SCIENTIFIC RESEARCH IN THE MODERN WORLD*

O. M. SOLANDT

THIS lecture is delivered to honour the memory of Samuel N. Robertson. His great accomplishments, both as a classicist and as head of Prince of Wales College for thirty-six years, form an important chapter in the history of education in Canada. I propose in this memorial address to attempt to analyze some of the problems presented by scientific research in the modern world. Although I never had the privilege of knowing Dr. Robertson, I feel sure that there is no need to apologize to his shade for discussing science. I am certain that were he alive today he would be as much concerned with the general problems of science as any scientist and probably able to make a more intelligent contribution towards solving them than most of us.

It is difficult—if not impossible—for anyone to look at his own epoch in perspective. Nonetheless, it is always interesting and often rewarding to try to do so. If we attempt to look at our own times as they will appear to historians of the future, it is reasonably certain that our times will be known as the Dawn of the Nuclear Age. In spite of the rise and fall of a new crop of dictators, the resurgence of Russian imperialism in a particularly ugly form, and the doubtful distinction of two world wars, I am sure that the first half of the twentieth century will be known mainly for its scientific discoveries.

By far the most significant of these discoveries has been the release of the pent-up energy of the nucleus. Through his mastery of nuclear energy man can now produce both hydrogen bombs which can destroy him, and almost unlimited power for the continued development of his industrial civilization. Were the discovery of the means for releasing and controlling nuclear energy merely a chance discovery, our problems would be simpler. But it was not a chance discovery; it was just one of the major discoveries resulting from a vast and almost world-wide stimulation of research which seems to have been brought about mainly by recurrent wars. We must therefore seek to understand and control not only nuclear energy, but also the vast mechanism of research that led to its discovery and that will

*The Samuel N. Robertson Memorial Lecture, given at Prince of Wales College, Charlottetown, P.E.I. March 28, 1957.

rapidly lead to many more important steps toward man's mastery of the physical world.

I do not propose to attempt to look critically at the nature of this vast research effort but only to give you a few figures to remind you of its scale. I shall then go on to describe some of the more dramatic results of research in recent years and to comment on their present and future importance both in peace and in war. Next I shall try to outline my views on the significance of this vast research effort, and finally I shall give some private views concerning desirable courses of action for the future.

This is a most ambitious programme, and I must hasten to add that I do not for a moment believe that my analyses are more penetrating nor my conclusions more correct than yours. However, I do feel that these problems are so important that every intelligent citizen should think about them and try to understand them. Hence I shall be well rewarded if I do no more than make you disagree with me.

A thumbnail sketch of its history in Canada is sufficient to illustrate the explosive expansion of scientific research. During the first twenty years of this century there were very few research workers in Canada. These few were almost entirely in the universities, and they did pure academic research aimed at adding to knowledge rather than attempting to solve any practical problem. During this period most Canadians, and many others, regarded research as a hobby for professors which they pursued because they could not afford to join the local golf club.

During the latter part of World War I, at the urging of the British Government, the National Research Council was formed in Canada, but it grew very slowly between the wars. The discovery of insulin by Banting and Best in 1923 gave tremendous impetus to university research in Canada and attracted the attention of promising young men all over the world, and especially in Canada, to the growing importance of research. Even so, it was not until the Second World War that research in Canada really blossomed. When the war started the National Research Council had a staff of about 80 scientists and a total strength of less than 300. When the war ended this staff had grown to nearly 450 scientists and a total strength of over 2,000. There were some who felt that this wartime growth was artificial and would dwindle rapidly after the war. Events were to prove them wildly wrong. In 1956 the tasks that had been done in 1946 entirely by the National Research Council had been divided among three agencies: the National Research Council itself with a scientific staff of 560 and a total strength of over 2,000;

Atomic Energy of Canada Limited at Chalk River with a scientific staff approaching 400 and a total strength of almost 2,400; and the Defence Research Board with a scientific staff of over 600 and a total strength approaching 3,000. In addition, this decade from 1946 to 1956 saw a much more rapid and substantial growth in industrial research in Canada than had occurred during the whole of the rest of Canadian history.

In 1938 the Dominion Government's expenditure on research was less than $5 million, and this was barely one-tenth of 1% of the gross national product. In 1956 the comparable expenditure was $164 million, which was more than one-half of 1% of the gross national product.

It might be thought that this vast expansion of research is peculiar to Canada during an early stage in the history of its development as a nation. However, a glance at the experience of other countries shows that although Canada's research effort did expand more rapidly than most during the past decade, there was also vast expansion in the older and more mature scientific communities. In the United States, for instance, the total expenditure on government and industrial research rose from barely one billion dollars in 1941 to six billion dollars in 1956.

Even with this spectacular growth of research, Canada still lags behind the United Kingdom, the United States and Russia in its expenditure on research, both in terms of gross national product and expenditure per head of population, so that there is still room for a healthy expansion of our research effort as our resources grow.

This rapid growth of research might be regarded as an unmixed blessing were it not so obviously dependent upon the impetus of war and the need for defence. Even the most cursory examination of the history of research during the last fifty years shows that not only the scale of research but also the main direction of research has been increasingly conditioned by the needs of war. The obvious and spectacular example of this influence is in the field of nuclear energy. Had it not been for the race to apply the newly discovered phenomenon of atomic fission to destructive ends, it is doubtful if the world would even yet have seen the first experimental atomic reactor. Under the spur of self-preservation, Britain, France, the United States and Canada pooled their scientific and engineering resources and compressed the research of many decades into a few years. Each of the countries made important scientific contributions to the task, but the role of the United States was unique. No other nation in the whole of recorded history had ever amassed the scientific and industrial resources required to develop and produce atomic weapons in so short a time while at the same time fighting a major war. Great Britain and possibly Germany might have produced a bomb had they suspended almost all other scientific and most industrial activity. However, since there was some doubt that a bomb could in fact be made, neither of those countries would have dared to gamble so much on the success of such a venture. But the United States had, even in the early years of the war, generated such a vast surplus of scientific and technical resources they they were able to make this huge gamble and to see it pay off.

Following the war, politicians in the United States mistakenly assumed that they had a monopoly of the secrets of how to make an atomic bomb. Later events have shown how seriously they misunderstood the nature of these secrets. The one great secret of the atomic bomb was the fact that it could be made to work. The explosions of Hiroshima and Nagasaki made this known to the whole world, and the British soon demonstrated that, even with the limited resources of their strained post-war economy, they had no difficulty in producing atomic weapons. The world will indeed be fortunate if we do not before long see a demonstration of the fact that very much smaller nations, with far less scientific and engineering talent, can duplicate this feat. The world has also learned that Russia still has great scientists and that its engineering and industrial capacity is rapidly overtaking that of the free nations.

The tremendous research effort that produced the atomic bomb was continued after the war and has led to the perfection of the hydrogen bomb and of techniques that will soon make it possible to deliver a hydrogen bomb within a few minutes to any part of the world. The power of these new hydrogen bombs is measured in terms of megatons of T.N.T. Bombs that will each release energy equivalent to ten million tons of T.N.T. will soon be considered a part of the normal armament of a major nation. The explosion of one of these bombs would damage ordinary houses beyond repair to a radius of eight to ten miles, and if it were detonated close to the ground, the radioactive fallout from its explosion would seriously contaminate an area of several thousand square miles. There is every reason to believe that such weapons exist, or soon will exist, in sufficient number that if all that are available were used in a single all-out war, most of the human race would perish and much of the world would become temporarily uninhabitable.

These are clearly weapons with a destructive power heretofore undreamed of. It is obvious that no nation would think of using them except when in mortal peril, and even madmen such as Hitler would shrink from using them if there was any possibility of retaliation in kind.

There is slight comfort in the thought that it is always possible to try to intercept the carrier before it reaches its target. Unfortunately, the outlook for the near future is not bright. Vast scientific effort on both sides of the Iron Curtain is going into the task of perfecting intercontinental ballistic missiles capable of carrying thermonuclear warheads to any part of the world. These missiles will travel high in the stratosphere at colossal speeds, and will be extremely difficult to intercept. There is every prospect that we will go through a period when the missiles for delivery have been perfected and there is no effective defence against them. Should the Communists get these weapons first and feel that the free world is without an effective defence, they might be tempted to use them in a desperate gamble to gain world domination. It is to avoid this possibility that the free world is devoting so much effort to research in this field.

From the point of view of the professional soldier, sailor or airman, many other modern scientific inventions are of just as great interest and, indeed, many of them may be of greater importance in winning limited wars and police actions to maintain world peace. However, from the point of view of the ordinary citizen, the hydrogen bomb and the intercontinental missile must form the framework for our thinking about the future of our civilization.

Fortunately, the tremendous research effort that has led to atomic and hydrogen bombs has also led to the development of practical power plants using energy from nuclear fission. Such plants are already operating to produce power for industrial use in Britain and Russia and soon will be in action in the United States and Canada. It will undoubtedly be many years before nuclear power is a major source of energy in any country, but the importance of these beginnings should not be underrated. If, to use a biblical phrase, it were possible to view the world as if a thousand years were but a day, it would then appear that the Almighty has decided to give man the secret of nuclear power on the day when his accustomed sources of power are beginning to fail him. The whole of our modern western civilization is dependent on large and increasing supplies of energy for all purposes. The standard of living in any nation or community is closely paralleled by the per capita consumption of power. The best opinion is that we are already approaching the peak rates of utilization of oil and gas, and that the peak for coal will follow not long afterward. Man, therefore, would soon be faced by the necessity of making a radical change in the whole course of his civilization were he not able to use either solar or nuclear energy. Fortunately, the development of nuclear power has already gone far enough that we are reasonably certain that it can ultimately replace coal and oil as the major energy sources of our civilization, and thus ensure the continued expansion of our energy-hungry industry. It is an ironical fact that this very force which makes possible the continued evolution of our civilization also makes possible its sudden and bitter end.

Nuclear physics was not the only field in which the war gave a tremendous impetus to research and to the application of the results of research. Unfortunately there is not time even to list all the fields in which military research is now paying big civilian dividends. However, I cannot resist the temptation to discuss briefly two of the most exciting—radar and electronic computers.

Radar was discovered just before the war. Scientists in several countries had found that it was possible to measure the height of reflecting layers in the upper atmosphere by using short pulses of radio waves. This principle was picked up by Sir Robert Watson Watt and his team in England and developed with amazing rapidity into an effective weapon of war. The basic idea of radar is very simple. It consists merely in sending out short pulses of radio waves which might be likened to golf balls that travel steadily at the speed of light. When they hit a solid object in the sky or, in fact, in certain conditions, on land or sea, they bounce back and can be received at the transmitting site. If the time from throwing the golf ball until its return is carefully measured, this will give the exact range of the object from which it returns. If enough golf balls are thrown, the pattern of their return will give a rough picture of the object from which they are bounding.

Radar has come to be used very widely for tracking aircraft for both civilian and military purposes. With a suitable radar it is possible to keep a continuous watch on the speed, position and direction of flight of any number of aircraft. Similarly, radar is used in ships to detect other ships and to see shorelines and harbor entrances even at night or in dense fog. Many modifications of radar are used as navigation aids for both ships and aircraft. Some of them are so accurate that they can even be used for surveying.

It is difficult to overestimate the importance of radar in future commercial flying. The airways are already so crowded that flying would be extremely dangerous were it not for the use of radar and radio aids to navigation. The experience of the past few years has shown that the existing systems are not adequate for the traffic densities that are even now occurring around major airports. Fortunately, we have only begun to apply the scientific knowledge that is available for the solution of this practical problem. There is every reason to believe that within a few years the major airways of the world will be controlled by complex electronic systems that will achieve a standard of control comparable to a good railway signal system.

Much is heard nowadays of the wonders of the computers and data-processing systems which are being designed for commerce and industry. Not all of those who use these devices realize that they were originally developed mainly for military purposes. There are two kinds of computers, digital and analogue. Digital computers can produce quick and accurate answers to any sort of problem that can be expressed in mathematical terms. They are really rather stupid machines, but because of their tremendous speed, great industry and excellent memories, they can be trained to do many things that are beyond human capacity. Most of the modern ones have only learned to count by twos and so are called binary digital computers. This system has some advantages over the familiar decimal system in which we count by tens. It also simplifies the performance of a computer when called on to act as a quiz kid since it can only answer questions by yes or no. All the amazing achievements of these computers are built up from a vast series of simple yes or no answers.

Analogue computers have more interesting personalities and appear to be more intelligent but are not nearly so accurate. They contain black boxes full of gadgets to simulate graphs relating the variables in the problems which they are asked to solve. By reading from these graphs they can make an approximate solution to a problem very quickly. They are, for instance, very widely used for solving problems arising in the design of guided missiles.

Computers are fascinating devices and can, if properly used, bring to mankind the great boon of relief from clerical labour. They can also solve many problems that are too complex or laborious for manual computation. However, no computer can really think; it can merely carry out a series of logical processes which it has been instructed to perform. This process of giving instructions to a computer is called programming. It is one of the newest and most important branches of science, and involves not only a thorough knowledge of the appropriate mathematics but also a complete understanding of the processes that are to be carried out by the computer and the logic that must be followed in the computation. I do not think that the generation of scientists who were brought up before the age of the computer will ever fully understand or appreciate them or be happy to keep them as laboratory, office, or household pets. Fortunately, there are already signs that the younger mathematicians and physicists are beginning to think like machines and thus can easily transfer their problems to the computer.

The word *computer* suggests that these devices are used merely for making mathematical calculations. However, this is far from the truth. They can be used to make all sorts of complex decisions provided the data is available. Computers have already been made that can calculate the trajectory of a shell or bomb faster than the weapon can travel. Others have been programmed to make complex decisions in air defence, and still others to look after reservations on airlines and trains. I need scarcely mention that the Canadian National Railways, like all other big companies, is already making extensive use of the simpler kinds of computers and is planning to use increasingly complex machines in the evolution of a completely integrated data-processing system. As you probably know, some cynics say that railroads are organizations for the production of statistics, and that some of the more successful roads also manage to produce some transportation as a by-product. If this cynical outlook is justified, the widespread use of computers should enable the railways to continue to produce their statistics and have much more spare effort for producing transportation.

Any mention of computers leads naturally to a discussion of automation. I do not think that there is anything fundamentally new in automation. Ever since the time of the industrial revolution or even earlier, man has sought to hand over his work to machines. However, the colossal acceleration in the pace of scientific discovery that is now upon us is daily producing new means for simplifying men's tasks. It is this great change in the rate of progress rather than any fundamental change in direction that has led to the coining of the term *automation* and to our concern about its social effects.

There is no doubt that a computer can be designed and built to take over and direct almost any repetitive task now performed by a man. The machine cannot think, but it can make very complex decisions provided it is given the facts and the rules on which to base them. I do not think that anyone, whether labour or management, is opposed to the idea of automation. Everyone feels that it is good to relieve man of routine tasks and to increase his productivity so that he can have a higher standard of living and a more interesting and creative job. What does worry many people is the pace to which this mechanization may be accelerated by the results of research. Human nature does not change nearly as fast as do machines, and the orderly introduction of complete automation in any industry will take a considerable time. Competition will probably force the pace in the introduction of automation but, nonetheless, we must seek to plan programmes of automation in order to make allowance for the human problems of re-adjustment even where there is no actual unemployment.

I have discussed briefly some of the benefits that have come to our civilian economy from research on radar and computers that was begun in response to military needs. Because of my interest in transportation, I am tempted to add a section on the effect of military needs on civil aviation. Unfortunately, time is limited and it is a long story. It is sufficient just to say that military aviation is already far in the lead and that the forerunners of the airliners of the future are already flying in military service.

Important as are these direct applications of military research to peacetime problems, the greatest effect of military research on our peacetime economy has been to produce a vast increase in the whole scale of scientific research. Industrial executives have become used to handling the huge research teams and research budgets required for military problems. They have been impressed by the successes achieved by these teams. This has encouraged them to spend increasing amounts of their own money to recruit similar teams of scientists and engineers to tackle their own industrial problems. The striking way in which military research, both in government and industry, has stimulated industrial research for peacetime purposes is nowhere seen more clearly than in Canada. Much of the increase in research effort, which has been so beneficial to Canadian industry since the war, has been directly stimulated by contact with military research and development.

Thus far I have discussed the tremendous upsurge of scientific and engineering research and development that has been one of the most distinctive features of the past generation. Two other outstanding features of the world today are the growing materialism of our western society and the tense idealogical conflict backed by a colossal scientific and technical arms race between the East and the West. One is immediately tempted to wonder whether the upsurge of scientific research and development is the cause or the effect of these phenomena.

While I am not one who believes that the world is going rapidly to the dogs and who yearns for the good old days, nonetheless, I do feel that there has been a decline in the standard of values of the Canadian citizen in the past generation. There is no doubt that we tend to rate success in terms of dollars and progress in terms of television sets and Cadillacs. Here in Prince Edward Island, you have always retained far more of the ancient Scottish respect for education and for real character and culture. You are to be congratulated on this, but I am sure that you have not been immune to the general increase in materialism in our society. I personally cannot believe that scientific research is responsible for this materialism. True scientific research merely gives man new knowledge of his environment, and it is not the fault of the scientist if this knowledge is applied to selfish or destructive ends. However, I would not like to plead that the scientist or the engineer is any better than the next man when it comes to enjoying the materialistic fruits of the application of research. Fortunately, in this field there is some room for optimism, particularly in Canada. There are signs that we are beginning to realize that because of the tremendous natural resources with which the Lord has endowed Canada, life can be too easy and that we are in real danger of losing our souls, both as individuals and as a nation.

It is not so easy to refute the suggestion that scientific research has done much to contribute towards the arms race and the horrors of the hydrogen bomb. There is no doubt that scientists could have refused to work on atomic and thermonuclear bombs, and in fact a good many of them did. However, the average scientist feels himself to be an ordinary patriotic citizen of his country and seeks to contribute his special skills to the defence of the country in time of peril, just as if he were a fighter pilot or a front-line infantryman. Most scientists do not feel—and I agree with them—that they should attempt to veto the decisions of the society in which they live. It is far more appropriate that they should try to influence these attitudes and decisions by more effective participation in the social and political lives of their community. I shall return later to this theme.

I am confident that the principal cause of the present turmoil in the world is not the rapid pace of scientific research and discovery, but rather the failure of man's social organization to keep pace with the new mastery of his environment that research has made possible. A cursory glance at the world today shows that neither the individual man nor his social and political organizations have evolved nearly fast enough to cope with the new problems of our mechanized civilization. The individual is overwhelmed by the vast mass of information that is poured over him by newspapers, radio and television, and he is confused by his ability to be on one continent for breakfast, another for lunch, and a third for dinner. Similarly, the national and international organizations of the world are not yet sufficiently effective to grapple with the threat of the vastly increased destructive power of atomic and thermonuclear bombs and intercontinental guided missiles. In this field also, I am not entirely pessimistic because, although progress has been slow, there has been real progress. Though the United Nations has been far from perfect, it has been more successful than any of its predecessors. Similarly, the North Atlantic Treaty Organization has been one of the most successful of military and political alliances. There is possibly even more hope in some of the less obvious and spectacular accomplishments in world organization. A heartening example is the work of ICAO, the International Civil Aviation Organization. Largely because of its efforts the technical integration of world airways is excellent, and it is possible to travel by air to almost any country in the world—very often without change of plane.

It is all very well to say that the cause of our present difficulties is that social organization has failed to keep pace with scientific development. Most people would agree that this is obviously true; however, it is not so obvious what we can do about it. Firstly, I think we should dismiss the idea of trying to stop the advance of science. All human history suggests that it is folly to try to stop the evolution of such a dynamic force as modern scientific research. However, we can probably do something to guide science into more productive fields, and we can certainly do a good deal to accelerate the evolution and perfection of our social organization. Here the fundamental problem is the production of wise, competent and aggressive leaders who will give effective guidance at every level from world organizations down to the smallest community. One of the first things to be done in this direction is to try to regain the respect for education and for qualities of the mind and of the spirit that led to the development of men like Samuel Robertson. If we can evolve a society in which a man is more respected because he is a wise and patient teacher than because he can afford two Cadillacs, we will have gone a long way toward solving our problems of social organization. I might possibly add in parenthesis that in this utopia the community will value the services of the teacher so highly that he will be able to own at least one Cadillac, although he will no doubt still have to wash it himself.

In the field of education I am something of a reactionary. I strongly favour working young children hard in their early days at school. I think that they enjoy learning and do not feel that it is an imposition, provided everyone is in the same boat. If they are well taught and work hard they can get a thorough grounding in the 3 R's in their early youth and have much more time later for broadening their education. Early specialization should be avoided as far as possible and a reasonable basic knowledge of science should be included in everyone's early training. Students in secondary schools and universities would then have far more time for developing the qualities of leadership and for learning the techniques of living together amicably because they would not be so harried by the need for belatedly cramming their minds with informatiou.

Much has been said and written recently of the shortage of scientists and engineers. There is no doubt that the evolution of Canada may be slowed down unless we can produce more engineers and scientists, and that the possibility of a third world war may be increased if the free world ever lags seriously behind the Russians in military research and development. However, the mere production of more scientists and engineers for these two purposes is of little importance compared to the need for the evolution of leaders. In the past, many of our great leaders have been trained in history or the classics. In the present state of the world the kind of men who took history or the classics and went on to be world leaders—people such as Lester Pearson who has done such a magnificent job as Canada's Secretary of State for External Affairs—might, if they were starting over again now, be attracted by the glamour of science and engineering. If this supposition is correct, it then follows that we should look in the future to the ranks of scientists and engineers for more of our political and social leaders. But in addition, we must not allow our concentration on science and engineering to starve out the study of the social sciences, history, the classics and the arts in our colleges and universities. We must seek to produce new leaders with diverse backgrounds, but in seeking new avenues to wisdom we must not abandon the old and well-tried ones.

Compared with the rest of the world, Canada has done well, both in her contribution to science and engineering and in her production of leaders, but we have no reason to be complacent about our accomplishments. Canada is a very favoured nation. Providence has given us far more than our share of natural resources. We have inherited the traditions of two of the greatest European cultures. The British parliamentary system of government, as it has evolved in Canada, still seems to be as satisfactory a pattern of national organization as man has yet devised. Instead of the regional enmities of the older parts of the world, we have on our borders a powerful friend and understanding neighbour. I am sure that many nations look at Canada as a proving ground for man's aspirations. They feel that if man cannot contrive to live happily and productively in Canada, then there is no hope for the race. We therefore must strive to continue to supply leaders, not only to perfect our own way of life, but to help to lead the world toward better social and political organization.

Even a few years ago that sentence would have ended such an address. Now it is essential to add a final note of warning. We can no longer be satisfied with the slow evolution of human society. We must urgently seek means of speeding up the process, because the existence of the hydrogen bomb and the systems for delivering it means that our very civilization is in danger of extinction. Should a third world war occur, the human race may well survive but social evolution could be set back by hundreds of years. Therefore, while maintaining our military strength as a deterrent to war, we must do everything possible to hasten the improvement of social organization so that war will no longer be thought of as an instrument of national policy.