BIG SCIENCE IN GERMANY
PAST AND PRESENT

by

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In 1918, on the occasion of Max Planck's sixtieth birthday, Albert Einstein gave an address entitled 'The Principles of Research'. He began: 'The temple of science is a house of many mansions.' If one day an angel of the Lord were to drive out of this temple all those who were pursuing exclusively utilitarian purposes, he went on, those who remained would be 'rather peculiar, withdrawn, and lonely fellows', people who had found the temple on their 'flight ... from everyday life, with its painful harshness and desolate monotony'.[1]

This image of the scientist as a lonely researcher, cut off from the world, is still valid in a number of disciplines in which the crucial breakthroughs to new discoveries often take place in the loneliness of a study. But many areas of research today depend on complicated, large-scale equipment, teamwork between large numbers of scientists in different disciplines working towards a common goal, and on institutions with efficient managements addressing the specific needs of the state, society, and industry. A new type of scientist is needed to lead such organizations. He or she must possess the ability to inspire and motivate individuals and to co-ordinate the work of large groups of scientists, as well as the qualities of a top-level business manager, and the skills of a politician in balancing interests and justifying the organization's work in public. This type of scientist represents a new form of research which is known as 'big science', or, in German, as *Großforschung*. The Manhattan Project, which was set up to develop and construct nuclear bombs in America during the Second World War, is generally regarded as the prototype of this new type of research. This project cost more than 2 thousand million dollars, and 250,000 people were employed on it.[2] Out of it developed the USA's large national laboratories, which in turn provided the model for large research centres such as Harwell in Britain, and Saclay in France.

Initially, these American laboratories and their counterparts in Britain and France concentrated on nuclear energy, and their work was largely dictated by military needs. Later, the potential civilian use of nuclear energy became more important and new fields of research, such as space research, modern information technology, genetic engineering, and environmental research also called for solutions which only big science could offer.

The first institutions devoted to big science in the Federal Republic of Germany were set up after Germany regained sover-

eignty in 1955, and Allied bans on research in applied nuclear physics, applied aerodynamics, and rocket propulsion were removed. In Germany, too, the first of these institutions were centred around nuclear reactors and closely connected with nuclear research. The organizational structure of big science research establishments in Germany was, however, by no means settled from the start. Rather, the solution emerged slowly, in practice. German big science research institutions (*Großforschungseinrichtungen*) differed from comparable research organizations in the USA, the Soviet Union, Britain, and France in three ways. *First*, the military had no influence on their establishment and in defining their objectives. *Secondly*, as associations governed by private not public law, their specific organizational and legal structure, which was deeply rooted in the history of science in Germany, permitted them to work closely with central government, the *Länder*, science, and industry. It gave them a measure of freedom from the rigid regulations governing public budget and employment law, and gave them the chance to retain a certain degree of autonomy within the framework of the tasks they were set. *Thirdly*, in Germany big science included fields such as environmental research, for example, which in other Western countries were not seen as part of it, and for which its characteristically large-scale organizations were regarded as inappropriate.

As well as differences, however, there are a number of similarities between big science as pursued in modern industrial societies, and these are perhaps even more important: a close association between science, industry, and the state; the view that science is a factor in productivity and an instrument for solving both present-day problems and the problems of providing for the future which industry cannot deal with adequately, or at all; and finally, the practice of bringing together, within an institutional framework, a large number of technicians, administrators, and scientists in different disciplines in a complex, large-scale organization whose management, despite its lack of market orientation, is in many ways like the management of a big business. It is also a characteristic of big science that it shows clearly both the potential risks of modern science and technology – these cannot be discussed in detail here, but I shall just mention Chernobyl, the possible abuse of electronically stored data, and genetic engineering – and the potential benefits of modern science in improving our standard of living.

This essay will describe the emergence and development of big science in Germany and its place in state and society. I shall first show that big science in Germany did not begin in the 1950s, as is often claimed, but that its historical roots go back to the end of the nineteenth century. Two sections describe the specific nature and the main phases in the development of institutions devoted to big science in Germany since the 1950s. Finally, I shall briefly mention the problems which the merger of science between the Federal Republic and the former GDR has produced for scientific research, especially in big science.

I

I shall begin with the early history of big science in Germany. The term *Großbetrieb der Wissenschaft* (large-scale scientific enterprise) was first used in Germany by the eminent theologian, organizer of scholarly projects, and founder of institutions, Adolf von Harnack, in an article published in 1905.[3] Like the famous historian Theodor Mommsen, who had spoken of *Großwissenschaft* (big science) in an address to the Prussian Academy of Science as early as 1890,[4] Harnack was referring to co-operation between a large circle of scientists or scholars – the word *Wissenschaft* in German covers both the natural sciences and the humanities – working in academies or scientific institutions, on large scientific or scholarly projects, such as producing a Latin dictionary, the *Thesaurus Linguae Latinae*.

The beginnings of co-operation between science, industry, and the state, characteristic of modern big science, were already apparent in Germany in the nineteenth century – rather early by comparison with other modern industrial states. Since the eighteenth century, science and scholarship in the German territories had been much more directly influenced by the state, and their structures modelled more closely on those of the state, than was the case in Britain and America. In Germany, this took a new form after the Napoleonic Wars at the beginning of the nineteenth century. In addition, Wilhelm von Humboldt's notion that research and teaching should go together had early ensured that research found a home in the state universities. A second factor was the strong commitment of the German states to encouraging technical education in vocational schools, and scientific research at universities and *Technische Hochschulen*. Thirdly, Germany's pioneering role in the application of scientific knowledge to

industry contributed significantly to making Germany's electrotechnical, optical, and chemical industries world leaders before 1914. A fourth factor, one which increased the prestige and influence of science in German society, was the transition to the interventionist and welfare state. In Germany this development was based on older traditions. It took place during the last twenty-five years of the nineteenth century, which was very early in international terms.[5] The creation of the welfare state made an important contribution to improving social and economic statistics, to the development of empirical social sciences, and to encouraging medical research.

All these factors together led to the establishment, at the turn of the twentieth century, of a number of non-university research institutions with various different structures and organizations. Some of them contained elements of an early form of big science. I shall first mention the *Staatsanstalten des Deutschen Reiches*, central state institutes, set up during the Kaiserreich, in the natural sciences, technology, and agricultural science. They had to overcome objections from individual states which were concerned about safeguarding their own rights *vis-à-vis* central government. Early versions of this type of organization, which continues to play an important part today in research agencies under the control of specific ministries, can be traced back to the first half of the nineteenth century in certain states, in particular, Prussia.

The most important of these *Staatsanstalten des Deutschen Reiches* was the Physikalisch-Technische Reichsanstalt. It was founded in 1887 on the initiative of the industrialist Werner von Siemens, in the face of opposition by the Verein Deutscher Ingenieure (Society of German Engineers) and the Deutsche Gesellschaft für Mechanik und Optik (German Society for Mechanics and Optics). Its first president was the eminent physicist Hermann von Helmholtz. Siemens's and Helmholtz's high expectations that it would become a centre for experimental physics, generously endowed with modern apparatus and scientific staff, were only partially fulfilled. However, it did separate research from teaching in one area. It also helped to establish teamwork as a method, and for the first time, deliberately placed basic scientific research into the service of the development of technology and industry. The National Physics Laboratory in England (est. 1899), the National Bureau of Standards in Wash-

ington (1901), and a Japanese institute for research in physics and chemistry, also founded before the First World War, were all modelled on the Physikalisch-Technische Reichsanstalt.[6] Its establishment marked the beginning of modern big science in Germany.

The Kaiserliche Deutsche Gesundheitsamt (royal German board of public health) was founded even earlier, in 1876. Robert Koch made his pioneering discoveries of the TB and cholera bacilli in its bacteriological laboratory. Another example of the state subsidizing research in the non-university sector is the Biologische Reichsanstalt für Land- und Forstwirtschaft (biological institute for agriculture and forestry), which grew out of a department of the board of public health. Its establishment underlines the state's traditionally strong involvement in agriculture, a field in which, to the present day, in contrast to industry, almost no research is done independently of the state. As well as the Reich institutes already mentioned, individual German states maintained experimental and research institutes. The Reich institutes carried out research on a statutory basis, receiving commissions directly from central government. Often the projects commissioned had to do with public services in such areas as planning for the future, establishing standards and measures, and checking and controlling.

In addition to the work done at these institutes, and at those devoted to general academic research (which, from the mid-nineteenth century was increasingly encouraged by the establishment of laboratories in individual universities), a third type of scientific research developed from the end of the nineteenth century: product-orientated and market-regulated industrial research. There were also mixed forms, such as the institute for serum testing and research, headed by Paul Ehrlich, and financed by the German central government, the city of Frankfurt, and industrial concerns such as Hoechst and Casella. This organizational form depended on close co-operation between the state, industry, and academic science.

The establishment of the Kaiser-Wilhelm-Gesellschaft,[7] the predecessor of today's Max-Planck-Gesellschaft, was a crucial step in the development of modern big science in Germany. Space permits only brief mention of the many and varied motives and interests which led to the establishment of this highly successful type of non-university, but academically orientated, re-

search organization. They include the development of a state policy for science at the end of the nineteenth century, enthusiastically promoted by Friedrich Althoff, all-powerful head of the division responsible for science and universities in the Prussian Ministry of Culture; the idea that national prestige depended on success in science; and the realization that as a factor in productivity, science plays an essential part in economic competition between nations. There were also good scientific reasons for creating this sort of institution. Since the end of the nineteenth century, large, non-university research institutions had been set up in the USA, Britain, France, and Sweden. German science was in danger of falling behind in important areas, in particular, chemistry, biology, and experimental medicine.

The Kaiser-Wilhelm-Gesellschaft, set up under the protection of the Kaiser, supported a number of non-university research institutes, built up around individual scientists. Initially they were financed by private capital, especially that provided by Jewish benefactors, and by the state of Prussia. The Society was set up as a self-governing academic institution under the supervision of the state. Thus a private organization was created on the basis of civil law. This was intended to provide protection against the influence of industry as well as against excessive control by the state bureaucracy.

A number of external initiatives were crucial for the creation of the first institutes. They were by no means limited to pure research. The Kaiser-Wilhelm-Institut für Kohlenforschung (institute for research on coal) in Mülheim on the Ruhr, for example, was set up in June 1914 with the help of Hugo Stinnes and the support of industry in Rhineland-Westphalia, which he mobilized. It was primarily a centre for applied research.

The First World War strengthened the general trend towards state intervention in science and industry. In Britain and Germany the responsibility of the state for research expanded during the war. In Germany, it was central government in particular whose role in relation to that of the governments of the individual states became more important. Fritz Haber's discovery in 1908 that ammonia could be synthesized from nitrogen and hydrogen under pressure, and its development on an industrial scale by Carl Bosch, provided the basis for the saltpetre industry which was created in the middle of the war. It allowed Germany to be independent of saltpetre imports from Chile. Given the

importance of saltpetre in the production of explosives and artificial fertilizers, it was only this industry that made it possible for Germany to continue the war beyond 1915-16. Fritz Haber, a fervent Jewish patriot for Germany, placed his Kaiser-Wilhelm-Institut für physikalische Chemie und Elektrochemie (institute for physical chemistry and electro-chemistry) fully in the service of the German war effort. He turned it into a centre for developing the new weapon of gas warfare in order to break the deadlock of trench warfare in the West. This was, in essence, a big science project, anticipating the Manhattan project on a smaller scale. In 1917, it employed 1,500 people.

Some of the other Kaiser-Wilhelm institutes also made essential contributions to defence technology and the German war economy during the First World War. Since the foundation of an experimental institute for aviation at Berlin Adlerhorst in 1912, the state had also played an important part in aviation research. During the war, research in this area was governed almost solely by military interests.[8]

After the First World War, the Kaiser-Wilhelm-Gesellschaft, like other scientific institutions, faced a serious crisis. Precipitating factors were the international isolation of German science, the general loss of capital and private benefactors, and the withdrawal of state money for military related research. This crisis was overcome relatively quickly, mainly because of the network of social connections which had been established before the First World War between representatives of science, leaders of industry, and the heads of the science bureaucracy. In addition, science found powerful new allies in the parliaments, and in almost all political parties. This, together with the greater responsibilities given to central government under the constitution, allowed it to replace private benefactors in promoting scientific research.

Germany's political, economic, and academic élites were astonishingly unanimous in their view that science, like industry, was a significant reservoir of strength as a type of substitute for Germany's lost political and military power. It could be drawn upon to encourage national economic development, for confirmation of national identity at a time of growing social and political tension, to help overcome Germany's international isolation, and to strengthen its position in the world. A number of remarkable historical parallels present themselves to the histo-

rian. One is with the beginning of the nineteenth century when, after being defeated by Napoleon, the Prussian state tried to regenerate and integrate society by supporting science, in spite of its financial difficulties. There is also a parallel with the period after the Second World War, when science again served as a kind of substitute for power, as a focus for recreating a national identity after the horrors of National Socialism, and as a way of gaining access to the international community of nations.

The foundations of the German system of promoting science which is still functioning today were laid during the Weimar Republic. In 1920 the Notgemeinschaft der Deutschen Wissenschaft was founded – the predecessor of the Deutsche Forschungsgemeinschaft (German Research Association). Similarly, the Stifterverband für die Deutsche Wissenschaft, a foundation set up by private business to support science, was created at that time. Another aspect of the present-day system which developed in those years was the strong involvement of central government in financing research outside universities, which are financed and controlled by the *Länder*.

During the Nazi period, German science suffered as a result of the country's increasing isolation within the scientific community, and from the forced emigration and dismissal of Jewish scientists, including Fritz Haber, a co-founder of the Notgemeinschaft and one of the leading members of the Kaiser-Wilhelm-Gesellschaft. German science suffered further from attacks on freedom of research and the administrative independence of scientific institutions, and from the confused overlapping of responsibility for science among various state agencies. Although the crucial prerequisites for a successful research policy were therefore lacking in Nazi Germany, the trend towards big science was nevertheless also expressed there.

Typical structural features of present-day big science research in Germany were visible in aviation research during the Third Reich. These include the employment of large numbers of people (more than 10,000 in 1944); the structure of a non-governmental association; a close connection between the interests of the state, industry, and science; the involvement of a number of scientific disciplines in joint projects; and the large part played by the state in financing and determining the objectives of the project. The German counterpart to the Manhattan Project was the project to develop a ballistic super rocket, which was ultimately fired at

targets in England and Belgium in 1944-5. Thousands of scientists and engineers were employed on this project undertaken by the Heeresversuchsanstalt Peenemünde,[9] and hundreds of thousands of workers, most of them POWs, were forced to work on it under inhuman conditions.

II

In the history of German science, as in so many other areas, 1945 was not a zero hour. There was a great deal of continuity in the rebuilding of German science.[10] This applies to institutions – the universities, the Kaiser-Wilhelm-Gesellschaft, renamed Max-Planck-Gesellschaft, the Stifterverband, and the Notgemeinschaft der Deutschen Wissenschaft – as well as to the people who had been responsible for promoting scientific research during the Weimar Republic and during the Third Reich, when they had been involved with National Socialism to varying degrees.

The Fraunhofer-Gesellschaft, set up in 1949 on the initiative of the Bavarian Ministry of Economics, and representatives of industry and the universities, was a completely new departure. During the 1950s and early 1960s, however, it went through a crisis which threatened its very existence. In 1968 the German central government decided to finance the Fraunhofer-Gesellschaft and integrate it into the federal programme of promoting science. On this basis, it has developed into a large, efficient organization for applied research, which co-operates closely with industry.

However, the crucial turning point in the promotion of research came in the mid-1950s with the establishment of a new type of big science research organization. A growing awareness of the importance of the natural sciences for the economy and society, and the general euphoria after the first international Atomic Conference at Geneva in August 1955 played an important part in this development. In 1955 the Bundesministerium für Atomfragen (federal nuclear ministry) was created. It later evolved into today's Ministerium für Forschung und Technologie (ministry for research and technology). In 1956 the first four of the present-day big science institutions, centred around nuclear reactors, were set up. The Wissenschaftsrat (Science Council) was established in 1957. It was intended to promote co-operation between central government and the *Länder* on science and research policy, and to help science to regulate itself.

Nuclear research and nuclear technology became the first focus of German science policy, which shifted more and more from the *Länder* to central government. The six research centres founded between 1956 and 1960, which later came to be known as big science research institutions, concentrated on this area. The main reasons for this development were high expectations of nuclear power as a cheap and inexhaustible source of energy, the belief that nuclear technology and the development of a domestic nuclear industry were vital for the existence of the German economy, a recognition of the significance of co-operation on nuclear research for European integration, and the desire of politicians and scientists to catch up with developments abroad – it was estimated that Germany was lagging about ten to fifteen years behind other countries.

As already mentioned, nuclear research in Germany differed from that undertaken in the other nuclear powers of the time – the USA, the Soviet Union, Britain, and France – in two respects. German nuclear research did not have a military purpose, and the institutions in which it was done were private organizations. A deliberate decision was made not to set up a powerful, central nuclear authority. A nuclear ministry was established to co-ordinate research. Its administrative staff, initially recruited mostly from the Deutsche Forschungsgemeinschaft, at first subscribed to the traditional academic view that science should be autonomous. An Atomic Commission advised the ministry. Its committees of experts and study groups decided, *de facto* but not *de jure*, which projects were to receive federal funds.[11] It was characteristic of the first nuclear research centres that there was no central planning, and that a variety of groups and interests were involved in attempts to develop nuclear research. Initiatives often came from groups of researchers, or even from individual scientists, who wanted to set up a research centre for their university, or for a number of universities, concentrated around a particular large piece of equipment. Similarly, the *Länder* in which these institutions were located – Bavaria, Baden-Württemberg, North Rhine-Westphalia, Hamburg, and Berlin – and sometimes even individual politicians in these *Länder*, often played an important part in their establishment.

However, close links with industry, which were widely desired and regarded as financially important, were achieved from the start only by the first nuclear reactor built in the Federal

Republic, in Karlsruhe, and by the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt (company for the utilization of nuclear energy in shipbuilding and shipping), established in Geesthacht near Hamburg. Co-operation between the state, academic science, and industry soon fell victim to the conflicting interests of the parties involved. This was especially clear in the case of Karlsruhe, where industry refused to participate in expanding the nuclear reactor into a comprehensive nuclear research centre. It transferred its 50 per cent holding in the original company to central government and the *Land* of incorporation without charge, and withdrew completely from the whole undertaking.

A general feature of the early development of these nuclear research establishments, some of which can point to considerable scientific achievements which cannot be discussed here, was that by the end of the 1950s the influence of the *Länder*, which had initially been crucial, had largely been replaced by central government. This was mainly the result of the explosion in the cost of running the centres which, since industry had stopped contributing anything, was too great a financial burden for the *Länder* to bear. The role of central government in the purchase of reactors and enriched uranium abroad, its responsibility for the safety of reactors and radiation protection, as well as for co-operation with Euratom, also gave it a high public profile in this area.

Support from central government was crucial from the start in the systematic development of other areas of big science in the 1960s. The main initiatives no longer came from the *Länder* or from individual groups of researchers, but from the former nuclear ministry, renamed Bundesministerium für wissenschaftliche Forschung (federal ministry for scientific research) in December 1962.

The discussion of what part Germany should play in space research stimulated central government to concentrate responsibility for science policy in one ministry. In the development of rockets and satellites, Germany, in contrast to France and Britain, gave precedence to foreign policy considerations over the development of new technologies. Germany wanted Europe to be independent of the USA in this sector, and especially to hasten the process of European integration, which was stagnating in the early 1960s, by co-operating in newly created European research

institutions – the European Space Research Organization (ESRO), and the European Launcher Development Organization (ELDO).[12] Under pressure from German central government, the scattered institutions for aeronautical and space research, which had generally been incapable of co-ordinating and directing their own work efficiently, were amalgamated into the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (German research and experimental institution for aeronautics and space research), which was subject to stronger state controls and planning.

In the field of information technology, too, the initiative for founding the Gesellschaft für Mathematik und Datenverarbeitung (society for mathematics and data-processing), a big science research institution, in 1968, came largely from central government. In April 1967 the federal government passed a bill defining a comprehensive programme designed to push ahead in this field. Its main aim was to help German firms to catch up with American computer companies by directly supporting research and development, and by expanding computer science in the universities.

Shortly thereafter, these new programmes were supplemented by projects to develop new technologies, oceanography, biotechnology, medical research, and environmental studies. All these initiatives were an expression of the central government's growing interest in determining the goals of research, in concentrating available means on specific projects, and thus in exerting more control over research than before. As the instruments of this policy, a number of new institutions devoted to big science were set up in the areas mentioned above. The transition to a deliberate strategy of research planning, which went hand-in-hand with the development of a specialized administration in the ministry for scientific research, was forced by the economic recession of 1966-7. Furthermore, the Grand Coalition set up in 1966 turned away from the neo-liberal economic policy associated with Ludwig Erhard in favour of the Keynesian notion of global regulation of economy and society. Within this framework, science was to make an essential contribution to ensuring economic growth. It was also intended to assist the state in some of its main tasks of providing for the present and planning for the future, especially in securing the energy supply, improving public health, and safeguarding the environment.

These new trends in science policy were linked with a lively discussion about the status and function of big science and the institutions devoted to it. Ultimately the Wissenschaftsrat (Science Council) acknowledged the big science research institutions as a specific form of research organization outside the university sector. The Max-Planck-Gesellschaft originally opposed this move because it considered that it could itself provide an institutional framework for some of the organizations devoted to big science.[13]

The tightening up of state science policy and the parallel debate on the nature of big science, the organizational forms best suited to it, and its relationship with the state, played an important part in forging a common identity between these big science research institutions. After all, they had been created independently of each other, and were very different in terms of objectives and legal structures. The process of forging a common identity led to the setting up of the Arbeitsgemeinschaft der Großforschungseinrichtungen (association to promote co-operation between big science research institutions) in January 1970. The Arbeitsgemeinschaft drew up a ten-point programme on relations between the state and big science.[14]

The problem of financing the big science research institutions after the expiry of the first big nuclear projects, and of defining their position within the German science community, acted as a catalyst in debates between central government and the *Länder* about financial reform and the restructuring of West German federalism in the 1960s. These discussions resulted in what was known as *Gemeinschaftsaufgaben* (communal tasks) being incorporated in the constitution in May 1969. These communal tasks included, among other things, supporting scientific organizations and projects of supra-regional significance. In anticipation of this solution, the difficult problem of financing big science research institutions had been settled by establishing that in most cases, central government would pay 90 per cent of their running costs, and the *Land* of incorporation 10 per cent. This necessitated a revision of the organizational set-up of the various big science research institutions. In addition, their relationship with the state needed to be more precisely defined.

After heated controversies between government agencies and the research centres, the federal minister for education and science finally, in November 1970 and July 1991, issued guide-

lines[15] which committed the state to the principle of *Globalsteuerung* (global control) over the research centres. Working on the basis of a comprehensive policy for science, the state decided on the general aims of research, and the total amount of money which would be allotted to it. According to these guidelines, the state, acting through its representatives on the supervisory bodies of the big science research institutions, establishes priorities, co-ordinates the work of the various research establishments, checks efficiency, and ensures that public money is spent profitably. Within this framework, the principle that research establishments have sole responsibility for themselves applies. Especially in technical and scientific matters, experts have the main say.

The principle of global control was accepted in the new versions of the constitutions and articles of incorporation which were drawn up for the big science research institutions in 1971-72. In addition, a 'finance charter' was fixed in response to the demand of big science institutions for greater flexibility in managing their funds.

III

The development of state-financed big science since the mid-1970s was closely connected with the problems posed by the expiry of old programmes and the constantly changing needs of state and society. The new catch-phrase was diversification of research. This was intended to allow a shift in the emphasis of funding from nuclear research and technology to other fields, the tackling of additional tasks without new centres being created, a check to be placed on the rising expenditure on big science, and better use to be made of research capacities in existing centres. An example of this sort of diversification is the Gesellschaft für Strahlenforschung (society for radiology), founded in 1964, which was restructured into a centre for life sciences, in particular, environmental and public health research.[16]

Just as the planning euphoria of the late 1960s and early 1970s abated with the economic recession of 1973 and the formation of the Schmidt government in 1974, when doubts were again voiced about whether developments in the state, economy, society, and science were susceptible to planning at all, the hope that diversification would solve all the problems of the research centres later gave way to a more sober assessment. The trend towards turning

them into scientific 'general grocery stores' was replaced by a greater emphasis on their specific identities.

During the 1970s the goals of subsidized research varied in line with changes in political priorities. Under Brandt's government, from 1969 to 1974, for a few years the emphasis in science policy was on improving the quality of life and preventing the negative social and economic side-effects of industrial growth. But under the next government, led by Schmidt, economic objectives again gained the upper hand, partly also because of the economic recession. This change was reflected in the demand that the centres should concentrate more on increasing the efficiency and competitiveness of the economy, and on improving technology transfer between state-subsidized science and industry. Around 1980, however, the limits of practical co-operation with industry emerged more clearly. Since then, the fundamental differences between industrial research and big science financed by public money have become more clearly visible again, and the specific functions of big science research institutions for state and society have been defined more precisely.

These new trends prompted the federal government to draw up a report in co-operation with the research centres in April 1984 on the status and prospects of big science research institutions. It was supplemented in 1985 by a publication by the association to promote co-operation between big science research institutions on the thematic orientation of big science in the 1980s and 1990s.[17] According to these two publications, the main task of the big science centres was to provide a scientific basis for state measures to deal with important current and future problems, such as, for example, guaranteeing the quality of life and of the environment, developing new technologies, in particular in the fields of biotechnology, micro-electronics, information and communication technology, and promoting research on materials. These technological developments were also intended to ensure Germany's international competitiveness, especially given the challenge represented by the USA and Japan. The chair of the association, Hans Wolfgang Levi, however, immediately qualified the notion that developing the new technologies required by industry was a task of the big science centres, and objected to the centres adopting the 'mental attitudes, working practices, and organizational structures of industry'.[18] In the meantime, expectations that the centres can make a serious contribution to the

direct transfer of technology to industry have been substantially reduced.

In general, the functions and character of big science in Germany changed profoundly in the 1980s, especially in applied science. At first, big science research institutions, as stated in another federal government report, dated October 1986, had typically concentrated on 'the development of large technical systems (for example, nuclear engineering, aeronautics, space research, oceanography) with relatively clearly defined goals'. Now they were concerned more with 'investigating large, complex systems involving a broad spectrum of scientific disciplines'. Unlike technical projects, 'few of these cases had clear objectives, detailed costing plans, and specific time frames from the start'. Examples include research on the environment, the climate, and health, and the 'early warning network' for identifying the potential risks and benefits of new technologies, called for by the 1984 federal government report.[19]

In general, the necessity for big science is still accepted. Its tasks, however, as emphasized in a report, dated September 1991, by the Ministry of Science and Technology are less clear-cut than they seemed in the two decades after 1955. The importance of big science research centres in polar research, nuclear fusion, space research, and fundamental physics using extremely expensive equipment for their experiments, is undisputed. Big science research institutions are still regarded as indispensable 'for the achievement of complex, inter-disciplinary, long-term objectives, which require security of institutional resources', especially in dealing with environmental and health problems. Current thinking is that the research of the centres should be more concentrated, and that closer co-operation with other research activities, especially in the universities, is required. In promoting new technologies, however, the centres should, with a few exceptions, limit themselves to areas of special public interest, while basic research in the key new technologies is to be left mainly to the universities.[20]

More emphasis is now being placed on the independence of individual centres and their specific scientific profile, than on what they have in common. At the same time, they are under growing pressure to justify their continued existence because of the increasing overlap between their work and the research that is done in universities, Max-Planck institutes, the research estab-

lishments of various ministries, and in certain branches of industry.

In 1989, the last year for which exact figures are available, 3.58 thousand million DM were spent on big science research institutions. This represents only 5.4 per cent of the total of 66.1 thousand million DM spent on research and development in the old *Länder* of the Federal Republic.[21] Big science research institutions, however, received the lion's share – 43.3 per cent – of the research funds that went to non-university research institutions. Thus they received much more than the Max-Planck-Gesellschaft (13.7 per cent), and the *Forschungsanstalten* of the *Bund* and the *Länder*, which together received 17.8 per cent.[22]

In 1989 by far the largest proportion of the Federal Republic's research budget – 46.2 thousand million DM, or 69.9 per cent – went to industry. According to estimates which include the new *Länder*, since then this proportion has declined to 66.4 per cent. In 1989 research and development accounted for 2.87 per cent of Germany's GDP. This put Germany in the same league as Japan (2.98) and the USA (2.80) in the leading group of seven main Western industrial nations and clearly ahead of Britain and France, who spent 2.24 and 2.34 per cent respectively of their GDP, and Italy, at only 1.24 per cent.[23]

IV

It is still too early to say with any certainty how the German scientific landscape will change as a result of unification with the former GDR, because the process of reforming science in the new *Bundesländer* is by no means yet complete. The scientific system of the GDR differed from that of the old Federal Republic in that it was entirely directed by the state. Also, modelled on the Soviet system, most research was carried out not in universities, but in the four big academies, and in large industrial collectives (*Kombinate*). Moreover, science in the GDR had little contact with international developments, and suffered from over-staffing and under-resourcing in terms of equipment.

The main problem at present is the withering away, or complete collapse, of industrial research which, before the *Wende*, employed about 86,000 people, accounting for two-thirds of the GDR's research capacity. The federal research ministry, with the support of the leading industrial associations, has made strenu-

ous efforts to encourage Western businesses to invest more in research and development in the new *Bundesländer*, and to persuade the Treuhand to maintain sensible levels of research when enterprises are restructured and privatized. In addition, high subsidies are available for specific research projects initiated by industry. None the less, only a small proportion of staff, about 24,000 in 1992, continues to be employed, or can be absorbed in other research institutions. Many of the larger enterprises with their own research departments have collapsed. In others, the struggle for survival has meant a radical reduction in research and development, or doing without it altogether. The setting-up of special research companies staffed mainly by people previously employed in the research departments of industrial collectives has not worked. It seems that the specific advantages of industrial research, its product and market orientation, is quickly lost when it is separated from industry. In the long term, East German industry will become more competitive only if enterprises are developed or founded in research-intensive branches of industry. This is a matter of urgency. The federal government's policy on research and technology aims to improve the infrastructural conditions for this development by providing public money for research establishments. In the long term, however, this cannot replace the development of modern, efficient, and market-orientated industrial research.

It is especially difficult to assess the future direction of scientific research in the universities in the new *Länder*. The universities will continue to exist, and a number of new ones have been established. The necessary redundancies among university staff, however, have meant that universities often resist taking on scientists and research teams from the non-university research institutions of the former GDR, even when they come with a five-year guarantee of funding from the federal government. But without the injection of some new staff, it will not be possible to revive research in the universities.

For the large academies already mentioned, employing a total of more than 40,000 staff, unification has meant their demise as independent institutions. From the start it was clear that because the *Länder* are autonomous in cultural matters, education, and large areas of science these academies, like other centralized, state-run institutions in the former GDR, would become the responsibility of the new *Länder* and a reunited Berlin, which do

not have the financial resources to run them. The academy of educational science was dissolved without further scrutiny, but the other three have been subjected to a thorough inspection by the Science Council on the basis of Article 38 of the unification treaty between the Federal Republic and the GDR. The purpose of this evaluation was to integrate these institutions into the German scientific landscape, to establish the basic principles of the West German scientific system – autonomy, self-administration, subsidiarity of non-university *vis-à-vis* university research – and to transform the centralized structure of science and research into a more strongly federal one.[24]

The practical outcome of the evaluation process[25] has been the creation of about 11,000 posts in research institutions outside the university sector, and about 2,000 in the universities. Additional scientists have been employed permanently on about thirty long-term research projects; about 3,000 have been temporarily engaged through job-creation schemes.

The independent institutes of what is known as the Blue List, generally financed half by central government and half by the *Länder*, have almost doubled in size with the creation of about 4,700 new positions in the east. The staff of the Fraunhofer-Gesellschaft has increased by about one quarter (1,000 new posts). These two types of institutions have thus become relatively much more important than before within the framework of research outside the university sector. By contrast, the Max-Planck-Gesellschaft, which had a total staff of 8,700 in 1989, received only about 800 additional positions and thus grew by less than 10 per cent. At the beginning of 1992, 1,700 new positions were created for big science research institutions, which had employed about 21,400 people in 1989. Most of these additional posts were allocated to three big science research centres set up in the new *Bundesländer*, in addition to the 13 big science research institutions existing in the old Federal Republic.

The Max-Delbrück centre for molecular medicine is intended to be a biomedical research centre of international standing. Fundamental research and clinical research are to be closely linked in a way hitherto unprecedented in Germany. A geo-research centre in Potsdam studies the continental lithosphere, that is, the top 100 kilometres of the earth's crust. The centre for environmental research in Leipzig-Halle, plus 15 new institutes primarily devoted to ecological problems, are a response to

extreme environmental pollution in the Halle-Leipzig-Bitterfeld area. This centre, co-ordinating a number of research institutions, is to work with the universities and industry on solving environmental problems in highly industrialized and congested areas.[26]

In general, the incorporation of the former GDR into the German scientific scene has actually encouraged the trend, criticized by the Science Council, towards shifting research out of the universities and into non-university research establishments. Further, the position of central government *vis-à-vis* the *Länder* has been strengthened, as it has largely taken responsibility, at least temporarily, for financing non-university research in the new *Länder*. Non-university research outside industry had previously been concentrated in East Berlin which, with just under 8 per cent of the population, had housed about 40 per cent of East Germany's research capacity in this field. This figure has now been reduced by about one third, in favour of the new *Länder*.[27] However, especially in the structurally weak *Länder* of Mecklenburg-Vorpommern and Thuringia, there is still an urgent need to develop research capacity, above all, for economic reasons.

The union of science and research in the two Germanies represents one big challenge to German science. Another is the creation of the single European market on 1 January 1993. It will be necessary to make more and better use of the funds provided by the European Union for encouraging research. Another task will be to incorporate a stronger global or European dimension into the projects being undertaken by German institutions. Above all, a great deal of work, plus new ideas, will be needed in order to maintain the German scientific system's relatively large degree of self-organization and autonomy within the European Union, most of whose member states have scientific systems which are far more centralized and more directly controlled by the state.

The future role of big science, and of the big science research institutions in particular, in the new scientific landscape that is taking shape in Germany has not yet been clearly defined. Since the end of the nineteenth century, but especially since the Second World War, big science has become increasingly important. But since the beginning of the 1970s, the phase of rapid expansion seems to have come to an end. The total budget for big science research institutions in the old Federal Republic has thus been frozen for the period 1991 to 1994. Taking into account inflation

and public sector wage increases, both present and future, this means a cut in real terms of about 15 per cent. Admittedly, each institution is affected differently by this.[28] The further development of big science research institutions as a specific organizational form of big science depends on a number of factors: whether, despite their size and specialization, they will be able to react quickly and flexibly to the constantly changing demands of the state, industry, and society; whether they will succeed in working together much more closely with non-university research institutions, the universities, and industry; and whether, by increased co-operation with foreign research institutions, they will be able to give their work a more strongly European, or global, orientation than before.

Translated by Angela Davies

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