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DEFENCE SCIENCE AND ITS ORGANISATION*

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On behalf of the Defence Science Organisation and on my own it is my pleasant duty to express our gratefulness to Dr. Bhatnagar and Dr. Krishnan for providing us with all facilities to hold the second Defence Science Conference in the buildings of the National Physical Laboratory. Dr. Mathur and other members of the N.P.L. staff have given us unstinted help and we are thankful to them.

To the distinguished scientists and Service Officers, many of whom have come from distant places, to the officers of the Ministry of Defence and other guests we are grateful for their presence and participation in the Conference.

We are grateful to Mr. Patel for opening this Conference. He has from the very beginning taken a keen and abiding interest in the promotion of Defence Science. I cannot adequately express my gratefulness to him, and in any case I shall not attempt to do so in his presence, as it will embrass him, and embrass me no less.

The time available for making preparations for the Conference has been rather short, but the many imperfections you will notice are not all due to that. However, one and all members of the Defence Science Organisation have striven hard to make the Conference reasonably useful, and I am indeed grateful to them, and so also to the many Service Officers who have helped us in numerous ways.

It has been my good fortune to have in the Defence Science Organisation a band of people (scientists and administrative staff) who have always, and so willingly, given so much of themselves for their work and for the Organisation. I cannot speak about them, and also about some of my colleagues in the Services and the Ministry without emotion and deep feelings of gratefulness.

I do not know whether at the end of the Conference you would feel that your time here has been usefully spent, but of one thing I can assure you that by your coming here and participating in the Conference you have given us no small encouragement and impetus in our work.

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(My talk this morning deals with rather general matters: Specialist topics we shall take up at later sessions.)

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It is common knowledge that the scientific method is an immensely powerful thing. Science and its impact on society have in the course of less than three centuries radically altered man's material environment and have deeply influenced his pattern of thinking and his sense of values, material and spiritual. This method of experiment and observation has proved amazingly fruitful in the discovery of new knowledge and in the application of this knowledge to meet man's manifold requirements. We know on the one hand of things more minute than the atoms-electrons, mesons and what

* Read at the Second Defence Science Conference on April 21, 1952.

not—; and on the other hand with the 200-inch telescope spiral nebulae have been observed which are so distant from us that light from them travelling at the speed of 186,000 miles a second takes 340 million years to reach us. The more we know about nature the more it becomes clear how little it is we know in comparison to what appears knowable. As Whitehead has observed, it is a real marvel that even such little knowledge as we possess has given us so much power.

Experiment and observation constitute the core of natural science, but experiment, in fact, the very concept of it, pre-supposes the existence of some theoretical knowledge or conceptual scheme. The continued, and ever increasing, impact on each other of theory and experiment is the essence of the scientific process. Theories lead to new experiments and these in their turn modify the original theories and so the process continues, and every time our insight into nature gets progressively deeper and more refined. A scientist (if true to his profession) is always busy—passionately busy—experimenting and theorising, but even a life-time devoted completely and entirely to it is not enough. Left to himself alone what he can observe and experiment and theorise about will be extremely limited and almost microscopic. He, therefore, makes it his most important business to learn as much as he can about theories, experiments and observations made by fellow-scientists. This constant exchange of information and ideas among scientists is the thing that really determines the rate of progress in science. Thus it is no accident that the cultivation of science, systematically and on a large scale, in Western Europe, became possible after the introduction of the printing press in the fifteenth century. The founding of the Learned Societies in the seventeenth and eighteenth centuries which enabled men of science to meet and discuss about their work, and which by publishing journals helped in the easy flow of information between them, played a most important role in the growth of science. By comparison, the Universities, up till the middle of the nineteenth century, played an insignificant part in promoting natural knowledge. A Conference such as this which provides opportunities for exchange of ideas and information and discussion of scientific problems is, therefore, probably the most basic thing necessary for the promotion of Defence Science.

The existence of science depends on communication amongst scientists, but the basis of such communication must be complete integrity and sincerity: Propagation of lies cannot advance science. One must notice, however, that the observance in scientific work of rigid standards of honesty, objectivity and truthfulness, which we now take for granted, did not come about suddenly. As Conant has observed in his stimulating book—*Science and Commonsense*—"As one skims the histories of the natural sciences, it seems clear that in the embryonic stages of each of the modern disciplines, violent polemics rather than reasoned opinion often flowed most easily from the pen .... It was only gradually that there evolved the idea that a scientific investigator must impose on himself a rigorous self-discipline the moment he enters his laboratory. As each new generation saw how the prejudice and vanity of its predecessors proved stumbling blocks to progress, standards of exactness and impartiality were gradually raised. But as long as science was largely a field for amateurs, as it remained into the nineteenth century, a man could regard his discoveries like so many fish. If he defended their size against all detractors, and if in the process their length increased, well, his opponent was well-known liar, too ! ...." He continues, "The man who was inclined to use the same weapons in philosophical as in political and theological debate gave way to the modern scientist who places little reliance on persuading his opponent with rhetoric or driving him from the field with invective." In the middle ages, the men who contributed to and kept alive the tradition of impartial and objective thinking, men who pronounced the truth as they saw it and stood by it under difficult odds, were not so much the scientists themselves (alchemists and astrologers as they were then known), but rather the humanists and philosophers. Thinking of our times, and possibly of all times, what more luminous example there can be of disinterested and selfless pursuit of truth, and fearlessness in propagating it, than that of Mahatma Gandhi. Rightly viewed, his is a profound and lasting contribution to the process of the scientific tradition taking roots in our soil. (He called his Autobiography "My Experiments with Truth"). And that it takes time for the scientific tradition to grow is well emphasised by Polanyi : "Those who have visited the parts of the world where scientific life is just beginning, know the back-breaking struggle that the lack of scientific tradition imposes on the pioneers. Here research work stagnates for lack of stimulus, there it runs wild in the absence of any proper directive influence. Unsound reputation grow like mushrooms: based on nothing but commonplace achievements, or even on mere empty boasts. Politics and business play havoc with appointments and the granting of subsidies for research. However rich the fund of local genius may be, such environments will fail to bring it to fruition".

Science and warfare have always profoundly influenced each other, sometimes more and sometimes less, sometimes more the one way and sometimes more the other way. Lewis Mumford in 'Technics and Civilisation' asks : "How far shall one go back in demonstrating the fact that war has been perhaps the chief propagator of the machine?" In ancient times there was the poison-arrow, there was the armed chariot "with the scythes that revolved with its movement, moving down the foot-soldiers". Long before the Christian era burning petroleum and Greek fire were effectively used in sea warfare. There were high-powered mechanical devices, catapults and ballistas, hurling stones and javelins to several hundred yards. The swords of Damascus were noted for their effectiveness in battle : It is very likely that the steel for these swords came from India.

Leonardo Da Vinci and Galileo were concerned a great deal with improving artillery and the art of fortification. The use of fire-arms made tactics of offence and defence much more deadly than before. Building of roads, canals and bridges became a necessary part of military operations. This led to a new type of professional man—the military engineer. It was not until the eighteenth century that we have civil engineers as distinct from military engineers: Originally all engineers were military engineers. Arms factories began to rise, one of the earliest being founded by Gustavus Adulphus in Sweden, in the seventeenth century.

Thus, warfare has always depended heavily on science. This has grown with the growth of science itself and now modern warfare is completely dependent on applied science (—war has been described as applied science—) and methods of precision mass manufacture which originated in the last few decades. The time-gap between laboratory results and their application to defence has been continually diminishing, and in certain fields (radar is a striking example) the laboratory can be regarded as almost a frontline of offence and defence. Notice also that in World War II two things happened which did not happen in earlier wars. First, "World War II was the first war in human history to be effected decisively by weapons unknown at the outbreak of hostilities. This is probably the most significant military fact of our decade: that upon the current evolution of the instrumentalities of war, the strategy and tactics of warfare must now be conditioned. In World War II this new situation demanded a closer linkage among military men, scientists and industrialists than had ever before been required, primarily because the new weapons whose evolution determines the course of war are dominantly the products of science, as is natural in an essentially scientific and technological age." Secondly, it was in World War II that for the first time deaths in the fighting services caused by epidemics and septic wounds were less than actual deaths in battle. In all previous wars the number killed in battle was much less than the number who died of disease and septic wounds. In the last war, more than 80 per cent of the wounded returned to normal health. This was due to great advances in medical science—the single greatest thing being the discovery of penecillin.

In the sense the necessity for a Defence Science Organisation has been well expressed by Bertrand Russell. In his "Reith lecture" he said—"So long as war is at all probable, ... if one side were equipped with scientists and the other not, the scientific side would almost certainly win". Mark the significance of the word 'almost': Russell does not say that the side with the scientists would certainly win: to say that would be to say nonsense.

Without a proper Defence Science Organisation no Defence Service can for long maintain its efficiency, make full use of its weapons and equipment, modify them to meet local conditions or keep in contact with the rapid progress in weapon technology. The main functions of the Defence Science Organisation must broadly be to help in the integration of scientific and military thought. Such an integration was, for the first time, effectively achieved in the United Kingdom during the World War II. The extreme importance of this integration is now universally recognised. It is the essential condition for successful scientific work for the Services. It is well known, for instance, that considerable German scientific war effort was wasted because of lack of enough contact between the scientific side and the Services, and between the Services themselves. To illustrate the point, here is an interesting case dealing with torpedo development. In Germany during the last war there were for torpedo development six large establishments at a total cost of many millions of pounds and engaging over 12,000 men, but there were two major defects in all this huge effort :—

(i) "The relations between the German Navy and Goering's Air Force were bad. Neither party knew that work was taking place on the other side.

(ii) Development and research in Germany was not well integrated with the Services. An example is interesting :—

"The German scientists put much work into developing a non-contact pistol for the warhead of a torpedo which was worked by the shadow cast by a ship—in other words when a torpedo passed under a ship the explosive warhead was detonated by the shadow cast by the ship. It never seemed to have occurred to these scientists and no German naval authority seems to have informed them that the torpedo is primarily a weapon for use at night, and therefore a shadow operated pistol would be of little value". (Capt. Davis, Proc. Roy. Inst. Great Britain, Vol. 33).

The same thing was true of the Schnorkel, a device which the Germans fitted to an U-boat to enable it to run its engines even when submerged. Here was a device of extreme importance to the German Navy. It could have been developed and put into operation much earlier, if there were effective contact between the scientists and the German Navy. For a Science Organisation to play a useful role for the Services, it must be, and always, in the closest possible touch with the Services, and this not only at the highest levels but at all levels.

We now turn to the Defence Science Organisation in our country. For historical reasons into which one need not enter, prior to 1947 Defence Science was a sealed book to Indian scientists (with a possible exception here and there). Such civilian scientists as were engaged by the Services during the war years were almost entirely concerned with inspection of stores. In any planning of Defence Science, therefore, the fact that the Indian scientists are completely new to this field must be constantly borne in mind.

In 1946 the Government of India invited Dr. Wansbrough Jones, at that time Scientific Adviser to the Army Council, U.K., to advise them on the setting up a Defence Science Organisation for India. Later the Government had the benefit of the advice of Professor P.M.S. Blackett and as a result the Defence Science Organisation was set up under the Ministry of Defence by the end of 1948. The Government also set up two Committees, *viz.*, the Defence Science Policy Board and the Defence Science Advisory Committee, to deal with matters of scientific research in relation to Defence. These Committees have a mixed composition of service and civilian members.

The *Defence Science Policy Board* which, in a sense, corresponds to the Defence Research Policy Committee in U.K., is concerned with the wider aspects of Defence Science and policy. The members of the Board, of which the Chairman is the Defence Secretary, include the Commanders-in-Chief of the three Services—Army, Navy and Air Force—Dr. S. S. Bhatnagar (Secretary, Ministry of Natural Resources and Scientific Research), Dr. H. J. Bhabha (Director, Tata Institute of Fundamental Research, Bombay), Dr. K. S. Krishnan (Director, National Physical Laboratory, New Delhi), the Financial Adviser (Defence) and the Scientific Adviser to the Ministry of Defence.

The functions of the *Defence Science Advisory Committee* broadly are : to consider the technical and scientific aspects of service requirements, to keep in close contact with research and development in the service (technical) establishments, to initiate basic research in relation to Defence Science in the Service Laboratories and in collaboration with Universities and research institutions, and to keep in touch with the scientific and industrial development in the country generally. Its members include the Scientific Adviser (as Chairman), the Master General of the Ordnance, the Engineer-in-Chief, the Director General of Armed Forces Medical Services, the Director General of Ordnance Factories, the Director of Technical Development (Army Headquarters), the Chief of Material (Naval Headquarters), the Director of Technical Services (Air Headquarters), the Deputy Chief Scientific Officers (Army, Navy and Air Force). There are also on the Committee the representative of the Council of Scientific and Industrial Research (Dr. K. S. Krishnan), the representative of the Ministry of Commerce and Industry (Dr. Nagaraja Rao), Under the Defence Science Advisory Committee Panels for Ballistics and Operational Research will be shortly constituted ; a Personnel Research Panel already exists.

Since the institution of the Defence Science Organisation a number of scientists have been appointed—these include physicists, chemists, engineers, physiologists and psychologists. They are concerned with various aspects of Defence Science, but broadly speaking the work in the Defence Science Organisation can be classified under the following heads :—

(1) Performance of weapons and equipment,

(2) Operational Research,

(3) Special studies, e.g., defence food problems,

(4) Preliminary sorting out of problems for detailed study in appropriate Establishments.

The problems under investigation range from ballistics, communications, soil research, food, explosives, general stores, study of training methods, time and motion study, corrosion to environmental physiology, personnel selection and so on. Some of the problems which are studied by the scientists will be discussed in the following sessions of the conference : in particular problems in the field of ballistics, operational research and personnel research, and environmental physiology will be dealt with. The Defence scientists spend a good

L68Army

proportion of their time at the Services Establishments and Service Officers are also attached to the Defence Science Laboratory.

It is gratifying to observe that as a result of the first Defence Science Conference and in pursuance of the efforts of the Defence Science Organisation, some of the Universities have introduced ballistics as a subject for post-graduate studies. There are still, however, a large number of basic subjects of defence interest, such as shock wave studies, non-linear equations, servo mechanisms, thermodynamics of explosives and so on which yet do not find an adequate place in the Universities. It is to be hoped that the University authorities will examine the possibility of including some of these, at any rate, in the post-graduate courses.

At this stage a brief mention may be made of the Defence Science Service.

Perhaps, the single most important thing that can be done with regard to the proper organisation of research and development is the institution of a scientific service. A beginning has been made by instituting a *Defence Science Service* which will include all civilian scientists engaged in research, development or teaching employed in any of the three Services or in the Ministry of Defence. This Service will come into operation shortly.

It may be mentioned that in the United Kingdom all scientists employed by the Government whether in civil departments or in Service establishments belong to a unified Scientific Civil Service. It would be useful to summarise here some of the salient features of this Scientific Civil Service as these would be applicable *mutatis mutandis*, to our Defence Science Service.

The service, in its present form was instituted in 1945, with the object of providing for scientists working for the Government such conditions of service as to attract men of high calibre, and to enable them to play their full role in the national development. The three essential conditions of a strong and healthy Scientific Service, as laid down in Cmd. Paper 6679 (1945) are :—

(1) Better conditions of service for scientists, and, in particular, conditions under which their own experimental research will be both facilitated and stimulated,

(2) Improvement of their status and remuneration, and

(3) Centralised recruitment.

It is interesting in this connection to refer to a study made by Syracuse University (The Maxwell Graduate School of Citizenship and Public Affairs, Syracuse, New York) on the 'Attitudes of Scientists and Engineers about their Government employment' e.g., what scientists think of Government employment. There is not time enough to go into the details of this interesting study. I merely content myself by reproducing the table summarising the results of the investigation. (Please see Appendix).

A reference may also perhaps be made to the Institute of Armament Studies to be established at Kirkee. It will devote itself to the study of the basic principles of weapons and in status and character it is intended to be something like a first-rate University College.

Here civilian scientists from the Universities and other research institutions would be welcome as 'visiting scientists' to acquaint themselves with aspects of defence science of interest to them. Such contacts will, of course, be most useful to the defence scientists; these will keep the defence scientists in the closest touch with the main currents of Indian scientific thought and research.

Defence research is necessarily, and at any rate by and large, applied research. This means that the problems one has to work upon are in their broad sense already determined by the requirements of the Services and the exigencies of the situation. In fact the most important and also the most difficult thing in Defence research is the identification of problems and the assignment of priorities to them; in other words, a correct formulation of what may be called the tactics and the strategy of science. In the selection of problems three general principles have to be borne in mind :—

(i) The problems must be of direct usefulness to the Services,

(ii) The problems must be amenable to solution with the resources available, and

(iii) The speed with which the problems can be solved.

It will in general be found—and it is so even in countries like U.K. and U.S.A.—that the number of problems for investigation is much too large than what can be tackled with the resources available. The secret of successful defence research, as indeed of any successful scientific work, is to concentrate on a very small number of problems well and wisely chosen. If the scientific effort is scattered over a large field, nothing really worth while is likely to be achieved. The one outstanding lesson that scientists learnt from the Services during the last war, was the lesson of concentration, of focussing of effort, on a selected number of problems. In fact, the age-old principles of war such as concentration, co-operation and economy of effort, can all be most usefully applied to the organisation of scientific work.

Speaking of Defence research one or two general remarks about applied research and pure research may be permissible. I shall not attempt any definition of pure research and applied research, and in any case no precise definition is possible because of lack of sharp demarcation line between the two. However, in most cases, I believe, it is easy enough to say whether a given investigation is to be classed as pure research or applied research, and I will leave it at that. The aim of pure research, is to push the frontiers of knowledge, it is to seek understanding of nature; whereas the aim of applied research is to make known knowledge useful and to harness it in the service of the community. The quality of pure research is judged by its newness and originality, the quality of applied research by the extent of its usefulness. Very often the methods of investigation are the same in the two cases, only the objectives are different. Known knowledge, so long as it remains burried in books and journals, is of no usefulness. In order to apply it one has first to assimilate it, and often to enlarge and integrate it.

There seems to be a fashion in some quarters to unduly extol the glory and glamour of pure research. There can be no doubt that hardly anything is more inspiring and satisfying to the innermost depths of our being than a devoted pursuit of pure research, provided one has the competency and temperament for that kind of work, and such men are not too abundant. Again, one can have no criticism to offer of a person who takes to pure research bacause he thinks that it gives him satisfaction and pleasure or because he *thinks that that is the only worthwhile thing he can do.* What I am concerned with, however, is the person who takes to pure research not because he has an intrinsic liking for it, but because he is carried away by the fashion of the times. Very often he suffers from a distorted sense of values and even if wasting his time in pure research he looks down upon applied research as a much inferior kind of thing. This is a wrong attitude and is often responsible for keeping away potentially good applied scientists from undertaking applied work. In applied research one does not meet with that glamour and chance of individual recognition as in pure research. In a sense applied work is more for the community—pure research more for the individual. Good applied research as much as good pure research requires men of high abilities and character. We must not feel shy of devoting our time to learning what is known. Only that way we can apply known knowledge to the benefit of the community. It is exhilarating to discover new knowledge, but from the point of view of the community the application of existing knowledge is far more useful and urgently necessary. As has been pointed out by several distinguished men of science, there is even in Western countries a terrific lag between what is known and the extent to which known knowledge is applied to useful and practical ends. In our country the situation is obviously far more dismal. Applied science should be looked upon as respectable a profession, if not more, as the pursuit of pure science. In disseminating this outlook the Universities have to play a very important part.

Research requires competent men to undertake it, but it also takes time, needs sustained effort, and it also costs money. Let us have a glance at the cost side.

The present world expenditure on armament may be roughly put down as $ 100—150 billion a year, which is about Rs. 80,000 crore a year. The U.K.'s annual expenditure on Defence is about $ 4 billion a year. U.S.A. is spending about $ 60 billion*. As announced in the Soviet budget the military expenditure of that country for this year is $ 30 billion.

The increase in the range of action of weapons, the improvement in striking power, in speed and mobility, and the accuracy with which they can engage a target, all imply increased technical refinement leading to higher costs of production and still higher costs in maintenance and repair.

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* The U.S. Senator McMahon observed the other day this huge expenditure has faced even the U.S.A. with the difficult choice of either military security at the expense of economic solvency or high level social economy at the expense of military security. (See Bulletin of Atomic Scientists, October 1951).

In U.K. for instance, the cost per man in the Armed Forces is now over £ 1,000 a year. It is roughly two to three times higher in U.S.A. In our case, and understandably so, the figure is one-third and possibly less than what it is for U.K.*

It is difficult to say how much of the Defence Budget is spent on scientific research and development, it is difficult firstly because figures in many cases are not available and also because there is no sharp demarcation line between research/development, production of prototypes and user trials. Roughly, one may say somewhat less than one-third of the Defence Budget of countries like U.K. and U.S.A. is spent on research and development†. The total research expenditure, civil and military, is about 1 per cent of the national income for these countries. In our case defence research and development expenditure is about 1/200th of the Defence Budget. It is no doubt a very small beginning, but how else can big things grow except through small beginning.

* The following table serves to indicate the rise in cost of American equipment in typical cases :

The Rising Cost of Defence (Combat Forces Journal, February 1951).

	World War II	1950 (before Korea)
	$	$
Garand Rifle	31	64
Bazooka	..	65
Medium Tank	55,000	200,000
Anti-aircraft Gun	10,000	200,000
Medium Bomber	185,000	1,246,000
Pursuit Bomber	50,000	183,000
Infantry Division (with the original equipment but exclusive of pay, clothing, food etc.)	14,500,000	74,300,000
Airborne Division	15,000,000	75,000,000
Armoured Division	30,000,000	200,000,000

The initial cost of an infantry division (USA) was $ 14 million in 1944, whereas now it is more than five times larger. Similarly an armoured division which costs $ 30 million in 1944 would now cost $ 200 million.

As another illustration of the same trend, take the case of Logistics. One infantry division requires 8,000 vehicles and deployment of several thousand men. Ammunition, petrol, oil and other stores required per man per day is about one-fourth ton : 50 per cent is POL. A division requires supply of more than 500 tons a day, and for a campaign, a division needs something like one million to ten million tons of supplies of ammunition, POL and general stores.

As a comparison between Defence expenditure and expenditure on necessities/amenities of life, notice that $ 1.5 billion a year is spent by U.S.A. women on shoes, $ 1.6 billion on cosmetics and so on. (*Fortune*, January 1949).

† "Thus, while the Royal Navy will decline in size by about 20.000 men, it will spend another £ 10,000,000 on production and research. The Royal Air Force is expected to remain at its present strength in men, but will spend an extra £ 13.5 million on research and development, and while the regular Army will decrease from about 185,000 to 178,000 men, it will spend £ 7,000,000 more on research. These increases more than offset the reductions in the pay bill, and research and development now represent 31.9 per cent of the defence estimates as against 24.1 per cent in 1948-49. Further, it must be accepted now budgetary provision for new equipment is likely to grow rather than diminish if the existing forces are to be kept reasonably efficient."

(See 'Nature', April 8, 1950 : White Paper (U.K.) on Defence Estimates for 1950-51).

Speaking on expenditure on research and development, it is also of interest to see what is the available scientific manpower and how it is distributed for the various sectors of research. U.K. has about 60,000 pure scientists (half of them are employed as teachers), roughly an equal number of medical men and an equal number of engineers (including agricultural technologists). This makes a total of something less than 200,000 scientists of all categories. U.S.A. has about 500,000 scientists, engineers and medical men. The figures for the Soviet Union are not known with any reliability, but the number would possibly be comparable to that for the U.S.A. Thus the world total of scientists (including engineers and medical men) is something between one to two million. Incidently, the number of coalminers, though larger, is of a comparable order. Why this is so, it is easy to see. More scientists mean more technical development, more applications of science and hence ultimately more industrial production. But production requires power and power comes from coal—and it will be so at any rate, for a few decades to come, till perhaps atomic energy, or may be, solar energy, takes its place. Thus number of scientists and coalminers keep pace with each other. In India we lack both.

For the 60,000 scientists (excluding engineers and medical men) in U.K. the subdivision under different sectors for research very roughly is as under :—

Teaching	30,000
Scientific Civil Service—	
(i) Defence Research	5,500
(ii) Civil Research	2,500
Public Bodies	800
Research Associations	1,200
Industry proper	10,000
Unclassified	10,000

Thus we see that about 10 per cent of the total number of scientists are employed on defence research. This percentage is likely to be larger in the U.S.A., and possibly larger still for the U.S.S.R.

*The organisation of research is incidentally made much more difficult than organisation in other fields of work. It is difficult to explain precisely to non-technical authorities concerned, what the programme will accomplish. Funds for research programmes have to be assigned largely on faith. Condon has said "It is characteristic of most fundamental research that several years are required for the completion of any work of importance and that the end result may be difficult to evaluate by any one except specialists. What, for example, is the cash value of Einstein's discovery of the relation $E = mc^2$. No doubt it is an astronomically large value now. But what was its worth at the time of is formulation ? And who was qualified to make the evaluation ? The point simply is this : pure knowledge cannot be evaluated in cold cash, and pure knowledge is independent of such evaluations. Unfortunately, appreciation of this fact is not

* This section is taken from D. S. Kothari's address to the H.E.F.T. Association, Kirkee.

as widespread as it should be, which suggests the story of two partners who had long operated a chemical manufacturing business. They finally decided to employ a research chemist. Along about 11 A.M. of the first day of his employment, one partner said to the other, "Shall we go and see whether that research chap has discovered anything?" "No" replied his partner, "It is a little too soon. Let's wait until after lunch."

Generally speaking the object of a defence research and development is two-fold: (i) it is to enable the armed forces to make the best operational use of their existing weapons and equipment, and (ii) to continually seek new weapons (including serious modifications to existing weapons) so as to gain a lead over possible enemy countries. The first object is largely met by operational research, whereas the second requires background of high level scientific knowledge and industrial productivity. Operational research is the application of scientific method to the study and analysis of operational effectiveness of weapons, and this has been a conspicuous feature of the last war. "Operational Research is a scientific method for providing executives with a quantitative basis for decisions". Probably no other field of research or development has provided a larger yield than this in relation to the effort expended on it. The assessment of the operational effectiveness of weapons (weapon efficiency and weapon economics) has now become one of the most important, if not the most, field of defence research. Often it is a matter of highest complexity to decide whether a proposed weapon "A" is superior to an existing weapon "B", and if so is this superiority sufficiently large to make the replacement worthwhile. It has to be realised that this assessment of weapon efficiency must take account of the tactical use of the weapon and the level of training of the troops in its use and so on. A less accurate weapon or a less sophisticated one may, depending on the tactical situation, give better battle-value than a more accurate or complex weapon. There is no such thing as the absolute superiority or efficiency of a weapon: it is always in relation to tactics, the nature of the terrain, the ability and resourcefulness of our fighting men and of the enemy. This, therefore, can only be done by the scientists in the closest association with the fighting services. Assessment of weapon effectiveness demands an intimate knowledge of its performance and experience in its operational use. Such a knowledge is essential if we are to utilise existing weapons to their maximum advantage, and effect such improvements as may be required to meet local requirements, and also to help us in purchasing weapons best suited to our needs.

The Defence Science Laboratory, at present, accommodated in the N.P.L. Building, in Delhi is intended to be the central place for such studies. It is somewhat on the lines of the Army Operational Research Group, Byfleet, U.K., but, of course, in our case on an inter-service basis. In this sense we shall have some advantage over the UK set-up, where the operational research work for the different Services is not as closely joined together as it should or can be.*

The important thing about Operational Research particularly emphasised by Blackett, the chief founder of Operational Research, is that there must be intimate contact between Operational Research Teams and the Executives (i.e., Staff Officers in the Armed Forces) who are concerned with taking decisions. For successful Operational Research work it is essential that the research workers should have complete access to all relevant information, should enjoy the confidence of the Executives concerned and should be present (as observer) at the meetings of the Executives. This is necessary so that operational research workers may understand how the Executives approach their problems, how they deal with conflicting evidence and the way they arrive at decisions. The operational research worker should also have a large measure of freedom in selecting problems for investigation. It was soon found during the last war that the most fertile problems, and the ones which yielded the greatest dividends, were not those that were put to the Operational Research Teams but they were the problems the Teams discovered themselves. To find a problem, to identify it for solution, often needs deep scientific insight.

An Operational Research worker needs primarily a basic training in scientific thinking, that is he must be trained to approach a problem in the way that is characteristic of a scientist experienced in scientific research. It is this point of view which an operational

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* Apart from operational research, scientists are required also to assist the Services in other ways. All these may perhaps be summarised as below :—

(a) Purchase of weapons : The help of scientists is required to assess the operational effectiveness of the different weapons so that within our purchasing resources the most effective weapons are purchased.

(b) Optimum use of existing weapons : This is a most important subject in which the contribution of operational research scientists is well recognised. In relation to the effort put in, this study yields very often the largest dividends.

(c) Modification to existing weapons to suit them to local conditions : (e.g., tropicalisation : super-refraction in the case of radar).

(d) Development and design work : With a view to produce in India existing (conventional) weapons which at present are imported. This is becoming most important in view of the difficulties in importing weapons now from abroad.

(e) Research and also development and design : With a view to produce in India new weapons in general of the World War II class.

(f) Research and study to keep in contact with advanced weapons work in foreign countries.

(g) Research with a view to develop radically new weapons. (This stage is not likely to arise in the country for the next few years).

(h) To suggest improvements in inspection techniques and procedures.

research worker requires above everything else. With this essential qualification it is desirable that he also has a knowledge of the particular scientific or technical field with which his operational research work is concerned, but this, by no means, is essential. He must have a capacity to take a whole or integrated view of the problem so that important, but may be obscure, factors are not ignored.

In the last war some of the best operational research work was done by physicists and biologists. It does not mean, however, that other disciplines do not combine well with operational research. I will not describe here examples of war-time operational research. These have been done often enough in recent literature. The fascinating application of operational research to U-boat campaign, to planned flying and planned maintenance and so on are by now commonplace. Applications of operational research to sea-warfare have been dealt at great length by Morse and Kimball in their stimulating book entitled "Methods of Operations Research". The applications of operational research to peacetime industry e.g. as applied to the boot and shoe industry, textile industry, road and transport problems and so on have been described in a recent publication of the Manchester Joint Research Council called 'Operational Research—its Application to Peacetime industry'.

It would, however, not be inappropriate to touch briefly on the wider question as to why it happened that only during the last war operational research, for the first time, played such a vital role. There are many answers to this question. One is that the weapons used in the last war, particularly those concerned with air warfare, radar and so on, are intrinsically well suited to stimulate both the necessity and the application of operational research. However, I leave this aside and consider what perhaps is the more basic reason, namely, that the characteristic feature of the scientific climate of the present times is statistical reasoning. This has come about because of the impetus of biological experimentation which, distinct from physical experimentation depend for their successful prosecution on the use of the statistical methods. The factors concerned in biological experiments are so numerous, and often uncontrollable, that without the proper use of statistical methods it becomes almost impossible to draw any valid conclusions.

Incidentally, it applies with even greater force to what is known as parapsychology. Hence, valid experiments in that field could hardly have been possible before the emergence of the modern statistical methods.

Besides this the rapid growth of kinetic and statistical theories in physics culminating in quantum theory has made the statistical approach to phenomenon in general as almost commonplace. As an illuminating example of this statistical approach one is reminded of Professor Young's fascinating book '*Doubt and Certainty in Science*' where he claims that the human body and the human brain should not be compared to a machine, a clock or a net-work of telegraph-lines, but according to him a much more fruitful model is a statistical model containing a large population, e.g., to compare the brain to the human population itself. Then there is Shannon's beautiful work on communication of information. The unit information is defined and the unit is called a Bit. The concept of informational entropy is developed and found exceedingly fruitful. In this context there comes atonce to mind Neumann and Morgenstern's classic book entitled "Theory of Games and Economic behaviour". This is undoubtedly the most profound contribution yet made to the purely theoretical study of operational research in its wider sense. If operational research be described as the science of the application of science, then Neumann's book deals with the pure, as distinct from applied, aspects of this branch of science. The characteristic novelty of Neumann's work is that herein is considered the theory of 'games of strategy'. The great French mathematician Laplace started the theory of probability in the last century by considering games of chance. For the first time Neumann, one of the greatest contemporary mathematicians, basing his investigations on the general pattern of quantum theory thinking, has produced a mathematical scheme which deals with, at any rate, the simplified aspects where the players can combine into groups, into coalitions, where they resort to bluff and fraud. In other words here is the mathematical scheme which deals with, at any rate, the simplified aspects of the market place. This is the first, but indeed a great, step to a proper theory of economic behaviour. The book develops new mathematical methods and indeed shows that the older mathematical methods are not capable of dealing with games of strategy. A study of Neumann's book sharpens one's thinking as to what is strategy, what is tactics, what is bluff and so on.*

As already mentioned, by and large the most fertile field for operational research is that concerned with weapon economics, that is the evaluation of effectiveness of a weapon 'A' compared with say another weapon 'B'.

This problem of evaluation of weapon efficiencies, or weapon economics for brevity, arises at all levels. One may ask: is it an advantage to change from say Rifle A to Rifle B, and if so what will be the relative advantage gained? Is it worthwhile, and if so to what extent, to replace say TNT in shells by RDX. It is also concerned with larger questions such as 'What is the optimum distribution of a given amount of resources in money and materials between, say, building more fighters, bombers and manufacturing of anti-aircraft guns'. Still larger questions, and these fortunately are no worry of ours, are, for example, to what extent the effort must be divided between atomic weapons and conventional ones.

Under Operational Research one also asks such basic questions as 'what is sea-power'? 'what is air-power'? How can one describe precisely the difference between fire-power of artillery and of infantry?

One may think that questions such as these can hardly admit of any scientific answer. One may think that scientific analysis can possibly make no contribution to such problems. Without dilating unduly on this point I would say atonce that in fact, as actually

* Also see Contributions to the Theory of Games: H. W. Kohn and A. W. Tucker (Editors). Princeton Uni. Press (1950).

demonstrated, operational research has proved most fruitful even when dealing with such complex problems and situations as mentioned above. It is possible to assess in numerical terms—not in absolute sense, but for the practical objective in view—even such things as morale. It has been found, for instance, that shelling to the extent of one 25-pdr. shell for about every 100 sq. yds. of territory occupied by defending troops neutralises them, though the actual casualties are 1 or 2 per cent. This was found to be true for many theatres of war for which data were available and analysed. More of these examples, some of them most exciting indeed, will be discussed during later sessions of this Conference.

If we are to learn from past experience, if we are to draw useful lessons from it, we should express it in such a way that we can compare it with present situations and future situations likely to occur. Only when we can compare, we can know which is better and which is worse. In a broad sense, therefore, one may say that whereas it is said that we learn from history, that we do not learn from history; it can also be said that by using the technique of scientific method (that is operational research), it is possible for us to learn from history. The possible applications of operational research to peace and war are many and diverse. They exist almost everywhere and there is a rich harvest ready to be collected. All we need is a sustained and devoted application of the scientific method combined with commonsense, imagination and boldness. And we can be sure of reasonable success not only in operational research, but in all Defence science work, if we remember what Appleton has said: "In all our actions (i.e., D.S.I.R. actions) we have recognised that while it is impossible to plan discovery, it is quite possible to plan for it .... It is possible to get almost anything done, if one is prepared not to claim credit for it .... A scientific man should also be the complete 'citizen of the world'. He should not only be fit to live, but also fit to live with."

APPENDIX

Conditions that make any technical position desirable.	Advantages of employment		
	Government	University	Industrial
1. Opportunity to do interesting, challenging, or important work and to have more freedom in or responsibility for one's work.	1. Job security.	1. Freedom of research and opportunity to pursue research work of interest to the individual.	1. Adequate compensation.
2. Adequate compensation and economic advancement.	2. Desirable leave policies.	2. Desirable environment and professional atmosphere.	2. Opportunity for advancement.
3. Desirable working conditions with respect to equipment, plant facilities, and the handling of service functions.	3. Opportunity to do interesting and important work & to have freedom of action in research.	3. Desirable working conditions.	3. Good equipment and facilities.
4. Opportunity to work with competent and congenial co-workers.	4. Good physical facilities & equipment.	4. Competent associates and co-workers.	4. Desirable working conditions.
5. Opportunity for professionl development, advancement, and recognition.	5. Compensation.	5. Opportunity for professional development and advancement.	5. Competent supervisor and co-workers.

Conditions that make any technical position desirable.	Disadvantages of employment		
	Government	University	Industrial
1. Opportunity to work for competent supervisors.	1. Poor general administration, including personnel administration.	1. Inadequate compensation.	1. Job insecurity.
2. Matters of personal convenience and preference.	2. Poor compensation	2. Poor equipment and facilities.	2. Production demands and pressures.
3. Personal security.	3. Poor Advancement opportunities.	3. Excessive teaching load.	3. Poor working conditions.
4. Opportnity for advancement based on merit.	4. Lack of opportunity.	4. Poor chance for advancement.	4. Inadequate leave and vacations.
5. Adequate number of competent assistants.	5. Lack of freedom of action and challenging and interesting work.	5. Poor working conditions.	5. Lack of patent rights.

(Taken from Science, May 4, 1951—Also see Attitudes of Scientists and Engineers about their Government employment (Syracuse University) Volume I).