OBJECTIVES OF SCIENCE AND TECHNOLOGY

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1. This symposium has been convened for collaboration in the utilisation of science and technology in developing countries.* We know the ultimate objective is the improvement of the level of living in developing countries. This means having a bigger and bigger supply for each person of food, clothes, housing and such other things, and also greater facilities for travel, medical care, education, etc., and cultural amenities. The aim must be a continuing increase in the per capita production of consumer goods.

Science and technology for economic growth

2. We have to think in terms of four levels. First, to increase the supply of consumer goods which is the first level. To do this, we must expand the production of capital goods; this is the second level. Both of these will require an increasing utilization of science and technology; this is the third level. Engineering and technological developments call for increasing applied research which in its turn requires a sound foundation of basic research. Results of research must then be used to make new innovations for a continuing improvement of productivity. This is the fourth level.

3. I have used the two words science and technology in their accepted sense in the advanced western countries. Science is knowledge of nature and natural processes. Technology is the use of scientific knowledge for some given purpose. Science and technology are intimately connected. Both are connected with education, of scientific and technological education and also general education. The word science is sometimes used in a more general sense for all these three aspects, science, technology and education.

Research and development

4. During the last 15 years, and more intensively during the last 5 years or so, increasing attention is being given to certain aspects of science and technology, namely, scientific research and technological development, which is called, briefly, research and development, and is known in the now familiar abbreviated form 'R & D'.

5. Research, consisting of basic research and applied research, is described as "systematic, intensive study directed towards fuller scientific knowledge of the subject studied." Basic research is "research in which the primary aim of the investigator is fuller knowledge or understanding of the subject under study, rather than, as in the case of applied research, a practical application thereof".[1] On the other hand, "applied research is directed towards practical application of knowledge". And, "development is the systematic use of scientific knowledge directed towards the production of useful materials, devices, systems or methods, including design and development of prototypes and processes.[2]

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[1] NSF. 65-11, May 1965, p.2. [2] NSF. 65-11, p.10

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Motivation

6. Some thought is being also given to motivation for R & D in the advanced countries, for example, "the needs have been divided roughly, and somewhat arbitrarily into four main groups:

- first, the spontaneous human need for wider and deeper knowledge, which animates institutions for fundamental research, especially the universities;
- second, the need for the solution of certain social problems, such as those related to health, nutrition, air pollution, road safety, etc.;
- third, the needs of national defence and - sometimes of a policy of prestige, needs which have greatly increased since the second world war;
- fourth, the needs related to the promotion of economic growth." (OECD. seggp 1963, 49).

Motivations for undertaking R & D are not independent of each other. Also results of research may have consequences which are at the same time social, economic, political and military, besides satisfying the thirst for knowledge. In the developing countries the focus of attention must be on rapid economic growth because it is only through a rapid growth of the economy that it would be possible to raise the level of living or to expand facilities for education, care of health, cultural amenities, etc., and, ultimately also to strengthen defence, national security and independence.

Special needs of developing countries

7. The scientific tradition has been taken for granted in the conceptual framework described above. This is proper in the case of the advanced countries where the scientific tradition is well established. In the developing countries, however, the scientific tradition has till to be established and continually strengthened. What then is this scientific tradition which demarcates the advanced countries from the developing countries?

The scientific tradition

8. Before the emergence of science there were only two types of human decisions. In one type there is freedom of individual choice in such things as food, clothes, etc., or in games, recreations etc., all within the limits of physical availabilities or social permissibilities. The second type of decisions is regulated by the "principle of authority" in which sanction is determined by the level or status in a hierarchial system of authorities in all organised human activities; in military, police, and administrative systems; in public and private enterprises; in church and religious organisations etc. A system of law is conceivable only when there is a possibility of an appeal from the verdict of a lower court or authority to a higher court or authority - at least from 'Phillip drunk' to 'Phillip sober' - and, also, if a complete reversal of the verdict of the lower court or authority is permissible. This principle of authority must be accepted for the very existence of society itself.

9. Individual freedom of choice and the principle of authority must, however, be completely rejected in the field of science. Cause and effect have been the subject of enquiry from time immemorial but only in respect of isolated events. A crucial change occurred with the emergence of the concept of natural phenomena as interconnected and amenable to rational and unified explanation. Modern science consists of a patient accumulation and critical study of observations and experimental results and their inter-relations, based on the uniformity or regularity of nature, which can be discovered by the human mind and can be unified and integrated by theory. Science introduced for the first time the concept of nature as objective reality and of the validity of the knowledge of this reality, which has its foundation in nature itself and which is not subject to individual choice depending on taste or preference, and which can not be changed or upset by any human authority however high.

10. The scientific method based on observations and experiments is essentially revolutionary in nature and must continually challenge established belief based on authority or superstition. In the developing countries a most urgent task is to establish and strengthen the outlook of science, and the experimental attitude of mind so that deeper knowledge of natural phenomenon and of social forces may be acquired through research, and such knowledge may be used to invent new devices, methods and techniques to bring about material and social changes. This is the only way to replace superstition and obsolete customs or dogma by rational decisions.

11. The scientific outlook and the experimental attitude of mind is then the scientific tradition, which is vested in a community of scientists enjoying complete equality of status for free exchange of views and criticisms in all scientific matters. In the developing countries a most important aim of science education and research must be to build up, as quickly as possible, a community of scientific workers with equality of status in scientific discussions, to foster the growth of the scientific tradition, to promote the social appreciation of science among the general public, and to help in bringing about a rapid transformation of a society based on authority into a modern industrial economy based on science and technology. Without such transformation sustained economic growth is not possible and political independence is not viable.

Technical services

12. There are many scientific activities which are taken for granted, in advanced countries, such as, the regular collection of meteorological and hydrological observations; systematic field surveys of various kinds (topographical, geological, botanical, zoological, etc.); socio-economic, statistical and surveys; also testing of raw materials or manufactured products, calibration of instruments and equipment, chemical analysis, clinical tests, biological assays, etc. which are being carried out as normal activities with, of course, increasing sophistication in the advanced countries. In addition, during the last twenty-five years or so, new techniques and technical methods are being increasingly used in the advanced countries, such as,

industrial standards; SQC (statistical quality control); design of experiments; operational research; electronic computers for processing, analysis, and programming; systems analysis, and controls etc.

13.- For convenience of reference, I shall call the above and similar activities 'technical services' which supply the infra-structure of science and technology in the advanced countries. There can not be any doubt about the need of rapid promotion of such services in developing countries. I should, therefore, suggest the addition of the word 'services' to 'research and development', to supply a wider concept of 'research, development and services' (R, D & S) which is more suitable for developing countries.

Expenditure on research and development

14. In this paper I shall consider briefly some aspects of the planning of research, development and services (R, D & S). Planning usually starts with the allocation of funds. In recent years much attention is being given to expenditure on R & D in the advanced countries; such expenditure increased appreciably only from the time of the second world war, that is, during the last twenty-five years or so. There was also a rapid rise after the release of the sputnik in U.S.S.R.; since then the additional expenditure has been mostly defence-oriented with special emphasis on missiles, anti-missiles, and space vehicles in U.S.A. and U.S.S.R., and to some extent also in U.K., and France. The rise in expenditure on non-military industrial R & D has also been particularly rapid in recent years in a number of science-based industries, such as, chemicals, electrical equipment and communication, electronic computers, etc.

15. Research ratio: The R & D expenditure is often expressed as a percentage of the gross national product (GNP) and is called the research ratio. In the U.S.A., the research ratio reached the level of about 3 percent in 1963. It was somewhat smaller and about 2.2 and 2.3 percent in U.K. (1962) and U.S.S.R. (1964); about 1.7 or 1.8 percent in Sweden (1962) and Netherlands (1962); 1.5 or 1.6 percent in France (1962-63); 1.4 percent in Japan (1963); 1.3 percent in West Germany (1962) and Switzerland (1963); 1.0 percent in Belgium (1962); and lower than 1.0 percent in other advanced countries like Canada (0.9 percent in 1963-64), Norway (0.8 percent, 1963); about 0.4 or 0.5 percent in Austria (1963) and Denmark (1962), and possibly only 0.3 percent in Italy (1963).

16. Distribution by type of activity: Basic research accounts for roughly 10 or 11 percent of the total R&D expenditure in U.S.A., U.K., U.S.S.R. and France; most of the basic research is done in the higher educational institutions. Applied research has a share of about 22 percent in U.S.A. and 25 percent in U.K. while development has the very large share of 68 percent in U.S.A. and 64 percent in U.K.; within industry development absorbs 78 percent of R & D expenditure in U.S.A.

17. Source of funds: Practically all military R & D is financed by Government. A good part of non-military R & D is also financed by Government for basic research mostly in higher educational institutions, and some exploratory type of applied research mostly in non-profit institutions which includes research on health, education, agriculture, etc. Oriented applied research and development, which is done mostly within industry is financed by industry itself.

18. Cost per R & D scientist: The cost per qualified scientist and engineer engaged in R & D was of the order of $ 35,000 per year in the advanced countries of the West, such as, U.S.A., U.K., France, Canada, West Germany, etc., in early nineteen-sixties. It was appreciably lower and something between $ 12,000 and $ 14,000 per year in U.S.S.R. The cost was still lower in Japan and of the order of about 7,000 dollars per research scientist per year in 1961. In India the average cost per scientist in Government institutions was roughly $ 7,000 per year or about the same as in Japan.

19. It is of interest to compare the cost per scientist in terms of per capita income. In U.S.S.R. the cost per research scientist was possibly something like 12 times the per capita income (adjusted for western concepts). In Japan, Canada or U.S.A. it was somewhat higher and of the order of 15, 16 or 17 times the per capita income. In Western European countries the cost was higher and of the order of about 25 times the per capita income. In India it was very much higher; of the order of about 80 or 90 times that of the average income per person. U.S.S.R., Japan and U.S.A. are in a relatively favourable position to increase the research ratio. It is somewhat more difficult to do so in the advanced western countries, U.K., France, etc., and far more so in India.

20. Selectivity within industry: Within industry, there is a very high degree of selectivity of R & D expenditure by type of industry, and by the size of the firm. Manufacturing industries have a proportionately larger share of R & D expenditure than non-manufacturing industries such as construction, transport, agriculture, commerce etc. Again, within manufacturing industries, five or six groups of industry, such as, aircrafts, electronics and electrical equipment, chemicals, metals, machinery, motor cars and transport equipment, absorb a large share, of the order of 70 or 80 or 90 percent, of the total R & D expenditure in the advanced countries (such as, U.S.A., U.K., France, Sweden, Netherlands and Japan).

21. R & D expenditure has a strong association with the size of the enterprise being much higher in the case of larger firms. For any particular type of product there is usually a minimum size of the R & D staff below which the results of R & D would be ineffective. To start even a small R & D unit is expensive. The cost of

the R & D unit must be recovered from sales; and has to be, therefore, generally a small fraction of sales, say, of the order of 10 or 5 percent or less. That is, sales must be large enough to make it possible to start R & D. As larger firms will have a larger production and larger sales, they will be in a more favourable position to incur R & D expenditure.

22. Progress of industrialisation would tend to increase the size of the firm, and the share of manufacturing industries in the national economy, and would create increasingly favourable opportunities for the emergence of more sophisticated, science-based industries which have larger shares of R & D expenditure. The research ratio may be expected normally to increase with the growth of the economy and increasing per capita income. On the other hand, in the early stages of industrialisation the size of the firm would be comparatively small; also it would be difficult, though not impossible, to take up sophisticated, science based industries generally. It would be, therefore, difficult to bring about a rapid rise in the R & D expenditure within industry, in advance of the general progress of industrialisation and economic growth.

23. Non-military research ratio: India and most of the other developing countries do not have much military research and development. It is, therefore, of interest to consider the research ratio based on, not the total R & D expenditure, but of the non-military or civilian part only. The position in 1962 or thereabout was as follows. Japan and Netherlands had the highest non-military research ratio of the order of 1.4 and 1.6 percent respectively. U.K. and U.S.A., had an appreciably lower level of 1.3 and 1.2 percent respectively and France a much lower value of 0.8 percent. Five most advanced countries in Western Europe (Belgium, France, Germany, Netherlands, and United Kingdom) taken together and also Sweden had a non-military research ratio of about 1.1 percent. Definite information is not available for military R & D expenditure in other countries in Europe; allowing a minimum of 10 percent for military R & D expenditure in such cases, the non-military research ratio would be for Switzerland about 1.2 percent, Norway 0.7 percent, Canada 0.6 percent, Denmark 0.4 percent, and Austria 0.4 percent.

24. Non-military, non-industrial research ratio: A second point to be noted is that most of the R & D expenditure is incurred within industry, the proportion varying from 50 to 75 percent in different countries with two-thirds as a representative figure. If industry is excluded, the research ratio would be of the order of 0.5 percent or a little less in U.K. (0.53), Japan (0.47), and Netherlands (0.45); at the level of 0.4 percent or a little less in five Western European countries taken together (0.41), West Germany (0.39), Belgium (0.38), Norway (0.37); of the order of 0.3 percent or less in U.S.A. (0.31), Sweden (0.27), Canada (0.26), and at the level of 0.2 percent or less in Switzerland (0.21) and Austria (0.16).

Research and development in India

25. Research ratio in India. In India reliable estimates are not yet available about the total R & D expenditure. Information from one source gives an estimate of expenditure of Rs.45 crores ($ 95 million) with G.N.P. of Rs.231 billion ($ 48.6 billion) and a research ratio of 0.19 in 1964-65, and an estimate of expenditure of about Rs.54 crores ($ 114 million), G.N.P. of Rs. 235 billion ($ 49.9 billion) and a research ratio of 0.23 in 1965-66. According to another source the R & D expenditure was much higher and the research ratio was about 0.33 percent in 1964-65; a difference of over 40 percent between the two estimates may be due partly to expenditure on what I have called 'technical services'.

26. The Indian expenditure refers to non-military research and development. Also, in India there is very little research and development in industry whether in the public or the private sector. The share of industry is possibly only about 4 or 5 percent of the total R & D expenditure compared with from 50 to 70 percent in advanced countries. The appropriate comparison of the Indian figure of research ratio would be, therefore, with the non-military, non-industrial research ratio in the advanced countries, which we have seen is at the level of 0.4 or 0.3 percent in many advanced countries, and lower in other advanced countries. The position in India is not unsatisfactory from the point of view of R & D expenditure even if the lower estimate of about 0.2 percent is accepted; the higher estimate of 0.33 would make the non-military, non-industrial research ratio in India as large as that in most of the highly industrialised countries in the world.

Number of qualified R & D staff in India.

27. It is extremely difficult to make international comparisons in respect of the number of qualified R & D staff because of the wide variations in definitions and standards arising from differences in the structure and quality of education in different countries. In India a minimum estimate of the number of qualified persons engaged in non-military R & D who have the master's or a higher degree or a university degree and good research experience, would come to about 15,000 persons in 1962-63. A second estimate would place the number at 27,000. If those persons with a pass B.Sc. degree who are associated with R & D are included, the number may go up to 44,000. The actual number would be something between say 15,000 and 44,000 (a range of nearly three times), depending on the standards of acceptable qualifications adopted for research workers.

28. The number of qualified R & D staff in some of the advanced western countries is as follows: Belgium 12,000; Canada 10,000; Denmark 2400; France 37,000; Germany 40,000; Netherlands 13,000; and Sweden 19,000. These are figures for the whole staff engaged on both military and non-military R & D; the number engaged in non-military R & D would be appreciably less. It is seen that the number of R & D staff in India (whichever estimate is taken) is of the same order as that in France or West Germany and larger than that in many other highly industrialised countries. Only U.S.A., U.S.S.R., U.K., and Japan have appreciably larger R & D staff than India.

29. It is worth mentioning in the present connexion that the stock of scientists and engineers in India with university level education is estimated as 215,000 (of whom 108,000 were scientists, 80,000 engineers and 27,000 agricultural scientists in 1963) which is larger than the stock in most of the advanced countries with the exception of U.S.A., U.S.S.R., U.K., and Japan. If the diploma level personnel are included, the number would be nearly 600,000 which places India, on paper, in a very favourable position.

30. If a comparison is made for the same type of activity, the expenditure which is being incurred in India at present for non-military, non-industrial research and development, or the number of persons engaged in non-military R & D, or the stock of scientists and engineers in India, would compare favourably with the advanced countries of the world with the exception of U.S.A., U.S.S.R., U.K., and Japan. Paper qualifications, however, are not enough. Experience of R & D activities and quality of work are the really important factors. In the U.S.A., out of 214,940 scientists (excluding engineers) whose names were in the National Register in 1962, 24 percent had more than 10 years experience, 20 percent between 5 and 9 years and 18 percent less than 5 years of experience (with 8 percent not reporting).[3] Among persons with a doctorate degree, 62 percent had more than 20 years experience and only 11 percent less than 5 years experience. Corresponding figures are not available for India but it is almost certain that the proportion of younger men with little experience of R & D work would be much larger in India. Rapid expansion of staff in such a situation would result in a good deal of ineffective work. Lack of experienced worker, and not money, would be the real limiting factor in expanding R & D activities in India and other developing countries.

Evaluation of R & D in India

31. Impact on economic growth: Has there been an adequate impact of research and development on economic growth in India? This is the crucial question. There is a view that the impact on economic growth has not been adequate as the results of research do not seem generally to have led to any appreciable improvement of the quality of the products or of any reduction in the cost of production in practice. There are no doubt many complex reasons which call for careful and continuing study.

32. Need of R & D in industry: To have a real impact on economic growth the urgent need in India and in other developing countries is to bring R & D close to production as in the advanced countries. R & D expenditure within industry has an in-built system of evaluation in terms of the cost of R & D in relation to sales, that is, the benefits which may be considered to be accruing from such expenditure. Also, there is an in-built system of feed-back. In firms in which R & D is successfully used to improve the quality of the products or to lower the cost of production there is continuing incentive to plough back a part of the profits to research and development. Benefits accruing from R & D would also promote economic growth which would facilitate making more funds available at the national level for research and development.

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[3] NSF 61-16, pp.8,10

General considerations

33. Sustained economic growth can be achieved only with industrialization, which in its turn would call for the emergence and the continual strengthening of the scientific tradition. The two main objectives of research and development in India and other developing countries must be, firstly, to foster the growth of the scientific tradition through basic research; and secondly, to promote rapid economic growth through industrialization.

34. The transition from an agricultural society to a modern industrial economy is an extended period of crisis in social, economic and political affairs. Scientists and technologists must look upon the period of social transformation as a continuing emergency like war, and help in improving the efficiency of production using all forms of activity, whether they fall within or outside the conceptual framework of research and development in the advanced countries. What I have called the technical services are of great value in increasing productivity. Such activities should not be despised or considered to be below the dignity of qualified scientists and technologists, but must receive proper attention together with research and development during the period of the crisis of industrialization.

35. I would go further. It will be useful in a country like India to copy faithfully such instruments, equipments and hardware which are in urgent demand but which have to be imported from abroad. Qualified scientists and technologists can guide such imitative fabrication, and study ways and means of making improvements in the design or adaptations of the imported hardware for domestic raw materials or local conditions of work.

36. Qualified scientists and technologists have a special responsibility to associate themselves with the design and development of instruments and equipment for scientific and industrial purposes. The highest priority should be given to applied research and development necessary for the manufacture of such scientific instruments and equipment for which the demand is sufficiently large to make domestic manufacture economical, or for which domestic manufacture would be advisable to save the foreign exchange which would be otherwise required for imports.

37. Research and development have at one end, basic research; and at the other end, development; with applied research as a connecting link between the two ends; and technical services as the infra-structure. During the period of the crisis of industrialization greatest attention must be given to the two ends, basic research at one end, and development with production at the other end, and also to the expansion of technical services. In underdeveloped countries it may be advisable to start with technical services and development close to production, to improve productivity with the help of already available technological knowledge, and to take up applied research only when necessary for clearly identified purposes. Applied research may also be taken up from the other end of already available results of basic research but only when necessary to meet clearly identifiable purposes.

38. During the period of the crisis of industrialization, applied research must be purposeful, programmed and formulated on a project basis, for concentrated effort over specified periods of time, in accordance with national priorities for food, defence, export promotion, import substitution and economic growth generally. It is important to guard against thinking of applied research as an end in itself. It is necessary that the results of basic research should be published in the form of papers. There is no such clear need in the case of programmed applied research the objectives would be fully realized even if the results of the applied research remain unpublished but are successfully utilized, through necessary development, in promoting the production of useful things, or in improving the efficiency of production. All projects of applied research must be, therefore, periodically reviewed on considerations of a cost/benefit type. Programmes which are not promising, or are not likely to be completed within a specified time, must be discontinued to enable the R & D staff, who would be released by such termination, to be deployed on other high priority projects.

39. Basic research may be considered to be a good thing in itself which satisfies the intellectual curiosity of the human mind and is also indispensable for the training of research personnel for the future. In the developing countries basic research has a special value of its own for the strengthening of the scientific tradition. In contrast, applied research is only a means to an end and is useful only when it leads to development. Development, in its turn, is also not an end itself but a means to an end, namely, the production of something which is useful or some improvement in the efficiency of production.

40. I have been pressing for a very long time for more funds for science, for R, D & S, in India and in other developing countries generally. We need more funds and more facilities for science. But expenditure, is necessary but not sufficient. We must also think of the reality behind the expenditure, of the research personnel and the research programmes. We must undertake the planning of scientific research essentially in terms of physical programmes and requirements of personnel, equipment and facilities; requirements of funds would then come out as the monetary counterpart. Once attention is focussed on the physical realities, priorities and limiting factors would gradually become clear, such as, shortage of experienced research staff, lack of instruments and equipment, need of bringing applied research and development closer and closer to production, and the expansion of the technical services. We, as scientists and technologists, must also ourselves undertake the responsibility of evaluation of our programmes, and strive continually to utilize available funds and facilities in the most effective way for the fulfilment of the objectives of science and technology.