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CONTENTS

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TEAM WORK IN SCIENCE

IN the accounts of scientific effort during the War on which the veil of secrecy has now been lifted, one common feature stands out on even the most casual reading. Whether we look at the efforts which went to the development of the atomic bomb, of radar, of 'Pluto', 'Fido', and British flame weapons, or in a vastly different field, of penicillin, the extent to which the achievements depend on team work is unmistakable. Sir Cecil Weir was at pains recently to emphasize the way in which in 1942 the Ministry of Supply brought together potential manufacturers of penicillin and interested men of science, and the fact that production was under way or about to commence in twelve factories run by eight firms was the direct outcome of the team work thus engendered. As a particular instance is the help given by experts of the Medical Research Council, and especially Dr. R. I. N. Greaves, of the Serum Drying Unit, Cambridge, in the design of the freeze-drying plant of the Glaxo penicillin plant at Greenford.

Again, Mr. Geoffrey Lloyd, who was in charge of the Petroleum Warfare Department from its formation in 1940 until the resignation of Mr. Churchill's Government, in reviewing the lessons from petroleum warfare, stressed the immense value of research and development teams, and the advantage, in dealing with a particularly stubborn problem, of getting almost completely separate teams to work from quite different aspects. Research and experiment, while they must be directed towards definite objectives, should proceed on a broad front, and policy control should be elastic. Mr. Geoffrey Lloyd was urging the need for a forward surge over the whole range of creative inquiry and invention for peace purposes, and it would be easy to multiply examples of this need and of the place of team work and co-operation in meeting it.

No field better illustrates this truth than the development of radar, and whether we take the Department of Scientific and Industrial Research's papers released in August by the Ministry of Production, the United States Government account "Radar: a Report on Science at War", or the article "Radar in War and Peace" which Sir Robert Watson-Watt recently contributed to *Nature* (**156**, 319; Sept. 15, 1945), the extent to which this great scientific achievement depended on a most remarkable integration of pure and applied science is clearly shown. In a statement to a Press conference at the Ministry of Information on August 14, Sir Stafford Cripps attributed to the bringing together of the Air Staff and their scientific advisers, distinguished outside scientific workers with wide contacts and fresh outlook, and the members of the National Physical Laboratory radio team, who had been encouraged by the Radio Research Board in fundamental research going right down to the root of radio problems, the immediate solution of the basic problem of air defence. From the appointment of this committee by Lord Swinton in 1935, considering the great complexity of the subject, progress was rapid, and an official document, cited by Sir Robert

Watson-Watt, describes the formation of this Committee for the Scientific Survey of Air Defence, with the contact between a user Department with a great need, and a Department which had fostered scientific discovery not wholly directed towards specific needs, as one of the most important events in our history.

Sir Robert Watson-Watt is at pains to bring out the way the story illustrates the need for encouraging scientific research in all fields and for making the needs of the State known to those who are engaged in scientific research, though he alone in his account passes over his own important contributions in these early developments. No account brings out more clearly than his own, however, the way in which the development of radar is based on Appleton's classical range measurement on the ionosphere and Breit and Tuve's powerful tool, the radio pulse. The beginnings of radiolocation, Sir Robert points out, lay in the work of those who laboured to understand more of the things that happened in the earth's atmosphere. Its later developments, and much of its technique at all times, were due to those who sought the inner secrets of the structure of matter.

Nor was this all. Sir Robert maintains that the most important thing about the British development of radiolocation is that it happened at the right time, and the essential differences between the British effort and that in other countries is to be found in the intangible factors which assured to us at each stage in development at least an adequate margin of time for meeting the successive crises of the War. Britain was a prominent leader in ionosphere research, and those researches were State-aided and generously and lightly State-controlled, and Sir Robert considers that without the peaceful pursuits of the Radio Research Board in general and of Sir Edward Appleton and his colleagues in ionospheric research in particular, radiolocation would have come too late to have any decisive influence in the War. Further, the Radio Research Board had trained a team of young research workers encouraged to see and explore the whole gap between the Morse key and the loudspeaker, and while turning their vision and imagination generally towards application, taking neither narrow nor short views. Sir Robert again stresses the importance of the spiritual ingredients—wisdom, sound judgment and courage—in the scientific advisers, the scientific workers, and the administrative officers who staked some millions of pounds of public money and revised the air defence system of the country; but the most significant factor was the unprecedented and unprecedentedly productive interplay between scientific and operational minds, which carried the basic technique from its first defensive application in an early warning system through more actively defensive phases to a wealth of offensive applications which had a decisive effect in every major phase of the War.

This intimate co-operation of scientific and military minds, he suggests, will remain as the real secret weapon in the British armoury. Nowhere else has there been a parallel to the practice followed from the first days of radiolocation research. This fruitful co-operation, moreover, extended to the selection and training of personnel to operate and maintain the systems, to the evolution and practising of tactical methods based on the systems, and to the whole complex of technical, tactical and logistic problems involved in introducing new scientific devices into heavily engaged operational formations.

Even that valuable tradition of constructive debate between General and junior scientific officer and the inextricable weaving of contributions from operational officer and scientific worker is not the only lesson of co-operation and team work that radiolocation has to teach. Almost equally impressive is Sir Robert's picture of the building up into a single team of the later and much more numerous recruits, not merely the cream of the physical research laboratories of the country but also chemists, physiologists, biologists, dons and schoolmasters, united by certain basic characteristics common to all branches of science. This whole combination of technical objectivity and the highest technical skill in one team, coupled with the remarkable organization for rapid production and team work on the part of industry to which Sir Stafford Cripps has paid tribute in addressing the Council of the Radio Industry, is indeed, as Sir Robert suggests, even more important and significant than the technical devices issuing from it.

Moreover, in this there was the partnership built up between the Government establishments, the universities and the industrial laboratories, and beyond that the pooling from the time of the Tizard mission in 1940 onward of British and American information over the whole field of radiolocation. The arrangements made for the interchange of information between the United States and the British Commonwealth, following on this first pooling of knowledge and ideas, were reinforced by the community of interest and understanding which at all times links the leading scientific workers in friendly fellowship as well as by the intimate contact with operational needs which the British workers, as Sir Robert shows, enjoyed from the start. In sum, the joint efforts have led to results which have not only been rightly described as the heart of our war effort, but may well prove to hold the key to success in the task of reconstruction.

Equally impressive is the picture of war investigations carried out by large groups which Prof. C. H. Lander gave in his Melchett lecture, "Team Work in Research". These investigations covered combustion work in connexion with gas turbines and jet propulsion, research and development of a model law to predict performances of flame-throwers, and research and development on petrol burners and their supply, and signalling arrangements for fog dispersal on aerodromes. Prof. Lander, moreover, points out that in his own experience in peace-time, when he was starting the survey of the coal resources of Great Britain, he had been faced with the problem of knitting together the contributions of organic, inorganic and physical chemists; of physicists, geologists, zoologists, botanists and palæobotanists; of mining, civil and mechanical engineers; and of oil and fuel technologists.

Much of Prof. Lander's lecture was of technical interest, but he was at pains to stress the importance of the task of the team leader in holding the balance between the specialized advices of his team members ; and he insisted that such a leader must above all possess that critical sense which is based on a wide experience and broad knowledge of scientific work. A team leader must also possess sufficient knowledge of the various sciences to enable him to follow the reasoning of the individual members of the team. Prof. Lander gave little indication as to how the organization of such a team should be built up, though his whole lecture was a challenge to narrow specialization in technical education. He recognized that the team leader requires breadth of understanding in the human as well as the technical sense, but he did not indicate so clearly as Sir Robert Watson-Watt that the members of the team should themselves possess similar qualities to some extent, particularly a capacity for the self-criticism necessary for realizing the possibility of bias and for generating toleration for the inevitable bias in others. It will be noted, however, that while Prof. Lander recognized that secrecy may be necessary, at any rate for the time, he stressed the great importance of publication, especially publication under the names of the men responsible for the particular pieces of work.

It is against the background of this experience and the lessons it enforces that we have to regard in fact future proposals for the organization of research and development, whether in industry, in the Government service or in the universities themselves. Proposals for the reorganization and recruitment of the scientific civil service, for the expansion of industrial research, and for university development must be considered from the point of view of how far they embody the relevant lessons of this war-time experience of team work and the full and free interchange of knowledge and ideas. These are not, of course, the sole criteria, but no proposals which fail to foster the outlook and the temper of mind in which team work of this kind flourishes best can well be entertained except on the basis of the most powerful and convincing reasons.

The two most impressive features of this particular aspect of radiolocation team work in development and research which are stressed not only by Sir Robert Watson-Watt, but also in the British and the United States official accounts, are indeed in regard to the interchange of information and the treatment of scientific staff. No one who has followed at all closely reports or statements on scientific and industrial research, such as that of Nuffield College, during the last two years or so, or studied the recent report of the Barlow Committee on Scientific Staff or, on the American side, those of Dr. Vannevar Bush and his advisory committees, can fail to note how well in line with precept and principles stressed in those documents practice has been. The team work on which the success of radar is firmly based is in fact a demonstration of the soundness of principles long pressed in these columns as essential for scientific advance and which must be far more widely applied in industry and in Government if our scientific resources are to meet adequately the new and immense demands of peace.

The interchange of information provides a highly instructive example. The critical importance of secrecy in regard to radar is unquestionable. None the less, this overriding demand for secrecy was not allowed to obstruct or exclude that close contact of mind and free and full discussion so essential to the fertilization of ideas, to constructive and creative thought and to scientific advance. The conditions for the stimulation of scientific thought and imaginative enterprise were secured. The instrument was limited to its purpose and was never allowed to become the master ; and there is no more satisfactory feature in the Government's proposals for a scientific civil service than the statement that it views sympathetically the recommendation that secrecy restrictions should be relaxed as much as possible, and scientific workers in Government service encouraged both to publish work of their own and to discuss their work with persons outside the Service engaged on similar problems.

That is a *sine qua non* of effective team work and co-operation, whether between departments, between industry, the Government or the universities. Scientific workers have given clear indications in recent months that they recognize the importance of restoring as quickly as possible full freedom of scientific communications, and it is to be hoped that neither in Britain nor in America will they miss the implications of radar but will insist on an improvement on, and not merely a return to, pre-war conditions in this respect. Freedom to know, to utter and to argue freely according to conscience is a fundamental condition of scientific advance. Radar provides a convincing demonstration that a solution of the problem of secrecy is possible on some such lines as those suggested by the Barlow Committee—that such freedom can be responsibly exercised.

A solution of this problem is essential if we are to attract to the services of the State the ablest scientific minds of each generation and if we are to make the most effective and best use of such minds in the employment of the State, of industry or of the universities. It is of course a special aspect, as the Barlow Committee recognizes, of breaking down the isolation of the scientific worker, whether or not he is employed in the Government service. Moreover, the further measures proposed for dealing with that isolation of the scientific worker in Government departments through the encouragement of mobility and interchange of staff and the introduction of the sabbatical year and the like, which the superannuation proposals of the Government are designed to assist, are exactly the type of measure equally adapted to break down departmentalism anywhere and that compartmentalism of mind whether in teaching or research to which the specialist is ever liable. Sir Robert Watson-Watt shows the brilliant success which has attended the elimination of such isolation and compartmentalism in the development of radiolocation. That very success calls for the closest study of the technique of organization by which it has been achieved, and it may confidently be predicted that the careful study of the factors responsible for such outstanding team work, and the application of the lessons of that experience in the elaboration of our post-war research structure, in Government departments, in industry and in the universities, will pay equally rich dividends.

Radar research has provided a convincing demonstration, not merely of the possibility of highly productive team work, but also of its existence side by side with conditions which favour creative work and encourage the originality and individuality, initiative and enthusiasm which are all-important in the advance of science. Here have been found and maintained exactly those conditions, those methods of treating the scientific worker so that the utmost use is made of his inherent abilities ; and no strategy of research which ignores such tactical measures is likely to achieve success. As we face the problems of reconstruction and the acute shortage of man-power which persists and is likely to remain with us, we do well to recall the reminder of an early report from the Select Committee on National Expenditure that the main need is a better use of the available forces rather than an increase in their number. Above all it is true of scientific man-power that efficient use depends not merely on having at our disposal an adequately staffed intelligence organization provided with ample means for collecting and interpreting the relevant data on the problems to be solved and determining their priorities, but also on giving to the human factor the right attention and treatment to enlist and hold its enthusiasm and highest creative and imaginative powers.

FORESTRY PROBLEMS IN THE UNITED STATES

Behold our Green Mansions

A Book about American Forests. By Richard H. D. Boerker. Pp. xvi+313+96 plates. (Chapel Hill, N.C. : University of North Carolina Press ; London : Oxford University Press, 1945.) 24*s.* net.

THIS is a book about forests in North America : forest conservation, soil conservation, timber, flood control, wild life, grazing, scenic beauty, recreation and the use of timber. All these are subjects very much under consideration at the present time, and most of them interest the general reader and all of them are of first-rate scientific importance. The subject-matter is based entirely on American experience, and brings out the scale of operations there in comparison with those in Great Britain and with the latter's small-scale problems and comparatively small climatic fluctuations. The subject is of importance in all the continental areas in the temperate zone, and the same disquieting condition is found everywhere—depleted forests causing soil movement, and an ever-expanding demand for timber.

Man's attempt at settlement in new countries has often been accompanied by a failure to recognize the dangers of interference with natural phenomena without a very detailed scientific knowledge of the factors involved. Interference with the natural cover of vegetation has nearly always been the cause of disaster. This process is well seen in the United States where, according to the U.S. Forest Service, only seven-eighths of the original virgin forest is left. This is illustrated in the work under consideration by three diagrams of forest areas dated 1620, 1850 and 1942. While there is little difference between 1620 and 1850, the 1942 map shows these virgin forest areas as very small and detached patches. It is during this latter period that the problem of soil erosion has arisen.

We have been accustomed to think of America as a land where natural resources are so rich as to be almost inexhaustible. Mr. Boerker starts by destroying this myth regarding America's forest wealth. During the War, timber was classified as a critical war material, and the forests were called upon for a tremendous output of material essential to the prosecution of the War. This was met, but was handicapped—as he explains in an interesting preface—"by our past gross neglect of our forests". He shows how through forest fires, bad and unscientific cutting of timber, through ignorance and for quick gain, and by indiscriminate cutting down of forest lands for farming, serious inroads have been made on timber resources. However, this is the negative side of the picture ; he goes on to show what is being done through conservation and re-afforestation to remedy this deficiency. But as he says, "it is one thing to gather scientific data and lay out a plan of action ; but it is quite another thing to acquaint the forest-using public with the facts". This is what this book claims to do, and in this the author has succeeded well.

The forest is treated in its relation to wild life, water supply, holding the soil, flood control and as a live-stock range.

With regard to wild life, the author gives examples of the delicacy of balance between species, and quotes instances of disastrous control due to ignorance of inter-relationships. In fact, man's attempts—in the absence of expert knowledge—to control Nature has often been as disastrous as his destruction of it for profit. This aspect is closely bound up with the importance of the forest as a region of recreation for the people. But with the artificial management of the forests, game laws have to be tightened or liberalized in proportion to the food available.

The many factors affecting forests in regard to water supply are complex, but broadly speaking, forests conserve water and prevent rapid run-off *causing erosion. Not only the trees of the forest* but also the ground vegetation of flowering herbaceous plants and shrubs, mosses, liverworts, lichens are all interdependent and act as anti-erosion agents. In northern regions these also retain snow and slow down its melting and run-off. Every type of forest has its characteristic undergrowth, and the balance is often a delicate one. Soil erosion is a world-wide problem, and while much of it is due to the destruction of forest, the breaking of natural grassland is equally destructive in semi-arid regions, where the erosion may be due to sudden storms or more frequently to strong winds.

Of the destructive agents the author has much of interest to say. While fire on a large scale is not a problem in Britain, it is a real menace where hundreds of miles of unbroken forest may occur, as in America, and where much lower relative humidity is encountered than in western Europe.