James I, quoted in R.W. Church, *Bacon* (London, MacMillan, 1909), p.72.

Chapter Two (pp.33-58)

1. Margaret 'Espinasse, "The Decline and Fall of Restoration Science", Past and Present, No. 14(1958), 71-89, p.71. This was of course an intellectual tradition already established, although in a more turbulent social setting expressed in utopian form, rather than explicitly as programmes for social reform. The emphasis on the utilitarian function of knowledge was particularly strong among earlier writers in the Hermetic tradition and pervaded the various utopian programmes advocated in such works as Campanella's City of the Sun and Andrae's Christianopolis. The movement was continued and popularised by the circle surrounding Samuel Hartlib, John Comenius and John Dury. Hartlib's Description of the Famous Kingdom of Maccaria, published in 1641 implicitly advocated an orientation of learning geared to immediate commercial utility. It is from the 1640's that Bacon's influence dates; see Christopher Hill, Intellectual Origins of the English Revolution (Oxford: Oxford University Press, 1965), p.96.

2. D.G.C. Allan, William Shipley: Founder of the Royal Society of Arts (London: Hutchinson, 1968), pp.10, 163-167.

3. Ibid.

4. Ibid., p.14.

5. The Dublin Society was incorporated in the Royal Dublin Society in 1749, and between 1761 and 1767 received £42,000 in government aid; see Sir Henry Trueman Wood, A History of the Royal Society of Arts (London: John Murray, 1913), p.2. For a survey of the various technical societies established in Scotland see; Archibald Clow and Nan L. Clow, The Chemical Revolution (London: Batchworth, 1952), pp.40-43.

6. See Roger L. Emerson "The Philosophical Society of Edinburgh 1737-1747", British Journal for the History of Science, 12 (1979), 154-191; Steven Shapin, "Property, Patronage and the Politics of Science: The Founding of the Royal Society of Edinburgh", British Journal for the History of Science 7 (1974), 1-41. Like its counterpart, the Royal Society of London, its early history indicates an interest in the more immediate utilitarian applications of learned knowledge which gradually assumed a less important position in its programme.

7. Trueman-Wood, op. cit., p.4.

8. Ibid., p.3.

9. Foreign imitators included the Patriotische Gesellschaft, set up in Hamburg in 1763, and the Free Oeconomical Society of St. Petersberg, set up in 1766. In France a similar society was not established until 1801 when the Societé pour l'encouragement de l'industrie nationale was founded; see K.W. Luckhurst, Some Aspects of the History of the Society of Arts, London 1754-1952 (unpublished Ph.D. thesis, University of London, 1957), Part I, p.19. Provincial societies with similar aims to the Society of Arts were established in Breconshire and Lincolnshire. William Shipley, prominent in the establishment of the Society of Arts, was himself instrumental in organising a society at Maidstone. A number of further societies promoting the development of agriculture, itself one of the Society of Arts' chief interests, sprung up including ones in Norfolk, Pembroke, Carmarthen and Cardigan; see Trueman-Wood, op. cit. p.6.

10. Luckhurst, op. cit., Part I, p.27.

11. Supported by this board Dr. William Cullen investigated supplies of ashes and the potential of substitutes for bleaching and Dr. Francis Home was called upon to analyse samples of dyestuffs submitted; see Archibald Clow and Nan Clow, op. cit., p.41.

12. Standard works begin with Thomas Sprat's The History of the Royal Society (London, 1667) and Thomas Birch, The History of the Royal Society (4 vols., London, 1746); Robert K. Merton, following the historical tradition established by both Weber and Tawney emphasised the protestant background to the Royal Society, a thesis which has brought continuing controversy; see R.K. Merton, Science, Technology and Society in Seventeenth Century England (New York: Howard Fertig, 1970, first published 1938), Margery Purver has put forward the view that the Royal Society was a full blooded implementation of the Baconian programme; see M. Purver, The Royal Society: Concept and Creation (London: Routledge, 1967). Purver's thesis has been further discussed and argued against by Christopher Hill, "The Intellectual Origins of the Royal Society", Notes and Records of the Royal Society of London, 23 (1968), 144-156. The embryonic geneology of the Society, whether attributable to the Oxford or London gatherings, has also continued to attract attention; see Purver, op. cit.; A. Rupert Hall and Marie Boas Hall, "The Intellectual Origins of the Royal Society - London and Oxford", Notes and Records of the Royal Society, 23 (1968) 157-168. L. Mulligan, ("Anglicanism, Latitudiarianism and Science in Seventeenth Century England", Annals of Science, 30 (1973), 213-219), equates interest in science with political and religious indifference. W.E. Houghton ("The English Virtuoso in the Seventeenth Century", Journal of the History of Ideas, 3 (1942), 51-73, 190-219), emphasised the virtuoso tradition among English gentlemen. P.M. Rattansi, in contrast examined the remnants of

the hermetic tradition in "The Intellectual Origins of the Royal Society", Notes and Records of the Royal Society 23 (1968), 129-143. For further evidence of the hermetic influence as well as the continuing interest in the supernatural see K. Theodore Hoppen, "The Nature of the Early Royal Society", British Journal for the History of Science, 9 (1976), 1-24, 243-273.

13. W.E. Houghton, "The History of Trades: its relation to seventeenth century thought", Journal of the History of Ideas, 2 (1941), 33-60, p.50.

14. Sprat, op. cit.

15. Statement by Robert Hooke outlining the business and design of the Royal Society (1663), quoted in Sir Henry Lyons, The Royal Society 1660-1940: A History of its Administration under its Charters (New York: Greenwood Press, 1968), first published 1944), p.41.

16. Raymond Phineus Stearns, Science in the British Colonies of America (Urbana: University of Illinois Press, 1970), p.94.

17. Ibid.

18. Sprat, op. cit., p.67.

19. Quoted in Stearns, op. cit., p.93.

20. Merton, op. cit., pp.46-47.

21. Philip George, "The Scientific Movement and the Development of Chemistry in England, as seen in the Papers published in the Philosophical Transactions from 1664/5 to 1750", Annals of Science, 8 (1952), 302-322, pp.310-311.

22. Houghton, "The History of Trades ...", op. cit.; in respect to interest in mining in relation to the History of Trades project, see P.C. Davey, Studies in the History of Mining and Metallurgy to the Middle of the Seventeenth Century considered in relation to the progress of scientific knowledge and with some reference to mining in Cornwall (unpublished Ph.D. Thesis, University of London, 1954).

23. See Daniel Defoe, An Essay Upon Projects (London, 1697).

24. Merton, op. cit., Preface and p.83.

25. Boyle prepared a detailed questionnaire for mine owners to complete. There was only one recorded instance, however, of a complete set of answers; see Davey, op. cit., p.233.

26. The standard published histories of what later became the Royal Society of Arts are: D. Hudson and K.W. Luckhurst, The Royal Society of Arts 1754-1954 (London: John Murray, 1954); Trueman-Wood, op. cit.; shorter accounts include A. Rupert Hall, "The Royal Society of Arts: Two centuries of Progress in Science and Technology", Journal of the Royal Society of Arts, 122 (1974), 641-658; H.B. Wheatley, "The Society of Arts", Engineering, 52 (1891), 83-86. It has been suggested, although no documentary evidence remains, that an informal agreement was made around 1775 by a group of leading members holding membership of both the Society of Arts and the Royal Society that the latter would occupy itself with pure science and leave applications to the Society of Arts; see Hudson and Luckhurst, op. cit., p.58.

27. Quoted in Allan, op. cit., pp.190-191.

28. F.W. Gibbs, "Robert Dossie (1717-1777) and the Society of Arts", Annals of Science, 7 (1951), 149-172, p.153.

29. Allan, op. cit., p.67.

30. Trueman-Wood, op. cit., p.22.

31. Quoted in Luckhurst, op. cit., Part I, p.6.

32. D.G.C. Allan, "The Society of Arts and Government 1754-1800", Eighteenth Century Studies, 7 (1974), 434-52.

33. Ibid., p.444.

34. Trueman-Wood, op. cit., pp.28-52.

35. Allan, "The Society of Arts and Government", op. cit., p.451.

36. In 1790 on the Society's advice the duty on the import of the West Indian cashew gum, used in dying and dressing black silk was lowered. In 1791, to encourage the domestic tanning industry duty on imported tanned goatskins was raised and that on raw skins removed. In 1796, to encourage the manufacture of black lead melting pots, the duty on imported black lead was reduced; Allan, ibid., p.451.

37. Any detailed assessment of the Society's programmes is beyond the scope of the present thesis. A number of interesting examples are worth pointing out, however. The Society encouraged various researches in animal diseases (Luckhurst, op. cit., Part II, p.16); forestry and the replenishing of woodland occupied much of the Society's time; in 1758 it became involved in experiments aimed at reducing the resistance of ships passing through water when G.F. Taffnell proposed that the Society should offer a prize for a "model of a ship's bottom which may soonest pass through a given space of water drawn by a given weight". The Society accepted this idea and later in the year announced that awards

were to be offered for scale models to "ascertain by experiments the principles on which a good vessel is founded, ... passing through the water with least resistance seeming to be the first quality necessary". The Society also stressed that "stiffness" or resistance to rolling was another quality it was looking for. When models were finally submitted the Society was then given the problem of testing them and suitable apparatus was then designed; Luckhurst, op. cit., Part VI, pp.19-22. As Luckhurst comments: "Unfortunately, these remarkable tests proved largely abortive as they were so far ahead of their time that the information which they brought to light, could not, at that stage in the science of ship-building be converted accurately into modifications in the shape of full-scale ships"; ibid., p.22. The use of models for the study of ship performance was much later to be sponsored by the Admiralty and even later formed an important aspect of the work of the National Physical Laboratory.

38. In 1757 furnaces were installed in the kitchens of the Society's office for analysing geological samples; Hudson and Luckhurst, op. cit., p.97. In the next century pressure for such a national centre was to be answered through the creation of the Geological Survey and Museum.

39. For a detailed account of the Society's activities in this field see J.B. Harley, "The Society of Arts and the Surveys of English Counties 1759-1809", Journal of the Royal Society of Arts, 112 (1963), 43-46, 119-124, 269-275, 538-543.

40. Robert Dossie wrote that: "Agriculture is peculiarly important to us, as a commercial nation; the support of our trade depending on our manufactures; those manufactures on the rate of labour; and the rate of labour, in a great degree on the price of the necessities of life"; quoted in Hudson and Luckhurst, op. cit., p.57.

41. Luckhurst, op. cit., Part II, p.2.

42. Thus the role of the Society was bypassed through the temporary activities of the Board of Agriculture and later the Royal Agricultural Society, founded in 1838.

43. See for instance Trueman-Wood, op. cit., chapter eleven; Hudson and Luckhurst, op. cit., chapter six.

44. Wedgewood, Boulton, Henry Cort, Isaac Wilkinson, Joseph Bramah, the elder Brunel and Thomas Telford were all members; see Hall, op. cit., p.644.

45. Trueman-Wood, op. cit., p.243.

46. Quoted in Allan, William Shipley ...., op. cit., p.46.

47. Quoted in Wheatley, op. cit., p.83.

48. James A. Williamson, A Short History of British Expansion: The Old Colonial Empire (London: MacMillan, 1951), p.262.

49. Ibid.

50. The relationship between the public patronage of science and the influence of maritime needs has been extensively investigated in G. Basalla, Science and Government in England 1800-1870 (unpublished Ph.D. thesis, Harvard University, 1963).

51. For a detailed study of the Board of Longitude, see ibid., Chapter 1.

52. For detailed information on the Society of Arts and colonial interests, see Trueman-Wood, op. cit., chapter four; for a study of the role of the Royal Society, particularly in relation to the development of the North American colonies, see Stearns, op. cit.

53. Quoted in ibid., p.104.

54. Ibid., p.106.

55. Ibid., p.257.

56. Quoted in Trueman-Wood, op. cit., p.98.

57. Ibid.

58. Ibid.

59. George Basalla, "The Spread of Western Science", Science, 156 (1967), 611-622, p.613.

60. See H.C. Cameron, Sir Joseph Banks (London: Angus and Robertson, 1952), pp.62-63.

61. G.B. Masefield, A History of the Colonial Agricultural Service (London: Oxford University Press, 1972), p.8 and p.19.

62. See Lucille H. Brockway, Science and Colonial Expansion: the role of the British Royal Botanic Gardens (New York: Academic Press, 1979).

63. Karl Marx, Capital (London: Lawrence and Wishart, 1974 edition), Volume 1, p.356.

64. For a review of the conclusions of historians regarding the contribution of science to the industrial revolution, see Neil McKendrick, "The Role of Science in the Industrial Revolution: A Study of Josiah Wedgwood as a scientist and Industrial Chemist", in M. Teich and R. Young, Changing Perspectives in the History of Science (London: Heineman, 1973), pp.274-319.

65. A.E. Musson and Eric Robinson, Science and Technology in the Industrial Revolution (Manchester: Manchester University Press, 1969); Robert Schofield, The Lunar Society of Birmingham (Oxford: Clarendon Press, 1963); see also McKendrick, op. cit., and C.C. Gillispie, "The Natural History of Industry", Isis, 48 (1957), 398-407.

66. See L. Trengrove, "Chemistry at the Royal Society of London in the Eighteenth Century", Annals of Science, 19 (1963) 183-238; 20 (1964), 1-58; 21 (1965), 81-130, and 175-202; 26 (1970), 331-354; Philip George, op. cit.

67. Musson and Robinson, op. cit., Chapter One.

68. The Lunar Society is an example which stands out, see Schofield, op. cit.

69. Robert E. Schofield, "Josiah Wedgwood and a Proposed Eighteenth-Century Industrial Research Organisation", Isis, 47 (1956), 16-19.

70. E.J. Hobsbawm, Industry and Empire (Harmondsworth: Penguin, 1969), p.27.

71. Ibid., p.56.

72. Andrew Ure, The Philosophy of Manufactures (London, 1835), p.3.

73. Ibid., p.104.

74. Morris Berman, Social Change and Scientific Organisation: The Royal Institution 1799-1844 (London: Heineman, 1978), p.3.

75. Characteristic was the work of the Society for Bettering the Condition of the Poor, founded in 1796; ibid., p.5.

76. Ibid.

77. Ibid., p.75. In 1805 the London Institution was founded following a breakaway by some of the more commercial elements within the Royal Institution; ibid. p.92; see also J.N. Hays, "Science in the City: The London Institution 1819-40", British Journal for the History of Science, 7 (1974), 146-162.

78. Berman, op. cit., p.95.

79. More than 44% of the initial proprietors of the Royal Institution held office on, or were honorary members of, the Board of Agriculture. Of the nineteen governors of the Royal Institution fourteen were members of the Board of Agriculture; ibid., p.41.

80. *Ibid.*, p.47.

81. The Royal Institution was in debt from 1803 to 1836; *ibid.*, p.11. By contrast the London Institution, patronised by the commercial classes accumulated funds of over £76,000 within its first year of existence; Hays, *op. cit.*, p.146.

82. Quoted in Berman, *op. cit.*, p.96. Copies of this resolution were sent to various government agencies; the Military Department; the Board of Ordnance; the offices of the Surveyors General of the King's Land Revenue, and of the Woods and Forests; the Board of Agriculture, and the Lord Warden of the Stanneries; as well as the Admiralty, offering "the assistance of the Institution, with respect to any objects of Experiment, or Analysis within the scientific means of this Establishment", Replies are said to have been generally encouraging; Berman, *op. cit.*, pp.96-97.

83. *Ibid.*, Introduction.

84. *Ibid.*, p. 162.

85. *Ibid.*

1. This was particularly fueled by the poor showing of British products at the 1867 Paris Exhibition relative to previous performances at international exhibitions. As Cardwell had pointed out, although it is inconceivable that the technical standards of British industry could have relapsed in the five years since the previous exhibition, the Paris Exhibition was widely believed to have revealed a state of affairs highly discreditable. One immediate result was the particular concern with scientific and technical education; see D.S.L. Cardwell, The Organisation of Science in England (London: Heinemann, revised edition, 1972, first published, 1957).

2. The period 1873 to 1896 became popularly known as the Great Depression. Whether the relative decline in growth was as serious as contemporaries believed, and many economic historicans assumed, has been seriously questioned more recently; see S.B. Saul, The Myth of the Great Depression 1873-1896 (London: Macmillan, 1969); Donald N. McClosky, Economic Maturity and Entrepreneurial Decline: British Iron and Steel 1870-1913 (Cambridge, Mass.: Harvard University Press, 1973). What is undoubted, however, is that there occurred a real decline in business confidence.

3. See Cardwell, op. cit., pp.187-198.

4. Jack Morrell and Arnold Thackray, Gentlemen of Science: Early Years of the British Association for the Advancement of Science (Oxford: Clarendon Press, 1981), p.xxi.

5. Ibid., p.109.

6. See ibid., pp.36-94; see also L. Pierce Williams, "The Royal Society and the Founding of the British Association for the Advancement of Science", Notes and Records of the Royal Society of London, 16 (1961), 221-233; O.J.R. Howarth, The British Association for the Advancement of Science: A Retrospect (London: The British Association for the Advancement of Science, 1931); A.D. Orange, "The Origins of the British Association for the Advancement of Science", British Journal for the History of Science, 6 (1972-3), 152-176; A.D. Orange, "The British Association for the Advancement of Science: the Provincial Background", Science Studies, 1 (1971), 315-329.

7. See Morrell and Thackray, op. cit., pp.267-270.

8. Ibid., p.269.

9. Ibid., p.267.

10. Ibid., p.42.

11. Ibid.

12. Ibid.

13. Quoted in ibid., p.353.

14. The role of the BAAS in the context of government support for science is discussed in; George Basalla, Science and Government in England, 1800-1870 (unpublished Ph.D. Thesis, Harvard University, 1963), pp.102-129.

15. On the early involvement of the BAAS in technological matters, see Morrell and Thackray, op. cit., pp.256-266.

16. For instance in 1868 a paper was presented to the annual meeting of the BAAS stressing the need for experimental investigation of the problems of ship propulsion resulting in the establishment of a BAAS committee to investigate the issue. As a result of the committee's deliberations, members agreed to approach the Admiralty to allow one or more of the Navy vessels to be towed in sheltered waters in conditions such that the associated resistance and speeds could be measured. William Froude dissented from this initiative believing that experiments with models would be more fruitful. The Admiralty refused the BAAS request but provided Froude with funds for experiments. His first experimental tank was a long trench excavated in a field near Froude's Torquay home. His work was the immediate precursor of later work at the National Physical Laboratory.

17. See for instance R.M. MacLeod, "Science and Government in Victorian England: Lighthouse Illumination and the Board of Trade, 1866-1886", Isis, 60 (1969), 5-38; idem., "Government and Resource Conservation and the Salmon Acts Administration 1860-1886", Journal of British Studies, 7 (1968), 114-50.

18. The great diversity with which scientific expertise was applied in issues related to public policy is clear from the Minutes of evidence taken by a Royal Commission set up to investigate scientific questions; The Royal Commission on Scientific Instruction and the Advancement of Science (the Devonshire Commission) (London: 1871-1875); see for instance Frankland's own evidence to the Commission, ibid., Volume 1 (1872), c. 536, paras. 356-357, 5768, 5772.

19. See R.M. MacLeod, "The Royal Society and the Government Grant: Notes on the Administration of Scientific Research 1849-1914", The Historical Journal, 14 (1971), 323-358. As MacLeod notes, the Treasury's acceptance of a private "trust" of scientists responsible for public funds but neither subject to detailed audits nor accountable to a Minister in Parliament was an important constitutional precedent; ibid., p.333.

20. See Basalla, _op. cit._, pp.56-67, for a more detailed account of these activities.

21. The example of geomagnetism summarised here is taken from John Cawood, "The Magnetic Crusade: Science and Politics in Early Victorian Britain", _Isis_, _70_ (1979), 493-518.

22. The iron and steel battleships and commercial vessels of the nineteenth century were the most complex machines of their day and their development demanded large amounts of basic research and the introduction of new production techniques. One particular consequence was that the Admiralty became irreversably wedded to the interests of private industry; see Hugh Lyon, "The relations between the Admiralty and private industry in the development of warships", in Bryan Ranft (ed.), _Technical Change and British Naval Policy_ (London: Hodder and Stoughton, 1977), pp.37-64. For a general revue of the transition to steam ships see Charles K. Harley, "The shift from sailing ships to steam ships, 1850-1890: a study in technological change and its diffusion", in Donald N. McClosky (ed.), _Essays on a Mature Economy: Britain after 1840_ (London: Methuen 1971), pp.215-234. Many of the technical problems associated with the transition from sail to steam are dealt with in A.M. Robb, "Shipbuilding", in C. Singer et al (eds.), _A History of Technology, Volume 5_ (Oxford: Clarendon Press, 1958), pp.350-390.

23. See note 16.

24. See Frederick John Evans, "On the Magnetic Character of the Armour-Plated Ships of the Royal Navy and on the effect on the Compass of particular arrangements of Iron in a ship", _Proceedings of the Royal Society of London_, _14_ (1865), 114-119; "Communication from the President and Council of the Royal Society to the Board of Trade on the subject of the Magnetism of Ships", _Proceedings of the Royal Society of London_, _14_ (1865), 300-305.

25. See for instance R.M. MacLeod, "Science and Government in Victorian England ...", _op. cit._

26. Edward Sabine, "Note on a Correspondence Between Her Majesty's Government and the President and Council of the Royal Society regarding Meteorological Observations to be made by Sea and Land", _Proceedings of the Royal Society of London_, _15_ (1866), 29-38.

27. See "Correspondence between the Board of Trade and the Royal Society in reference to the Meteorological Department", _Proceedings of the Royal Society of London_, _14_ (1865), 306-319.

28. The Royal Commission on Scientific Instruction ...., op. cit., Volume 3 (c.1365, 1975), evidence of R.H. Scott, Director of the Meteorological Office, para. 13, 867.

29. Later in 1919 a committee of inquiry recommended the transfer of the Meteorological Office to the Department of Scientific and Industrial Research. However, due to the representations of the Air Ministry, conscious of its relevance to air warfare, it was instead transferred to the Air Ministry and thereafter it remained a defence establishment.

30. See W.D. Hackman, "Underwater Acoustics and the Royal Navy, 1893-1930", Annals of Science, 36 (1979), 255-267.

31. P.B. Walker, "The Antiquity of the Royal Aircraft Establishment", Journal of the Royal Aeronautical Society, 70 (1966), 40-43; idem, Early Aviation at Farnborough: the history of the Royal Aircraft Establishment, 2 volumes (London: Macdonald, 1971 and 1974).

32. See Edward Bailey, Geological Survey of Great Britain (London: Thomas Murby, 1952).

33. Public Record Office, CAB 58/107, memorandum, The Nature and Scope of the Work Carried Out in the Laboratories of the Imperial Institute (undated).

34. See for instance Robert H. Kargon, Science in Victorian Manchester (Manchester: Manchester University Press, 1977); R.M. MacLeod, "Government and Resource Conservation ....", op. cit., idem., "The Alkali Acts Administration, 1863-84: The Emergence of the Civil Scientist", Victorian Studies, 9 (1966), 85-112; Eric Ashby and Mary Anderson, "Studies in the Politics of Environmental Protection: The Historical Roots of the British Clean Air Act, 1956", Interdisciplinary Science Reviews, 1 (1976), 279-290; 2 (1977), 9-26, 190-206; Elizabeth Porter, Water Management in England and Wales (Cambridge: Cambridge University Press 1978) pp.25-26.

35. The first instance of State-aided medical research arose indirectly from administrative measures taken in the interest of public health in the period 1833-1854. Dr. Thomas Southwood Smith was intermittently employed during this period, on inquiries for official commissions and later for the General Board of Health for England and Wales, set up in 1848. Various other studies were made in the context of commissions, such as the Poor Law Commission and the Health of Towns Commission. Following the establishment of the Board of Health, John Simon, its medical officer, had a definite policy for research, employing specialists on a temporary basis. These functions were continued under the auspices of the Privy Council following

the Board's abolition in 1858, and later by the Local Government Board, set up in 1871; see for further details A. Landsborough Thomson, Half a Century of Medical Research (London: H.M.S.O., 1973) 2 volumes, Vol. 1, pp.2-5.

36. Henry II appointed an assay master in an attempt to secure uniformity and reliability of coinage. Although some form of trial of the coinage may have been made as early as 1180 the Trial of the Pyx as the analytical test was known dates from 1279 when the manufacture of coinage came under more central control. The first trial along modern lines for which there is a record dates from 1281; Harold Egan, The Government Chemist Through the Ages, unpublished paper presented to the Mid-Anglian Section of the Chemical Society given in Cambridge on October 20, 1972.

37. Ibid. For a published account of the early history of what was to eventually become the Laboratory of the Government Chemist, see A.G. Francis, "Centenary of the Government Laboratory, Department of the Government Chemist", Nature, 150 (1942), 567-568.

38. Two notable contributions to analytical methods which came out of the work of the laboratory in its early period were to develop the present method of estimating the original gravity of beer, and establishing the basis on which denatured alcohol could be made available on a duty-free basis without risk to the revenue; ibid., p.567.

39. Public Record Office, File DSIR 26/3, Treasury Memorandum (May 8, 1911).

40. A notable increase in demand for the services of the laboratory from other government departments was noticeable towards the end of the nineteenth century. In 1897/8, for instance, thirteen departments employed its services. In addition investigations were undertaken for a number of Royal Commissions, and Parliamentary and departmental committees; see Peter Randman, Government Science in Britain 1875-1921 (unpublished M.Sc. Thesis, University of Manchester, 1977), pp.83-84.

41. Between 1897 and 1908 accounts paid to the Government Laboratory from departments other than the revenue department rose from £1,830 to £3,796 representing analyses totalling 3,480 in 1897 and 7,126 in 1908. Direct expenditure on the laboratory according to civil estimates rose from £1,675 in 1875/6 to nearly £25,000 by 1914/15; Treasury Memorandum (May 8, 1911) op. cit., Randman, op. cit., tables 2.1, 3.2.

42. The only extensive biographical details available on Strange are in Crowther's sympathetic and illuminating portrait; J.G. Crowther, "Alexander Strange 1818-76", in idem., Statesmen of Science (London: Cresset Press, 1965), pp.237-269.

43. His certificate of candidature for election described him as distinguished in geology and mathematics, and among those who supported his election from personal knowledge were Charles Babbage and William Hamilton. His election was also supported by the Duke of Devonshire; Royal Society Archives.

44. Lieut.-Col. A. Strange, "On the Proposed Inquiry, by a Royal Commission, into the Relations of the State to Science", paper read to a conference on "The Relation of the State to Science", March 31, 1870, reprinted in Journal of the Society of Arts, 18 (1870), 446-450, p.446.

45. Lieut.-Col. A. Strange, "On the Necessity for a Permanent Commission on State Scientific Questions", Journal of the Royal United Service Institution, 15 (1871-2), 537-566, p.564.

46. Lieut.-Col. A. Strange, "On the Necessity for State Intervention to secure the Progress of Physical Science", transactions of the Mathematical and Physical Section of the British Association, Report of the British Association For the Advancement of Science 1868 (London: John Murray, 1869), pp.6-8.

47. For a more detailed analysis of the origins, development and impact of the Devonshire Commission and its context within the so-called Endowment of Science Movement, see Cardwell, op. cit., pp.119-126; R.M. MacLeod, "Resources of Science in Victorian England: The Endowment of Science Movement 1868-1900", in Peter Mathias (ed.), Science and Society 1600-1900 (Cambridge: Cambridge University Press, 1972), pp.111-166.

48. In addition to the papers already cited these include A. Strange and Dr. Mann, "On National Institutions for Practical Scientific Research", Quarterly Journal of Science, 6 (1869), 38-50; as well as extensive disclosures in evidence to the Devonshire Commission itself.

49. A. Strange, "Lord Derby and Scientific Industry", Letter to The Times (February 6, 1874), p.7.

50. A. Strange, The Royal Commission on Scientific Instruction, op. cit., and Minutes of evidence, para. 10, 314.

51. A. Strange and Dr. Mann, op. cit., p.41.

52. These themes were particularly articulated in his papers to the Royal United Service Institution, op. cit., and to the meeting of the BAAS in 1871.

53. Strange, "On the Necessity for a Permanent Commission ....", _op. cit._, p.538.

54. _Ibid._

55. _Ibid._, in discussion, p.556.

56. _Ibid._

57. Macleod, "Resources of Science in Victorian Britain ....", _op. cit._, p.123.

58. Cardwell, _op. cit._, p.122.

59. E. Hobsbawm, _Industry and Empire_ (Harmondsworth: Penguin books, 1969) pp.147-149; see also John Gallagher and R. Robinson, "The Imperialism of Free Trade", in A.G.L. Shaw (ed.), _Great Britain and the Colonies_ (London: Methuen, 1970), pp.142-163; and D.K. Fieldhouse, _Economics and Empire 1830-1914_ (London: Weidenfeld and Nicolson, 1973).

60. Shaw, _op. cit._, introduction, p.21.

61. Thus Strange considered that if one substituted for "the peculiar language, and usages of the people of India, the peculiar language, methods, and principles of physical science", the existence of a Secretary of State for India, pointed the way for a Secretary of State for Science; "On the Necessity for a Permanent Commission on State Scientific Questions", _op. cit._, p.556.

62. _The Royal Commission on Scientific Instruction ...._, _op. cit._, Minutes of evidence, para. 12565.

63. Rawlinson cited a particular instance in which the combination of waste soda from a steel works and an artificial irrigation scheme had resulted in a large tract of land being rendered useless for cultivation. When the India Council had been approached by the Indian Government for advice it lacked any expertise to provide any useful answer. He disclosed that the Council was also having referred to it constant problems of a technical character relating to deforestation due to local climatic changes, problems of physical hydrography in harbours, and engineering problems associated with canal and railway projects. To few of these could the India Council provide effective advice; _ibid._

64. _The Royal Commission on Scientific Instruction ...._, _op. cit._, Minutes of evidence, para. 10,414.

65. Strange, "On the Necessity For a Permanent Commission on State Scientific Questions", _op. cit._, p.560.

66. Ibid., p.556. Scott Russell's humerous comment takes on a more ironic aspect, when in retrospect, one can see that the first major public funding body in the twentieth century, which in turn encouraged the expansion of both the National Physical Laboratory and the Royal Aircraft Establishment, was the Aeronautical Research Committee.

67. See for instance George Gore, "On a National Laboratory for Scientific Research", The Royal Commission on Scientific Instruction ....., op. cit., Minutes of evidence, Appendix X.

68. There were, in fact, precedents with respect to the call for a Council for Science. A proposal had been placed before the Government in 1857 in a report from the Government Grant Committee of the Royal Society, considering a model based on the defunct Board of Longitude; see Royal Commission on Scientific Instruction ...., op. cit., 8th Report (c.1298, 1875) p.29. Another initiative came from the British Association's Parliamentary Committee; see David Layton, "Lord Wrottesly, F.R.S.: Pioneer Statesman of Science", Notes and Records of the Royal Society of London, 23 (1968), 230-246, p.237.

69. Royal Commission on Scientific Instruction ...., op. cit., Minutes of evidence, para. 9554.

70. Ibid., para. 11,755.

71. See W.V. Farrar, "The Society for the Promotion of Scientific Industry 1872-1876", Annals of Science, 29 (1972), 81-86.

72. Editorial, The Times (January 19, 1874), p.9.

73. Strange, "Lord Derby and Scientific Industry", op. cit.

74. Farrar, op. cit., p.86.

75. See R.H. Scott, "The History of the Kew Observatory", Proceedings of the Royal Society of London, 39 (1885), 37-86.

76. For a detailed study, see Russell Moseley, "The Origins and Early Years of the National Physical Laboratory: A Chapter in the Pre-History of British Science Policy", Minerva, 16 (1978), 222-250.

77. Thus William Crooks observed in 1876 that: "The facts and truths that lay near at hand have already been gathered in. We have now to go farther afield, to use costlier, because rarer, materials, to correct approximate determinations of our predecessors and in so doing to employ expensive instruments of precision"; quoted in MacLeod: "Resources of Science in Victorian England ....", op. cit., p.114.

78. See for instance "Prof. Ira Remsen on Chemical Laboratories", Nature, 49 (1894), 531-535. For a recent study of the development of physics laboratories, see Romnaldas Sviedrys, "The Rise of Physics Laboratories in Britain", Historical Studies in the Physical Sciences, 7 (1976), 405-436.

79. Ibid., p.409-415.

80. Ibid., p.427-430, 433-436; see also J.G. Crowther, The Cavendish Laboratory 1874-1974 (London: MacMillan, 1974).

81. The response led to the establishment of an Electrical Standards Laboratory at the Board of Trade for limited work on the electrical quantities of resistance, current and electromotive force. This laboratory, however, undertook little work of an investigative nature and its major task was to hold the custody and superintend the use of the primary standards; see "The Board of Trade Electrical Standards Laboratory", Engineering, 81 (1906), 683-686.

82. Oliver Lodge, "Presidential Address to Section A of the British Association", Report of the British Association 1891 (London: John Murray, 1892) 549-551, p.549. For a more detailed analysis of these events, see Moseley, op. cit.

83. Quoted in ibid., p.226.

84. Quoted in ibid., p.233.

85. On private support for the National Physical Laboratory, see ibid., pp.245-248; also R.T. Glazebrook, "The National Industrial Research Laboratory", Engineering, 105 (1918), 252-256.

86. George Gore, "On the Future Extension of Birmingham Industries", Birmingham Morning News (March 29, 1872).

87. For an account of the ascendancy of German industrial power, see W.O. Henderson, The Rise of German Industrial Power 1834-1914 (London: Temple Smith, 1975).

88. "Presidential Address By His Royal Highness the Prince Consort", Report of the British Association 1859 (London: John Murray, 1860) pp.lix-lxix, p.lxv.

89. Lyon Playfair, Subjects of Social Welfare (London: Cassell, 1889), p.39.

90. Sir Norman Lockyer, "The Influence of Brain Power on History", Presidential Address to the British Association, Report of the British Association 1903 (London: John Murray, 1904) pp.3-28, p.6.

91. See for instance, W.M. Frew, "The Endowment of Technical Research: An Object Lesson", _Journal of the Society of Chemical Industry_, _20_ (1901), 219-221.

92. Percy F. Frankland, "The Chemical Industries of Germany", _Journal of the Society of Chemical Industry_, _34_ (1915), 307-316, p.315.

93. Quoted in Sir Henry Trueman-Wood, _A History of the Royal Society of Arts_ (London: John Murray, 1913), Preface.

94. Public Record Office, CAB 58/107, Memorandum by Mr. Vaughan Nash, _The Work of the Development Commission in aiding research in agriculture and fisheries_ (undated).

95. For a detailed analysis of the origins of the Medical Research Committee, see Landsborough Thomson, _op. cit._

1. The nature of the shortages, and the response of both the Government and the scientific community have been extensively covered elsewhere; see for instance Arthur Marwick, The Deluge (Harmondsworth: Penguin, 1967, first published 1965), pp.244-276; L.F. Haber, The Chemical Industry, 1900-1930 (Oxford: Clarendon Press, 1971), pp.184-246; L.F. Haber, "Government Intervention at the Frontiers of Science: British Dyestuffs and Synthetic Organic Chemicals 1914-39", Minerva, 11 (1973) 79-94; Roy M. MacLeod and E. Kay Andrews, "The Origins of the DSIR: Reflections on Ideas and Men 1915-1916", Public Administration, 48 (1970), 23-48; Roy MacLeod and Kay MacLeod, "Government and the optical glass industry in Britain 1914-1918", in J. Winter (ed.), War and Economic Development (Cambridge: University Press, 1975), pp.165-203; Ian Varcoe, "Scientists, Government and Organised Research in Great Britain 1914-16: The Early History of the DSIR", Minerva, 8 (1970) 192-216; for contemporary opinions of the shortages and particularly of comparisons with German provisions see Percy F. Frankland, "The Chemical Industries of Germany", Journal of the Society of Chemical Industry, 34 (1915), 307-316; N.H. Martin, "Germany and Chemical Industry", Journal of the Society of Chemical Industry, 33 (1914), 1130-1134.

2. The campaign by scientists against the neglect of science was particularly evident in the columns of Nature, see for instance; editorial, "Science and the State", Nature, 94 (1914) p.22; editorial, "Mobilisation of Science", Nature, 95 (1915), p.419; "Report of the Meeting of the British Science Guild", Nature, 95 (1915), 520-521.

3. Scheme For The Organisation and Development of Scientific and Industrial Research (London: H.M.S.O., 1915), Cd. 8005. The details behind these developments have been extensively reviewed elsewhere; see in particular Varcoe, op. cit., MacLeod and Andrews, op. cit.

4. For details see Report of the Committee of the Privy Council for Scientific and Industrial Research for the year 1915-16 (London: H.M.S.O., 1916) Cd. 8836, pp.49-50.

5. In the early years of the scheme two such co-operative initiatives were launched; one to develop supplies of chemical glassware and the other to support the Staffordshire Pottery Manufacturers Association. Both instances resulted from war-time shortages.

6. For details of the emergence and subsequent development of these provisions for co-operative industrial research; see P.S. Johnson, Co-operative Research in Industry (London: Martin Robertson, 1973); R.S. Edwards, Co-operative Industrial Research (London: Pitman, 1950).

7. See Haber, "Government intervention at the frontiers of science", op. cit.

8. See Michael Sanderson, "Research and the Firm in British Industry 1919-39", Science Studies, 2 (1972), 107-151.

9. In the initial post-war period, for example, the General Electric Company undertood to create central research laboratories, erected at Wembley, to serve the company's corporate interests; see C.C. Paterson, A Confidential History of The Research Laboratories (London: The General Electric Company Limited, 1945).

10. Roy and Kay MacLeod, "The Social Relations of Science and Technology 1914-1939", in Carlo M. Cipolla (ed.), The Twentieth Century, Fontana Economic History of Europe, Volume 5, Part I (Hassocks, Sussex: Harvester Press, 1977), pp.301-363, p.321.

11. After the war a number of industries, including the dyestuffs industry were singled out as warranting government supervision, because of their strategic importance to the security of the economy; see Haber, "Government Intervention at the Frontiers of Science ....", op. cit.

12. Lord Milner, Colonial Secretary from 1918-1921 was personally convinced that one of the keys to colonial development was scientific research. In 1919 a grant of £20,000 was provided to establish an Imperial Research Committee, reduced to £2,000 per annum under the Geddes cuts in 1922. Leopold Amery, writing in The Times on January 30, 1924, wrote that the development of the Empire was not only a great political and administrative problem, but also "a great scientific problem - a problem of applying scientific research to the practical task of making the most of our immense resources. The publication of the East Africa Report in 1925 was an indictment of post-war government administration in general. The report emphasised the need to develop the imperial dependencies as sources of cheap food, minerals, and timber, and in this context emphasised the importance of scientific research; see Roy M. MacLeod and E. Kay Andrews, "The Committee of Civil Research: Scientific Advice For Economic Development 1925-30", Minerva, 7 (1969), 680-705.

13. Ministry of Reconstruction, Report of the Machinery of Government Committee (London: H.M.S.O., 1918), Cd. 9230. On the background to the work of the committee in respect to the management and conduct of research see A. Landsborough Thomson, Half a Century of Medical Research, Volume I (London: H.M.S.O., 1973), pp.36-38.

14. Ibid., pp.39-40.

15. Ibid.

16. Public Record Office, File DSIR 17/119, Walter M. Fletcher to Sir Frank Heath (January 29, 1919).

17. Public Record Office, File DSIR 17/119, H.A.L. Fisher, Memorandum on the Proposed Extension of the Functions of the Privy Council for Scientific and Industrial Research (November 1918).

18. Ibid.: and Public Record Office, File DSIR 17/119, War Cabinet A Ministry of Research: Memorandum by the President of The Board of Education (February 1919).

19. Sir Frank Heath did not relinquish his personal ambitions for the DSIR, however. In 1920, for example, the Government Chemist's Laboratory was experiencing accommodation problems and the Office of Works suggested building a new laboratory at Teddington, an idea which appealed to Heath's vision of Teddington as a great public research centre under the control of the DSIR. He was conscious, however, of the threat from vested interests, for as he informed Sir Lionel Earle at the Office of Works: "If, as I hope, Teddington should in course of time become a great centre of Government Research it behoves us to move warily"; Public Record Office, File DSIR 10/1, Sir Frank Heath to Sir Lionel Earle (November 24, 1920).

20. An earlier initiative had come during the war when the Admiralty established a Board of Inventions and Research; see Roy MacLeod and Kay Andrews, "Scientific Advice for the War at Sea: The Board of Invention and Research", Journal of Contemporary History, 6 (1971) 3-40.

21. Further details on the organisation of research in the services in the 1920's can be found in Public Record Office, File CAB 58/107, Sir Frank Smith, Organisation of Government Research in Britain, memorandum submitted to the Sub-committee on the Co-ordination of Research of the Cabinet Committee of Civil Research (undated).

22. Public Record Office, File CAB 58/107, Report of the Committee on Research, Design and Experimental Work on Guns, Ammunition and Projectiles (Duckham Committee); (June 25, 1925), p.11.

23. See Landsborough Thomson, op. cit., pp.77-87.

24. A Radio Research Board had already been set up with the task of co-ordinating work in this field.

25. Criticisms of the effectiveness of the boards were voiced in 1926 by Henry Tizard, Secretary to the DSIR in evidence before the Select Committee on Estimates. In particular he claimed that the DSIR did not receive information from the Services regarding "confidential inquiries", which negated the functions of the boards. Second Report from the Select Committee on Estimates Session 1925/26, H.C.119, minutes of evidence paras. 2334-2349. Tizard revealed his views before the Sub-Committee on the Co-ordination of Research in February 1927, and the Committee's recommendations to disband them clearly were influenced by

Tizard's views; Public Record Office, File CAB 58/106 Cabinet: Committee of Civil Research, Research Co-ordination Sub-Committee, Reports and Proceedings of the Sub-Committee on Research Co-ordination (1926-1929).

26. Landsborough Thomson, op. cit., p.69.

27. This came to light when in 1925 Herbert Williams M.P., requested information on research expenditure which was duly produced in a Commons' written answer on May 15, 1925. A few days later Williams asked the Prime Minister whether action was being taken to ensure adequate co-ordination. In reply the Prime Minister admitted that the issue had created some public interest in view of the large sum disclosed. Sir Joseph Larmor, for instance, in a letter to The Times described the sum as "astonishing when contrasted with all the income of all the universities in the land". On July 27, 1925, a further question was asked in the Commons raising once again the issue; these events are described in Public Record Office, File CAB 58/107 Treasury Memorandum, Research Expenditure (undated).

28. Second Report from the Select Committee on Estimates, Session 1925/26, op. cit.

29. Department of Scientific and Industrial Research: Report For the Year 1947-8 (London: H.M.S.O., 1949), Cmd. 7761, Appendix V, Table 1.

30. On the circumstances surrounding the transfer of control to the DSIR see Eric Hutchinson, "Scientists and Civil Servants: the struggle over the National Physical Laboratory in 1918, Minerva, 7 (1969), 373-399; on the levels of DSIR expenditure in individual establishments in the inter-war period, see Appendix A.

31. Ian Varcoe, Organising for Science in Britain (London: Oxford University Press, 1974), p.36. There were anomalies, however. The staff of the new research stations were treated as temporary employees; ibid. The arrangements at the National Physical Laboratory whereby the same scales of pay applied to women as to men did not extend to other establishments; ibid., p.40. Salaries of scientific grades were in general lower than those for administrative grades particularly marked at junior levels; ibid., p.36.

32. For details see Russell Moseley, Science, Government and Industrial Research: the Origins and Development of the National Physical Laboratory 1900-1975 (unpublished Ph.D. thesis, University of Sussex, 1976), pp.225-257.

33. Source of data; The Association of Scientific Workers, Industrial Research Laboratories: A List Compiled by the Association of Scientific Workers (London: The A.Sc.W., 1936).

34. As Varcoe has observed it was the Advisory Council't duty to "lick into shape" and recommend proposals that came to them rather than sit down and devise original proposals; Varcoe, Organising for Science in Britain, op. cit., p.20. In the case of proposals for food research, for instance, the task of providing a detailed assessment was given to Sir William Hardy, a member of the Advisory Council.

35. For instance the testing and structures work which was undertaken at the Building Research Station, and prototype plant established at the Fuel Research Station.

36. Report of the Committee of the Privy Council for Scientific and Industrial Research For the Year 1915-16, op. cit., p.10.

37. Public Record Office, File DSIR 13/1, Advisory Council, Minutes of the Meeting held on 21 May 1924.

38. Ibid.

39. The laboratory's Ship Tank for instance provided an important source of repayment work on behalf of shipbuilders testing new ship designs. In times of recession this revenue dropped rapidly, and at the same time released staff to pursue more long-term research relevant to ship hydrodynamics. Thus net expenditure rose at precisely the time when economic retrenchment in public expenditure was most evident. In contrast, in more buoyant economic periods repayment work would rise reducing net expenditure, and was inevitably accompanied by concerns expressed in the laboratory's annual report about the health of its longer term research.

40. Russell Moseley, "Government Science and the Royal Society: the Control of the National Physical Laboratory in the Inter-War Years", Notes and Records of the Royal Society of London 35 (1980), 167-193, p.173.

41. Report of the Privy Council For Scientific and Industrial Research For 1916/17 (London: H.M.S.O., 1917), Cd. 8718, p.15.

42. Thus according to Lea, in its early days even minor financial expenditures did not escape the concern of the Building Research Board. This changed with the growth of the station, and financial and staffing matters became the responsibility of the director in negotiation with the DSIR; F.M. Lea, Science and Building: A history of the Building Research Station (London: H.M.S.O., 1971), p.72; similarly Rendle has noted that in the early years of the Forest Products Research Laboratory, the Forest Products Research Board was influential in formulating policy and in deciding the main lines of research. Later it became increasingly passive in policy matters; B.J. Rendle, Fifty Years of Timber Research: A Short History of the Forest Products Research Laboratory, Princes Risborough (London: H.M.S.O., 1976), p.67.

43. Ibid.

44. By May 1916 research applications bearing upon the issue before the Advisory Council included one from Marie Stopes of University College, London, to investigate the structure of coal: a proposal from the Institution of Gas Engineers for research on carbonisation; the Institution of Mining Engineers wished to investigate by-product recovery; and the National Physical Laboratory proposed experiments on the specific heats of gases; Public Record Office, File DSIR 8/1, Committee of the Privy Council for Scientific and Industrial Research, Advisory Council, Memorandum by the Secretariat on Researches bearing on coal and its uses (May 26, 1916).

45. Ibid., the Commission particularly warned of the dangers of excessive secrecy by commercial concerns searching for deposits. Indeed for a time the only published account of some bore holes made by British Companies was to be found in a German periodical and for others the German account still, in 1905 remained the only available record. Such disclosures had of course added significance after 1914.

46. Public Record Office, File DSIR 8/1, Memorandum by the Secretariat on Researches bearing on coal and its uses, op. cit.

47. Public Record Office, File DSIR 8/1, Lord Haldane to Sir William McCormick (August 11, 1916).

48. Ibid.

49. Public Record Office, File DSIR 8/1, Coal Conservation Sub-Committee Minutes (September 14, 1916).

50. Public Record Office, File DSIR 8/1, Advisory Council, Minutes of the Meeting held on November 3, 1916.

51. Public Record Office, File DSIR 8/1, Advisory Councils, Report of the Advisory Council on Fuel Research (February 2nd, 1917).

52. Ibid.

53. On the initial research activities of the Fuel Research Board, see Report of the Committee of the Privy Council For Scientific and Industrial Research for the Year 1916-17, op. cit., pp.17-22.

54. Report of the Committee of the Privy Council For Scientific and Industrial Research for the Year 1917-18 (London: H.M.S.O., 1918), Cd. 9144, p.3; see also Report of the Fuel Research Board on the Establishment of a Fuel Research Station (London: H.M.S.O., 1917).

55. See W.J. Reader, Imperial Chemical Industries: A History, Volume 2, The First quarter century (London: Oxford University Press, 1975), pp.162-182, for an account of I.C.I.'s involvement in this area.

56. Report of the Committee of The Privy Council For Scientific and Industrial Research for the Year 1920-21 (London: H.M.S.O., 1921), Cmd. 1491, p.43.

57. Thus in 1938 when the last pre-war DSIR report was published the gross annual expenditure of the Fuel Research Board amounted to £103,000 compared with £252,000 at the National Physical Laboratory, which was divided among various fields of research. After fuel research the next highest budget was taken up by building and road research at £97,000; Department of Scientific and Industrial Research, Report for the Year 1937-38 (London: H.M.S.O., 1939), Cmd. 5927, p.118.

58. In the year 1925/26 for instance net expenditure of the Fuel Research Board amounted to £63,000 compared with £56,000 at the National Physical Laboratory; Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1925-26 (London: H.M.S.O., 1927), Cmd. 2782, p.123.

59. For a more detailed review of the work of the Fuel Research Station see, Department of Scientific and Industrial Research, Fuel Research 1917-1958: A Review of the Work of the Fuel Research Organisation of DSIR (London: H.M.S.O., 1960); brief histories include, Sir Harold Hartley, "Fuel Research Station, 1919-1959; Fuel Research Board, 1917-1958", Journal of the Institute of Fuel 32 (1959), 566-568; A.C. Monkhouse, "Forty Years of Fuel Research", Steam Engineer, 28 (1959), 114-116; A. Parker, "The Fuel Research Station of the DSIR", Research, 1 (1947/48), 464-469.

60. Public Record Office, File DSIR 6/6, J. Raymond to Sir Albert Henry Stanley (February 6, 1917).

61. Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1917-18 op. cit., pp.25-26. Hardy was assisted in the preparation of the memorandum by W.M. Bayliss, J.B. Farmer, and F.G. Hopkins, all distinguished scientists.

62. Ibid., p.25.

63. Public Record Office, File DSIR 6/6, W.B. Hardy memorandum (March 18, 1918).

64. Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1918-19 (London: H.M.S.O., 1919), Cmd. 320, p.40.

65. Report of the Committee of the Privy Council for Scientific and Industrial Research for the Year 1919-20 (London: H.M.S.O., 1920), Cmd. 905, p.23.

66. See Dana G. Dalrymple, "The Development of an Agricultural Technology: Controlled Atmospheric Storage of Fruit", Technology and Culture, 10 (1966), 35-48.

67. Ibid., p.40

68. Department of Scientific and Industrial Research, Report For the Year 1937-38 (London: H.M.S.O., 1939), Cmd. 5927, p.10.

69. Along with contributions from both the Cambridge and Ditton laboratories the National Physical Laboratory was also closely involved in these developments, primarily through the work of Ezer Griffiths, who became one of the leading world authorities on the subjects of heat insulation, heat transfer and evaporation; see Sir Charles Darwin, "Ezer Griffiths 1888-1962", Biographical Memoirs of Fellows of the Royal Society of London, 8 (1962), 41-48.

70. Department of Scientific and Industrial Research, Report For the Year 1937-8, op. cit., p.10.

71. Department of Scientific and Industrial Research, Report For the Year 1927-28 (London: H.M.S.O., 1929), Cmd. 3258, p.13.

72. Department of Scientific and Industrial Research, Report For the Year 1929-30 (London: H.M.S.O., 1931), Cmd. 3789, p.173.

73. Department of Scientific and Industrial Research, Report For the Year 1931-32 (London: H.M.S.O., 1933), Cmd. 42549, p.164.

74. Report of the Committee of the Privy Council For Scientific and Industrial Research For the Year 1920-21, op. cit., p.48.

75. Ibid.; see also B.J. Rendle, op. cit., pp.1-2.

76. Ibid., pp.2-3.

77. Quoted in ibid., p.3.

78. Ibid.

79. Ibid., p.5.

80. For a review of the work of the laboratory in the years prior to the Second World War see ibid., pp.7-43.

81. Ibid., p.21.

82. Material included in this section has essentially been taken from F.M. Lea, op. cit.

83. Ibid., p.17.

84. *Ibid.*

85. *Ibid.*, p.79.

86. Public Record Office, File DSIR 13/1, Letter, Ministry of Agriculture and Fisheries to DSIR (October 31, 1923).

87. Public Record Office, File DSIR 13/1, Advisory Council, *Minutes of the Meeting held on May 21, 1924*.

88. *Ibid.*

89. Department of Scientific and Industrial Research, *Report For the Year 1929-30*, *op. cit.*, pp.103-108.

90. *Ibid.*

91. *Report of the Committee of the Privy Council for Scientific and Industrial Research For the Year 1920-21*, *op. cit.*, pp.54-56.

92. Public Record Office, File DSIR 5/1, Sir Richard Threlfall, *Memorandum on the need for Greater Facilities for Researches in Chemistry Required for National Purposes* (July 26, 1922).

93. See Department of Scientific and Industrial Research, *Report For the Year 1932-33* (London: H.M.S.O., 1934), Cmd. 4483, p.18.

94. *Ibid.*

95. Economic Advisory Council, *Report of the Committee on New Industrial Development* (London: H.M.S.O., 1932), p.18.

96. Department of Scientific and Industrial Research, *Report For the Year 1930-31* (London: H.M.S.O., 1931), Cmd. 3989, p.16.

97. See *ibid.* pp.68-70.

98. Sanderson, *op. cit.*, p.131.

99. Figure produced from staff lists appearing in the laboratory's annual reports 1918-1939.

100. G.W.C. Kaye, T. Smith and E. Griffiths.

101. C.E. Kenneth Mees, *The Organisation of Industrial Scientific Research* (New York: McGraw-Hill, 1920), p.14.

102. *Ibid.*

103. Public Record Office, File DSIR 17/280, Sir Joseph Barcroft to E.V. Appleton (October 4, 1943).

104. Quoted in Adam Gowans Whyte, Forty Years of Electrical Progress: The Story of G.E.C. (London: Ernest Beun, 1930), pp.91-92.

105. See Roy M. MacLeod and E. Kay Andrews, "The Committee of Civil Research ....", op. cit.

106. Sir Henry Tizard, "A Scientist in and out of the Civil Service", 1955 Haldane Lecture in Research, 8 (1955), 162-171, pp.164-165.

107. Roy and Kay MacLeod, "The Social Relations of Science and Technology 1914-1939", op. cit., p.320.

108. Department of Scientific and Industrial Research, Report For the Year 1927-8, op. cit., p.13.

109. Ian Varcoe, Organising For Science in Britain, op. cit., p.39. Varcoe also notes that the conditions of service were not fully conducive to the conduct of research.

110. Sir David Phillips, "William Lawrence Bragg 1890-1971", Biographical Memoirs of Fellows of the Royal Society of London, 25 (1979), 75-143, p.109.

111. See for instance James Phinney Baxter, Scientists Against Time (Cambridge, Mass.: The M.I.T. Press, 1946); Daniel J. Kevles, The Physicists: The History of a Scientific Community in Modern America (New York: Alfred Knopf, 1977); Ronald W. Clark, The Rise of the Boffins (London: Phoenix House, 1962); idem, Sir Edward Appleton (Oxford: Pergamon Press, 1971); Sir Robert Watson-Watt, Three Steps to Victory (London: Odhams Press, 1958); A.P. Rowe, The Story of Radar (Cambridge: Cambridge University Press, 1948); J.G. Crowther and R. Whiddington, Science at War (London: DSIR, 1947); Guy Hartcup, The Challenge of War: Scientific and Engineering Contributions to World War Two (Newton Abbot: David and Charles, 1970); Solly Zuckerman, From Apes to Warlords (London: Hamish Hamilton, 1978).

112. Ronald W. Clark, The Rise of the Boffins, op. cit., p.225.

113. In contrast in the U.S.A. the pattern was very different where, due to the lack of time to build up independent government laboratories, research teams were built around university institutions which had better industrial links then British universities. In addition one of the major war-time funding agencies, the National Defence Research Committee had no powers to build and operate laboratories, see R.V. Jones, "Research Establishments", Proceedings of the Royal Society of London, A342 (1975), 481-490, p.485.

114. R.M. Pike, The Growth of Scientific Institutions and Employment of Natural Science Graduates in Britain 1900-1960 (unpublished M.Sc. thesis, University of London, 1961), p.75.

115. Jones, _op. cit._, in discussion p.489.

116. See for instance Nuffield College, _Problems of Scientific and Industrial Research - A Statement_ (Oxford: Nuffield College, 1944).

117. Public Record Office, File DSIR 17/280, _Memorandum_ on "Research Mindedness" (undated).

118. See _Science and Industry_, Reports of the meetings arranged by the Manchester Chamber of Commerce in Collaboration with the Department of Scientific and Industrial Research (Manchester: Manchester Chamber of Commerce, 1944).

119. See The Federation of British Industries, _Industry and Research_, Report of the F.B.I. Industrial Research Committee (London: the Federation of British Industries, 1943).

120. See Sir Harry Melville, _The Department of Scientific and Industrial Research_ (London: Allen and Unwin, 1962), p.40; Clarks, _Sir Edward Appleton_, _op. cit._, p.109.

121. Melville, _op. cit._, p.40.

122. See _ibid._, pp.40-41; Clark, _Sir Edward Appleton_, _op. cit._, pp.106-109; Department of Scientific and Industrial Research, _Report For the Year 1947-8_, _op. cit._

123. DSIR, _Annual Reports._

124. _Ibid._

Chapter Five (pp.160-207)

1. R.V. Jones, "Research Establishments", Proceedings of the Royal Society of London, A342 (1975), 481-490, p.486.

2. Ibid.

3. Ibid.

4. Ibid.

5. R.M. Pike, The Growth of Scientific Institutions and Employment of Natural Science Graduates in Britain 1900-1960 (unpublished M.Sc. thesis, University of London, 1961), p.75.

6. The gross expenditure of the DSIR in 1956/7 was £8.2 m. compared with £682,000 in 1938/39. By the early 1960's its gross expenditure was over £20 m.; DSIR, Annual Reports.

7. See William McGucken, "The Royal Society and the Genesis of the Scientific Advisory Committee to Britain's War Cabinet, 1939-40", Notes and Records of the Royal Society of London, 33 (1978), 87-115; idem., "The Central Organisation of Scientific and Technical Advice in the United Kingdom During the Second World War", Minerva, 17 (1979) 33-69.

8. See P.J. Gummett and G.L. Price, "An approach to the Central Planning of British Science: The Formation of the Advisory Council on Scientific Policy", Minerva, 15 (1977), 119-143; P.J. Gummett British Science Policy and the Advisory Council on Scientific Policy (unpublished Ph.D. thesis, University of Manchester, 1973).

9. Lord Zuckerman, "Scientific advice during and since World War II", Proceedings of the Royal Society of London, A342 (1975), 465-480.

10. Ibid., p.475.

11. Ian Varcoe, Organising for Science in Britain (London: Oxford University Press, 1974), p.49. Examples where the line of demarcation was unclear included building research (Ministry of Works), fuel research (Ministry of Fuel and Power), fisheries and forestry (Ministry of Agriculture and Fisheries and the Forestry Commission).

12. Department of Scientific and Industrial Research, Report of The Research Council For the Year 1963 (London: H.M.S.O., 1964), Cmnd. 2394, p.5.

13. N.J. Vig, Science and Technology in British Politics (Oxford: Pergamon, 1968), pp.19-20.

14. Annual Report of the Advisory Council on Scientific Policy 1956-57 (London: H.M.S.O., 1957), Cmnd. 278, p.2.

15. Industries investigated included machine tools, shipbuilding and marine engineering, textile machinery, foundry engineering and the building industries.

16. Alexander King, "Science and Management", The Manager, 23 (1955), 507-511, p.507.

17. Ibid.

18. See also Sir Ben Lockspeiser, "Science and Our Industrial Future", address to the Parliamentary and Scientific Committee, in Research, 7 (1954), 236-241. Lockspeiser was at the time Secretary to the DSIR. The full exploitation of science by industry was also given some attention by the ACSP in the same period; see Sixth Annual Report of the Advisory Council on Scientific Policy 1952-1953 (London: H.M.S.O., 1953), Cmd. 8874.

19. Sir Henry Tizard, "Sponsored Research", introduction to "Sponsored Research Supplement", Research, 7 (1954), 400-423, p.400.

20. Fifth Report From the Select Committee on Estimates, Session 1957-8, The Department of Scientific and Industrial Research, H.C.245, Minutes of Evidence, para. 15.

21. Ibid., para. 138.

22. See S.T. Keith, "The Origins of the National Research Development Corporation", Minerva (forthcoming).

23. Fifth Report From the Select Committee on Estimates, Session 1957-8, op. cit., para. 25.

24. In fact the Hydraulics Research Station set up after the end of the war had already become heavily involved in repayment work, much of it for private contractors, which by 1964 accounted for 60% of its gross expenditure.

25. Department of Scientific and Industrial Research, Report For the Year 1947-8 (London: H.M.S.O., 1949), Cmd. 7761, p.1.

26. See Sir Harry Melville, The Department of Scientific and Industrial Research (London: Allen and Unwin, 1962), p.43.

27. Public Record Office, File DSIR 4/1631, Report of the Committee on the Post-War Programme of Building Research proposed by the Building Research Board (November 11, 1945). Prior to the war DSIR expenditure on building research amounted to £70,000 per annum; the committee considered that the level of expenditure proposed by the Building Research Board of £250,000 per annum was "in no way excessive" and a "minimum target"; ibid.

28. Public Record Office, File DSIR 17/234, Post-War Plans and Programme for the Department's Fuel Research Organisation (May 9, 1945).

29. Department of Scientific and Industrial Research, *Report For the Year 1947-8*, *op. cit.*, p.8.

30. *Ibid.*, p.6.

31. DSIR *Annual Reports* for the years 1949-50 and 1950/51.

32. Department of Scientific and Industrial Research, *Report For the Year 1950-51* (London: H.M.S.O., 1952), Cmd. 8494, p.9.

33. Department of Scientific and Industrial Research, *Report For the Year 1951-52* (London: H.M.S.O., 1953), Cmd. 8773, p.9.

34. Department of Scientific and Industrial Research, *Report For the Year 1950-51*, *op. cit.*, p.12.

35. Varcoe, *op. cit.*, p.43.

36. *Ibid.*

37. Department of Scientific and Industrial Research, *Report For the Year 1953-54* (London: H.M.S.O., 1955), Cmd. 9386, p.12.

38. *Ibid.*, p.14.

39. Among the themes which the economics section studied were productivity statistics for industry, technical innovation, the flow of technical information and studies of the needs of small firms.

40. Department of Scientific and Industrial Research, *Report For the Year 1954-55* (London: H.M.S.O., 1956), Cmd. 9690, p.14.

41. Sir Henry Tizard, "A Scientist in and out of the Civil Service", *Research*, *8* (1955), 162-171, p.166.

42. Public Record Office, File DSIR 25, *Pest Infestation Laboratory* (File Summary).

43. See Department of Scientific and Industrial Research, *Report For the Year 1947-8*, *op. cit.*, pp.20-22.

44. *Ibid.*, pp.39-40.

45. *Ibid.*, p.38.

46. Department of Scientific and Industrial Research, *Report For the Year 1933-34* (London: H.M.S.O., 1935), Cmd. 4787, p.20.

47. Public Record Office, File DSIR 17/214, Memorandum, *Committee on Mechanical Engineering* (undated).

48. William McGucken, "The Central Organisation of Scientific Advice ......", *op. cit.*, p.38.

49. *Ibid.*, p.37.

50. *Ibid.*, p.35.

51. Public Record Office, File DSIR 17/219, *Report of the Committee on the Essential Needs for Research in Mechanical Engineering* 1946).

52. *Ibid.*

53. Public Record Office, File DSIR 17/219, *Memorandum* dealing with a meeting of the Advisory Council (January 9, 1946).

54. Public Record Office, File DSIR 17/219, Advisory Council, *Memorandum on the Report of the Committee on Mechanical Engineering* (February 13, 1946), with a note attached dated May 2, 1916. The Guy Committee itself had recommended that the maximum strength of the laboratory should be 75-100. One can only assume that the Guy Committee was referring to qualified scientific staff, whereas the recommendations of the Advisory Council referred to total staff numbers.

55. Public Record Office, File DSIR 17/219, Sir Charles Darwin to Sir Edward Appleton (August 6, 1946).

56. D.H. Mallinson, *Pattern for Engineering*, conference paper made available by the author (November 6, 1979).

57. Department of Scientific and Industrial Research, *Report of the Mechanical Engineering Research Board 1947-1950* (London: H.M.S.O., 1951).

58. See Eric Hutchinson, "Government Laboratories and the Influence of Organised Scientists", *Science Studies*, *1* (1971), 331-356.

59. See Department of Scientific and Industrial Research, *Report For the Year 1955-56* (London: H.M.S.O., 1957), pp.22-23. The Jephcott Committee published its findings in full the following year: *Department of Scientific and Industrial Research, Report of a Committee of Enquiry* (London: H.M.S.O., April 1956), Cmd. 9734.

60. Department of Scientific and Industrial Research Act, 1956.

61. The view that the DSIR's Vote should be covered by statutory authority was expressed by the Public Accounts Committee as early as the session 1947-8 and the following year the Treasury agreed to undertake this task at the first opportunity. Lack of any such initiative saw the Public Accounts Committee return to this issue in the session 1953-54. In evidence to the Committee Sir Ben Lockspeiser, the principal secretary to the DSIR, when asked if the Departments functions and duties were set down in detail replied "I think I have seen nothing authoritative other then the original Order in Council"; *Third Report from the Public Accounts Committee*, Session 1953-4, H.C.231, paras. 66-68, Minutes of Evidence, paras. 2479-2624.

62. Varcoe, op. cit., p.3.

63. Ibid., p.4.

64. Department of Scientific and Industrial Research, Report of a Committee of Enquiry, op. cit., p.2.

65. Ibid.

66. Following Gibb's death in January 1959 Sir Solly Zuckerman became chairman and the committee reported in 1961; Office of the Minister for Science, Report of the Committee on the Management and Control of Research and Development (The Gibb-Zuckerman Report)(London: H.M.S.O., 1961).

67. Ibid., p.36.

68. Ibid., pp.37, 80, 94.

69. Fifth Report From the Select Committee on Estimates, Session 1957-8, op. cit., para. 629.

70. See C.F. Carter and B.R. Williams, Industry and Technical Progress (London: Oxford University Press, 1957), p.41. Carter was chairman of the DSIR Economics Committee.

71. Mallinson, op. cit.

72. Ibid.

73. Fifth Report From the Select Committee on Estimates, Session 1957-8, op. cit., paras. 24-25.

74. Department of Scientific and Industrial Research, Report of the Research Council For the Year 1961 (London: H.M.S.O., 1962), Cmnd. 1734, p.11.

75. Sir Harold Roxbee-Cox, "Government's Role in Civil Research", Engineering, 194 (1962), p.77.

76. David Insull and Harold Lind, "Government's role in applying science to industry", Planning, 29 (1963), 285-323, p.311.

77. Aubrey Jones, "Some Comments on Trend", The Technologist, 1 (1964), 19-24, p.23.

78. On some of the factors which combined to orientate the National Physical Laboratory more firmly in the direction of a commitment to basic research in the early 1960's, see Russell Moseley, Science, Government and Industrial Research: The Origins and Development of the National Physical Laboratory 1900-1975 (unpublished D.Phil. thesis, University of Sussex, 1976), pp.308-318.

79. See for instance, Editorial, The Sunday Times (November 3, 1963), p.14.

80. See Department of Scientific and Industrial Research, Report of the Research Council For the Year 1956-57 (London: H.M.S.O., 1958), Cmnd. 428, p.10.

81. Ibid.

82. See B.J. Rendle, Fifty Years of Timber Research: A Short history of the Forest Products Research Laboratory, Princes Risborough (London: H.M.S.O., 1976), pp.67-69.

83. The Tropical Products Institute came under the direct control of the Colonial Office in 1949. Prior to this it had formed the Plant and Animal Products Department of the Imperial Institute, responsible for producing scientific and technical information, aiding the production and marketing of plant and animal products produced or with the potential of production by British overseas interests.

84. Post-War Plans and Programme for the Department's Fuel Research Organisation, op. cit.

85. Public Record Office, File DSIR 17/234, Report of the Fuel Research Board on the Post-War Programme of Fuel Research (October 9, 1946).

86. Department of Scientific and Industrial Research, Report For the Year 1953-54, op. cit., pp.16-17.

87. Ibid.

88. Department of Scientific and Industrial Research, Report For the Year 1954-55, op. cit., p.16.

89. Department of Scientific and Industrial Research, Report of The Research Council For the Year 1956-57, op. cit., p.9.

90. See for instance A.C. Monkhouse, "Forty Years of Fuel Research", Steam Engineer, 28 (1959), 114-116, p.116.

91. Department of Scientific and Industrial Research, Report For the Year 1953-54, op. cit., p.17.

92. See, Department of Scientific and Industrial Research, Report of The Research Council For the Year 1956-57, op. cit., p.9.

93. Ninth Annual Report of the Advisory Council on Scientific Policy 1955-1956 (London: H.M.S.O., 1956) Cmnd. 11, pp.4-5. One occasion on which such issues were raised and a central mineral processing laboratory advocated was at a symposium on "Mineral Resources Policy", organised by the Institution of Mining and Metallurgy which took place in September 1955, see C.C. Hall, "A Brief History of Warren Spring Laboratory", Chemistry and Industry (September 7, 1968), 1219-1222, p.1219.

94. Interview, A.J. Robinson (July 7, 1980).

95. Ibid.

96. Reported in Research, 10 (1957), p.249.

97. Ibid.

98. Interview, A.J. Robinson, op. cit.

99. Department of Scientific and Industrial Research, Report of the Warren Spring Laboratory: 1959 (London: H.M.S.O., 1960), p.3.

100. "Warren Spring Laboratory", Nature, 184 (1959), 146-149.

101. S.H. Clarke, "Warren Spring Laboratory", Chemistry and Industry (February 3, 1962), 190-195.

102. Department of Scientific and Industrial Research, Report of the Warren Spring Laboratory, 1960 (London: H.M.S.O., 1961), pp.1-2.

103. Department of Scientific and Industrial Research, Report of The Warren Spring Laboratory, 1961 (London: H.M.S.O., 1962), p.15.

104. Hall, op. cit., p.1220.

105. Department of Scientific and Industrial Research, Report of the Research Council For the Year 1958 (London: H.M.S.O., 1959), Cmnd. 739, p.10.

106. Department of Scientific and Industrial Research, Report of the Research Council For the Year 1960 (London: H.M.S.O., 1961) Cmnd. 1365, p.9.

107. The Association of Scientific Workers in 1946 recommended that the Fuel Research Organisation be made part of the new Ministry's Scientific Service, providing the Ministry with full control of priorities in fuel research and immediate access to scientific advice; Association of Scientific Workers, Science and Government (London: A.Sc.W., 1946), p.8.

108. Fifth Report From the Select Committee on Estimates, Session 1957-8, op. cit., paras. 10, 17.

109. Ibid.

110. First Annual Report of the Advisory Council on Scientific Policy (London: H.M.S.O., 1948), Cmd. 7465, pp.7-8.

111. P.J. Gummett, British Science Policy and the Advisory Council on Scientific Policy, op. cit., p.128.

112. C.F. Carter and B.R. Williams, "Government Scientific Policy and the Growth of the British Economy", Minerva, 3 (1964), 114-125, p.120.

113. Report of the Committee on the Management and Control of Research and Development, op. cit., p.38.

114. Ibid.

115. The Committee of Enquiry into the Organisation of Civil Science (The Trend Report)(London: H.M.S.O., 1963), Cmnd. 2171, pp.42-44.

116. See Vig, op. cit.

1. A number of general accounts covering the work of the Ministry of Technology exist. An account of the Ministry's early years has been provided by its Permanent Secretary, Sir Maurice Dean, "The Ministry of Technology", Public Administration, 44 (1966), 43-60; Dean's successor has written a particularly comprehensive account of the full period of the Ministry, Sir Richard Clarke, "Mintech in Retrospect", Omega, 1 (1973), 25-38, 137-163; for more cricital analyses see Alan Mencher, Lessons for American Policy Making from the British Government's 1964-70 Experience in applying Technology to Economic Objectives (London: London Graduate School of Business Studies, 1975); Susan P. Wolff, Politics and Industrial Science Policy: A Study of the 1964-70 Labour Government (unpublished M.Sc. thesis, University of Sussex, 1975); Stephen Young and A.V. Lowe, Intervention in the Mixed Economy - The Evolution of British Industrial Policy 1964-72 (London: Croom-Helm, 1974).

2. Edmund Dell, Political Responsibility and Industry (London: Allen and Unwin, 1973), p.35.

3. Clarke, op. cit., p.145; P.M.S. Blackett, "Memorandum to the Select Committee on Science and Technology", Nature, 219 (1968), 1107-1110.

4. Clarke, op. cit., p.153. The Government's concern with industrial structure resulted in the establishment of the Industrial Reorganisation Corporation and enterprise which, according to the then Prime Minister, Harold Wilson, was designed to take small backward firms "by the scruff of the neck and bring them kicking and screaming into the twentieth century"; quoted in Young and Lowe, op. cit., p.93.

5. Ibid., p.28.

6. The particular event which precipitated the increase in the Ministry's interventionist role was the collapse of the National Plan in 1966 brought about by the economic crisis of that year. Its power was consolidated by the appointment of a forceful Minister of State, Anthony Wedgewood Benn, and an equally dynamic Permanent Secretary, Sir Richard Clarke. Its power base was widened by the transfer of the entire Ministry of Aviation in 1967. The new department consisted of 8,500 people at headquarters along with 28,000 in outstations with an annual gross expenditure of £750 m.; Sir Richard Clarke, "Merger of Technology and Aviation", New Technology, No. 2 (February, 1967), 1-2.

7. Anthony Wedgewood Benn, The Government's Policy for Technology, a lecture given at Imperial College of Science and Technology October 17, 1967 (London: Ministry of Technology, 1967), p.9.

8. The degree to which individual laboratories conformed to the traditional approach, generalised here, varied. The Hydraulics Research Station, with its high proportion of market oriented contract research was the exception rather than the rule, however.

9. A.W. Benn, "Mintech at the beginning of 1967", New Technology, No. 1 (January, 1967), 1-2, p.2.

10. Sir Richard Clarke, "The Structure of Mintech", New Technology, No. 14 (February, 1968), 1-3, p.3.

11. See Wolf, op. cit., p.67.

12. By 1968 the Ministry employed over 9,000 qualified scientists and engineers in its research establishments, around 16% of the total national manpower in this category; Clarke, "The Structure of Mintech", op. cit., p.3.

13. Dell, op. cit., p.75; Mencher, op. cit.

14. Ibid., Appendix 2, p.6.

15. Ibid.; see also Benn, "The Government's Policy for Technology", op. cit.

16. For a detailed discussion of this minimum viability hypothesis, see Christopher Freeman, The Economics of Industrial Innovation (Harmondsworth: Penguin, 1974) pp.198-221.

17. See P.M.S. Blackett, Technology, Industry and Economic Growth (Thirteenth Fawley Foundation Lecture, University of Southampton, 1966); "Blackett on British Technology - an extract from a lunchtime address to the Parliamentary and Scientific Committee", Nature, 213 (1967), p.755; Blackett, "Memorandum to the Select Committee ...", op. cit. Mencher considers that the Industrial Reorganisation Corporation had probably been originally conceived as an offshoot of Blackett's attraction to this idea; Mencher, op. cit., Appendix 2, p.8; the idea of a minimum level of defensive research, or "threshold" had already been published in the report of some industrial case studies sponsored by the National Institute of Economic and Social Research; see in particular C. Freeman et al "Research and Development in Electronic Capital Goods", National Institute Economic Review, No. 34 (1965), 40-91, pp.69-70. One of the conclusions drawn from this study was that it was firms with large resources and a wide product range that tended to devote a higher proportion of research and development expenditure to research activities, ibid., p.65.

18. Mencher, op. cit., Appendix 2, p.10.

19. *Ibid.*, p.11. Another advisor to the Ministry of Technology, Charles Carter, considered that such areas as defence research and nuclear physics should be reduced to release scientific resources for the private sector; C.F. Carter, "Government and Technology", *Nature*, *206* (1965), 652-654.

20. Interview with Sir Ieuan Maddock (July 8, 1980).

21. Mencher, *op. cit.*, Appendix 2, p.10.

22. Quoted in, "Science and Technology, and the New Labour Government", *Nature*, *201* (1964), 813-814, p.813.

23. Responding to a decision by the new Select Committee on Science and Technology to investigate the defence research laboratories, the journal *Nature* noted that: "Collectively, they (the defence research laboratories) are afflicted by the kinds of troubles which have been obvious now for several years at the Atomic Energy Research Establishment at Harwell - they have often outlived the immediate task of supporting the development of military equipment and have time and spare capacity to use in other fields"; "Parliament and the Research Establishments", *Nature*, *216* (1967), 949-950.

24. There were of course crucial exceptions to this policy; in particular in defence and nuclear policy where positive discrimination had long been utilised.

25. In 1968 Sir Solly (later Lord) Zuckerman in a speech to the Parliamentary and Scientific Committee remarked that: "It is no exaggeration to say that today our public institutions for dealing with science and technology are passing through a phase of rapid evolution as they adapt - not without struggle - to the facts of the scientific and technological age in which they are immersed"; Sir Solly Zuckerman "The State of Public Science", *Nature*, *217* (1968), 808-809, p.808.

26. Interview with John Lyons (July 22, 1980).

27. Ministry of Technology, *Industrial Research and Development in Government Laboratories: A New Organisation for the Seventies* (London: H.M.S.O., 1970).

28. Interview with Sir George MacFarlane (July 14, 1980).

29. *Ibid.*

30. *Ibid.*

31. *Ibid.*, and interview with Sir Ieuan Maddock, *op. cit.*

32. Mencher, *op. cit.*, Appendix 2, p.11.

33. *Ibid.*

34. *Ibid.*

35. *Ibid.*, p.12.

36. *Ibid.*, p.11; Interviews with Sir Ieuan Maddock and John Lyons, *op. cit.* In the late 1960's the Institution represented over 70,000 scientific, professional and technical staff employed in government departments and public undertakings.

37. Mencher, *op. cit.*, p.11.

38. Between 1968 and 1971 the Institution produced a succession of well argued contributions; see *Exploiting Technology* (London: IPCS, 1968); *The Role of Public Research and Development in Exploiting Technology* (London: IPCS, 1970); *The Role of the Government's Industrial Research Establishments in the 1970's* (London: IPCS, 1971).

39. Interview with John Lyons, *op. cit.*

40. Exploiting Technology, *op. cit.*, p.29.

41. *Ibid.*, p.36.

42. Officers of the IPCS had been impressed with this idea which had been suggested by Ieuan Maddock in a talk to the Institution; interview with John Lyons, *op. cit.* The idea was to resurface a number of years later in recommendations made by the Government's Advisory Committee on Applied Research and Development (ACARD); see Cabinet Office, Advisory Committee on Applied Research and Development, *Technological Change: Threats and Opportunities for the United Kingdom* (London: H.M.S.O., 1979). Both Maddock and Lyons were members of the Committee.

43. This elusive White Paper was mentioned by Benn in his lecture at Imperial College in October 1967 and further forecast in *New Technology*, the official journal of the Ministry of Technology in February 1968, as well as in a written Parliamentary reply the following April; Hansard, *H.C. Debates*, Fifth Series, *762* (April 1, 1968), written answers, col. 48.

44. Hansard, *H.C. Debates*, Fifth Series, *774* (November 27, 1968), cols. 496-497.

45. See "British Defence Research Examined", *Nature*, *222* (1969), 505-506.

46. See for instance Parliamentary intervention by Tam Dalyell, Hansard, *H.C. Debates*, Fifth Series, *760* (March 13, 1968), col. 324.

47. Reported in *Nature*, *218* (1968), p.1102.

48. _Ibid._

49. Mencher, _op. cit._, p.68.

50. See the leading article "Conjuring Away the Rabbits", _Nature_, _225_ (1970), 209-210, a lengthy review of the green paper. Subsequent issues provided a forum for comment on the paper lasting until mid-summer, 1970.

51. _Ibid._, p.209.

52. See for instance criticism provided by the Standing Conference of Industrial Research Associations reported in _Nature_, _226_ (1970), 95-96.

53. See _Nature_, _226_ (1970), p.204; quote attributed to the deputy General Secretary to the IPCS, John Lyons.

54. Reported in _Nature_, _226_ (1970), p.679.

55. _Ibid._, see also Peter M. Knowle (Secretary to the C.B.I. Research and Technology Committee), "What future for Government R&D", _New Scientist_, _45_ (1970), 500-501.

56. _Report from the Select Committee on Science and Technology, Session 1971-72_, H.C. 375, Research and Development: Minutes of Evidence, Memorandum by the Confederation of British Industry.

57. D.E.C. Price, "Science and Economic Growth", _Chemistry in Britain_, _3_ (1967), 433-436, p.434. These views were incorporated into the Party's General Election Manifesto in 1970.

58. Hansard, _H.C. Debates_, _744_ (1967), c.960. The enquiry was one of many asked during these years by Conservative members pressing the Labour Government continuously for information relating to personnel and expenditure in the public laboratories, in an attempt to embarrass the Government's declared policy of shifting the emphasis away from the public laboratories to the private sector.

59. Quoted in Eric Lubbock, "End of a Myth", _New Scientist_, _45_ (1970), 498-499, p.498.

60. _Third Report From the Select Committee on Science and Technology_, Session 1970-71, H.C.525, Research and Development Activities of the Department of Trade and Industry, p.iii.

61. Select Committee on Science and Technology, _Minutes of Evidence, 2nd August 1972_, Session 1971-72, H.C.467.

62. _Department of Trade and Industry, The Non-Reactor Research and Development Activities of the Atomic Energy Authority and the Industrial Research Establishments of the Department of Trade and Industry_ (London: H.M.S.O., 1972), Cmnd. 5176.

63. *Ibid.*, p.6.

64. "Responsibility without Government", *Nature*, *232* (1971), p.287.

65. The immediate cause of its appointment had been a proposal to transfer the Agricultural Research Council to the Ministry of Agriculture, Fisheries and Food, a suggestion which reflected the gradual shift in favour of departmental functional control. Council for Scientific Policy "The Future of the Research Council System", in *A Framework for Government Research and Development* (London: H.M.S.O., 1971), Cmnd. 4814, p.1.

66. See letter from Lord Rothschild in *Nature*, *233* (1971), p.80.

67. "Lord Rothschild in the Dock", *Nature*, *235* (1972), p.240.

68. *A Framework for Government Research and Development*, *op. cit.*; the Government's reply and outlining aspects of introducing the customer - contractor principles was published the following July; *Framework for Government Research and Development* (London: H.M.S.O., 1972), Cmnd. 5046.

69. Lord Rothschild was particularly scathing about the scheme devised in the Gibb-Zuckerman Report, commenting that "one wonders for whom this elaborate taxonomy was necessary and to whom it is useful"; Lord Rothschild, "Pure and Applied Research", *Journal of the Royal Society of Arts*, *120* (1971), 205-215, p.206.

70. Philip Gummett and Michael Gibbons, "Government research for industry: recent developments", *Research Policy*, *7* (1978), 268-290, p.271.

71. Interview with Sir George MacFarlane, *op. cit.*

72. *Ibid.*

73. These covered the following fields; chemical and process engineering, hovercraft, machine tools and numerical control measurements and standards, mechanical engineering, mineral processing and metal extraction, and shipbuilding and shipping; Gummett and Gibbons, *op. cit.*, p.271.

74. Ieuan Maddock, Chief Scientist at the Department of Trade and Industry was closely involved in setting up the Requirements Boards and admits to having first considered such an arrangement during his time as Industrial Controller with the Ministry of Technology; interview with Sir Ieuan Maddock, *op. cit.* The intention to set up the new Boards was first revealed in evidence to the Select Committee on Science and Technology in March, 1972.

75. The Institution of Professional Civil Servants, *Comments of the Institution of Professional Civil Servants on "A Framework for Government Research and Development, Cmnd. 4814"*, (London: IPCS, 1972), p.8.

76. *Ibid.*

77. Lord Rothschild, "The Organisation and Management of Government R&D", A Framework for Government Research and Development, op. cit., p.7.

78. The Royal Society, A Memorandum by the Council of the Royal Society on the consultative document (Cmnd. 4814) "A Framework for Government Research and Development" (London: The Royal Society, 1972), Appendix 2, "Report of the Industrial Activities Committee of the Royal Society".

79. See Michael Gibbons and Philip Gummett, "Recent Changes in the Administration of Government Research and Development in Britain", Public Administration, 54 (1976), 247-266.

80. "Calling the Tune and Paying the Piper", Nature, 238 (1972), 179-180, p.179.

81. The legislative powers authorising these changes were contained in the Science and Technology Act, 1965.

82. See Nature, 230 (1971), p.481.

83. Quoted in Young and Lowe, op. cit., p.23.

84. For an assessment of this change in policy, see Philip Gummett and Michael Gibbons, "Redeployment and Diversification at Harwell", Omega, 6 (1978), 65-69. For details of the more specific areas in which Harwell became involved see "How Harwell Helps Industry", The Engineer, 226 (1968), 200-202; "Harwell and Industrial Research", Chemistry and Industry (August 23, 1969), 1151-1158.

85. See David Fishlock, "Marshall the Energy: A Profile of Eric Varley's Chief Scientist", Nature, 254 (1975), 94-95, p.95.

86. Gummett and Gibbons, "Redeployment and Diversification at Harwell", op. cit., p.66.

87. R.J. Dowsing, "AERE Harwell finds profit in contract research", Metals and Materials (February, 1978), 20-24, p.21.

88. Gibbons and Gummett, "Recent Changes in the Administration of Government Research and Development", op. cit.

Chapter Seven (pp.240 - 277)

1. Ministry of Reconstruction, *Report of the Machinery of Government Committee* (London: H.M.S.O., 1918), Cd.9230.

2. The first director of the National Physical Laboratory not to receive a knighthood was J.V. Dunworth, appointed in 1964. Lawrence Bragg received his knighthood after he had left the Laboratory after a very short term in the position. The rest were knighted in office.

3. *Report of the Committee on The Civil Service, 1966-68*, Volume 1 (London: H.M.S.O., 1968), Cmnd.3638, p.105.

4. *Financial Times* (April 10, 1980), p.6.

5. Quoted in *ibid.*

6. Sir Richard Clarke, *New Trends in Government* (London: H.M.S.O., 1971), p.1; see also Sir Richard Clarke, "The Number and Size of Government Departments", *The Political Quarterly*, *43* (1972), 169-186.

7. *The Reorganisation of Central Government* (London: H.M.S.O., 1970), Cmnd.4506.

8. *Ibid.*, p.4.

9. Clarke, *New Trends in Government*, *op. cit.*, p.3.

10. *The Reorganisation of Central Government*, *op. cit.*, p.10.

11. For a detailed account of the introduction of the customer-contractor principle into the conduct of research in the Department of the Environment see, Michael Gibbons and Philip Gummett, "Recent Changes in the Administration of Government Research and Development in Britain", *Public Administration*, *54* (1976), 247-266, pp.247-252.

12. *Ibid.*, p.248.

13. *Ibid.*

14. Department of the Environment, *Report on Research and Development 1976* (London: H.M.S.O., 1977), p.2.

15. *First Report of the House of Lords Select Committee on Science and Technology*, Session 1981-82, "Science and Government", Volume II, Minutes of Evidence (London: H.M.S.O., 1981), Letter from Sir Ian Bancroft dated July 24, 1981, p.20; memorandum submitted by the Institution of Professional Civil Servants, pp.191-194.

16. Reported in *The Times* (August 5, 1980), p.2.

17. *Ibid.*

18. Interview with R.C.H. Russell (July 8, 1980).

19. Reported in *New Civil Engineer* (January 21, 1982), p.4.

20. Reported in *New Civil Engineer* (February 4, 1982), p.6.

21. These included the provision that £8m. of existing assets (land, building, and equipment) should be transferred free, an additional capital grant of £3.6m. for equipment, a £1m. working capital "float", and finally a sum of around £1.2m. provided annually to cover the background and development work required to maintain it as a centre of excellence; *ibid.*

22. Adrian Greeman, "HRS brave face to harsh new world", *New Civil Engineer* (April 8, 1982), p.10.

23. *Ibid.*

24. *Ibid.*

25. *Ibid.*

26. See *Building*, *241* (December 11, 1981), p.12.

27. Reported in *Building*, *242* (March 5, 1982), p.15.

28. Quoted in *New Scientist*, *94* (1982), p.340.

29. *Building*, *242* (May 7, 1982), p.11.

30. *Ibid.*, p.5.

31. Letter in *Building*, *242* (June 25, 1982), p.7.

32. See *Building*, *242* (February 12, 1982), p.9; *New Scientist*, *93* (1982), p.422.

33. Figures provided for the author by A. Silverleaf.

34. Interview, A. Silverleaf (July 16, 1980).

35. Figures provided for the author by A. Silverleaf.

36. *Ibid.*

37. *New Scientist*, *87* (1980), p.99.

38. Reported in *New Scientist*, *88* (1980), p.205.

39. *Ibid.*

40. *The Guardian*, (March 4, 1980), p.3.

41. Department of the Environment/Department of Transport, *Transport and Road Research 1978* (London: H.M.S.O., 1980), p.ix.

42. Cabinet Office, Advisory Council for Applied Research and Development, *Research and Development for Public Purchasing* (London: H.M.S.O., 1980).

43. *Ibid.*, p.16.

44. *Ibid.*, p.34.

45. *New Scientist*, *89* (1981), p.326.

46. *New Scientist*, *93* (1982), p.212.

47. *Ibid.*

48. *Ibid.*

49. Department of Industry, *Report of the Research and Development Requirements and Programmes 1978-79* (London: H.M.S.O., 1979), p.4.

50. National Physical Laboratory, Computer-Aided Design Centre, National Engineering Laboratory, Laboratory of the Government Chemist, Warren Spring Laboratory, National Maritime Institute.

51. Department of Industry, *Research Establishments Review 1979* (London: Department of Industry, 1979), p.3, figure 2.

52. *Ibid.*

53. *Ibid.*, p.6, figure 5.

54. *First Report of the House of Lords Select Committee on Science and Technology* Session 1981-82, *op. cit.*, Memoranda submitted by the Institution of Professional Civil Servants, pp.191-194.

55. See *Research Establishment Review 1979*, *op. cit.*, p.3.

56. *Ibid.*

57. Reported in *Financial Times* (November 3, 1980), p.7.

58. Letter, D. Ambrose, *Chemistry in Britain*, *16* (1980), 183-184.

59. *Ibid.*

60. Reported in *Financial Times* (January 10, 1980), p.6.

61. Letter W. McMillan, *Financial Times* (January 15, 1980), p.17.

62. Interview with Paul Dean (July 9, 1980).

63. Reported in Financial Times (April 10, 1980), p.6.

64. Warren Spring Laboratory 1977 (Stevenage: Warren Spring Laboratory, 1978), p.2.

65. Ibid.

66. Ibid.

67. Marek Meyer, "Britain slashes research on air pollution", New Scientist, 94 (1982), p.271.

68. Ibid.

69. Ibid.

70. Ibid.

71. Warren Spring Laboratory 1977, op. cit., p.2.

72. Financial Times (May 21, 1980), p.27.

73. Interview with A.J. Robinson (July 7, 1980).

74. National Maritime Institute, Annual Report, 1 July 1976 - 31 December 1977 (Feltham: National Maritime Institute, 1978), p.1.

75. Ibid., p.23.

76. National Maritime Institute, Report, 1980 (Feltham: National Maritime Institute, 1980).

77. Ibid., p.24.

78. Reported in Financial Times (December 7, 1979), p.10.

79. Michael Cross, "Government labs in the sale of the century", New Scientist, 90 (1981), 72-73.

80. Ministry of Defence, Consultative Document from the Steering Group on Research and Development Establishments (Strathcona Committee)(London: Ministry of Defence, 1980).

81. The Reorganisation of Central Government, op. cit., p.9.

82. Government's Organisation for Defence Procurement and Civil Aerospace (London: H.M.S.O., 1971), Cmnd.4611.

83. Admiralty Marine Technology Establishment, Admiralty Surface Weapons Establishment, Royal Signals and Radar Establishment, Admiralty Underwater Weapons Establishment, Royal Armament Research and Development Establishment, Propellants, Explosives and Rocket Motor Establishment, Chemical Defence Establishment, National Gas Turbine Establishment, Royal Aircraft Establishment, Aeroplane and Armament Experimental Establishment and the Atomic Weapons Research Establishment; in addition the Ministry of Defence remained responsible for the Meteorological Office.

84. Ministry of Defence, Consultative Document ...., op. cit., p.1.

85. Ibid., p.2.

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88. Ibid., p.3.

89. Ibid., p.6.

90. Ibid., p.7.

91. Ibid., p.9.

92. Ibid., p.14.

93. See Derek L. Bosworth, "Recent Trends in Research and Development in the United Kingdom", Research Policy, 8 (1979), 164-185.

94. See for instance Y. Shenin, Science Policy: Problems and Trends (Moscow: Progress Publishers, 1978), for a Soviet view.

1. In 1938 in the United Kingdom an estimated 0.28% of Gross National Product was devoted to research and development, 1.6% in 1954 and 2.8% in 1964; Maxwell Stamp Associates, The Role of Government Research and Development (London: Hill Samuel Occasional Paper No. 4, undated), p.10.

2. Sir Harry Melville, The Department of Scientific and Industrial Research (London: Allen and Unwin, 1962), p.94.

3. Department of Scientific and Industrial Research, Report of the Research Council for the Year 1959 (London: H.M.S.O., 1960), Cmnd.1049, p.11.

4. Ibid.

5. See Review of the Framework for Government Research and Development (Cmnd.5046)(London: H.M.S.O., 1979), Cmnd.7499.

6. Tube Investments, to take one example of a large British industrial organisation spends around £12m. on total research and development annually of which £3m. is spent in the group's central research laboratories at Hinxton Hall. At the central laboratories the research and development work is a half-and-half mix between work done directly at the request of companies in the TI group and work stemming from the initiative of the laboratory's staff; see Alan Cane, "Fiery Furnace of TI Research", Financial Times (January 21, 1982), p.33.

7. See Sajida Iqbal, Contract Research in British Science Policy (unpublished M.Sc. thesis, University of Aston in Birmingham, 1979).

8. Ibid., p.1.

9. Peta Levi, "Profits from applied research", Financial Times (December 11, 1981), p.28.

10. Ibid.

11. Ibid.

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13. See "Water Research neglected, Lords say", New Scientist, 94 (1982), p.127.

14. See Derek L. Bosworth, "Recent Trends in Research and Development in the United Kingdom", Research Policy, 8 (1979), 164-185.

15. Ibid., p.175.

16. Such a reassessment has for instance taken place at the Hinxton Hall laboratories of Tube Investments; as the research director of the laboratories recently observed; "We have made the move from the ivory tower into business"; quoted in Cane, op. cit. Cane's observation that: "The collapse of the ivory tower has left Hinxton leaner and sharper", has indeed a familiar ring about it in the context of public research.

17. First Report of the House of Lords Select Committee on Science and Technology, Session 1981-82, Science and Government (London: H.M.S.O., 1981).

18. See for instance, The Institution of Professional Civil Servants, Comments of the Institution of Professional Civil Servants on "A Framework for Government Research and Development", Cmnd.4814 (London: IPCS, 1972), p.12-13; The Royal Society, A Memorandum by the Council of the Royal Society on the consultative document Cmnd.4814) "A Framework for Government Research and Development" (London: The Royal Society, 1972), p.13.

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