ATOMIC ENERGY AS A HUMAN ASSET*

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THE ability to release atomic energy gives mankind great new powers. These powers can be used for good or ill. The first use of atomic energy was as a bomb the explosion of which stopped short a tragic war with the probable net saving of some millions of lives. Its terrific military destructiveness has made it necessary for us to consider afresh how we may avoid future wars. The dramatic demonstration of its explosive power has directed attention away from the significance of atomic energy to our industry, our habits of life and our culture. It is in such peace-time consequences that atomic energy will eventually mean most to man.

The atomic age has started as a period of keenest rivalry ; a rivalry between nations and social systems. The prize to be won is prosperity and world leadership. It can include peace and security. If only we agree to place war beyond the power of nations, the race is sure to make life of greater value. Such is the prospect of a world strengthened by unlimited power from atomic fission and forced away from war by the examples of Hiroshima and Nagasaki.

The human consequences of the release of atomic energy can be considered in three major directions : first, its effect on war and the world's political structure ; second, its application to the practical tasks of peace ; third, its effect in changing the form of our social life and customs.

How Shall We Prevent Another War ?

World government has become inevitable. The choice before us is whether this government will be agreed upon or whether we shall elect to fight a catastrophic third world war to determine who shall be master. Unity by agreement will bring greater life. Unity forced by another war will bring death to many millions and disaster to all mankind.

With regard to its economic and cultural life, the world has during the past century been developing into a unit in which the welfare of each person depends intimately upon that of the rest of humanity. Such development has not, however, resulted in political world unity. Now for self-preservation the great destructiveness of an atomic war, even to the victor, makes it necessary to ensure peace. In a quarrelsome world the only means of ensuring peace is to set up a world government which monopolizes the power to wage war. Thus it is that the new military developments culminating in the atomic bomb make inevitable a world government.

Now for the first time also it becomes feasible for a central authority to enforce peace throughout the world. Before the Second World War, many parts of the earth were difficult of access by a world police. To-day this is changed. Fast aeroplanes, long-range rockets and atomic bombs have now solved the technical problem of bringing to bear on any area at any time whatever destructive force may be required to quell resistance. A central authority having virtual monopoly of these major means of warfare can now be equipped to enforce international peace.

The fact is that the United States now has in its possession a sufficient monopoly of the weapons needed for such policing that it might be able to act in this capacity of world police. That Americans do not set themselves up as the world governors is simply because they do not want the job. They feel that world control is the world's business, not theirs alone. They know that if they used armed force to prevent other nations from fighting when American interests were not directly threatened they would be considered meddlers, and would gain only the fear and hate of other nations. America would prefer to withhold her fighting power unless her own safety is directly threatened, and confine her policing activity to her own reasonable share in keeping order within nations which are not now able to look after their own interests or which may become dangerous if not kept under control.

What is needed is an agreement which will make the safety of America much surer than could result from her own armed might, and which will at the same time provide for elimination of international wars elsewhere throughout the world. It is such an agreement that should be sought, sincerely, with determination, and with faith that it can be attained with reasonable promptness.

Other nations will not be prepared to challenge America with atomic weapons for the next five years. After twenty-five years, unless some mutual agreement prevents their development, such countries as Britain, the U.S.S.R. and France can arm themselves with weapons similar to those of the United States if they want to spend the necessary effort. The time required will not be greatly affected by whether America holds to her own secrets or not. It is in any event only a small part of the life-time of any nation that will elapse before the world may be faced with the awful possibility of an atomic war.

Now is the time when international agreements can best be made to prevent such a catastrophe. Other nations have not yet developed a pride in their atomic might which could give them dreams of world mastery. America's own effort has paid for itself many times over by stopping the course of the Second World War. All nations are now laying plans for the post-war years, and it will be much easier to shape these plans on the basis of world government than to stop the wild development of a renegade nation by imposing emergency military controls after it is set in its course.

It may be worth reviewing just what we mean when we refer to the great destructiveness of war in the age of atoms. For the first time in history it became impossible during the Second World War to protect one's home by holding the enemy beyond a wall or a fighting line. This change was brought about by armadas of aeroplanes guided by radar, jet-propelled aeroplanes travelling at almost the speed of sound, and long-range rocket bombs. What the atomic bomb added was merely a more efficient means of destroying a target. One aeroplane could now do the work that had required a thousand.

It must be remembered, on the other hand, that the atomic bomb is in its infancy. If the future demands it, science sees no reason to doubt that atomic weapons can be made that are related to the present atomic bomb much as the 'block buster' is to the blunderbus. Yet even the present atomic bomb is a highly effective weapon. If one bomb will devastate four square miles and damage a hundred square miles, how many bombs are needed to destroy the whole of a nation's concentrations of fighting and industrial facilities above ground ? That is a question for the military

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authorities to answer. It has been demonstrated that whatever bombs are required can be produced and delivered to their targets.

Let us try to imagine what may be expected to happen if a war between two major powers should break out in 1970. We may assume that by this time both sides will have such weapons in whatever amount they consider necessary, and of greater destructiveness and variety than those now possessed by the United States. Because of the enormous advantage of surprise, Pearl Harbour tactics will be employed. Jet-propelled aeroplanes or rockets with atomic warheads will be sent without warning at each of several hundred of the enemy's major production centres. No city of more than a hundred thousand population will remain as an effective operating centre after the first hour of the war. At least ten per cent of the attacked nation's population will be wiped out in the initial blow. If this nation elects to fight back, rockets and aeroplanes from hidden installations will carry the reply. The attacker in this case can expect no mercy. Though his citizens may have immediately moved underground, his great cities as well as his surface production plants will be annihilated. The fighting will continue until one side chooses to surrender or is unable to resist its opponent's army of occupation.

No feasible means of preventing the bombs from striking their targets has yet appeared on the horizon. Only two countermeasures have so far been proposed. The first is to disperse cities, preferably into hilly regions, so that more bombs will be required to destroy them. The second is to place all military installations and essential industries underground, and provide emergency underground shelters for all the population. Clearly such measures will seriously interfere with the normal life of the community.

Is there then any procedure which can free us from the threat of annihilation ? I believe there is. It makes, however, the hard demands of sacrifice of national sovereignty and of faith in other peoples that will give them a share in the responsibility for our own security.

Let us suppose that the United States, the U.S.S.R. and Britain agree to transfer their own total power to wage international war to a joint Military Commission. It will be better to include France and China as the other permanent members of the Security Council, so that the Military Commission can function within the framework of the United Nations Organisation. This Commission will have placed under its orders the united armies, navies and war weapons of the member nations. Its charter will give the Military Commission the responsibility for stopping any armed conflict between nations that may arise, including wars in which the member nations are themselves participants. This responsibility can be carried out since the major nations will have contributed to the Commission all their own fighting strength except that needed for their internal policing. To be effective it seems obvious that the actions of the Military Commission cannot be subject to the veto power of any single nation, but must be controlled by the joint action of some such group as the Security Council. For concreteness we may suggest further that this Commission have its seat in Canada, with its headquarters at either Ottawa or Vancouver. Canada will accordingly be the home-ground of the combined armies, the home waters of the combined navies, and in its vast territories will be dispersed the atomic weapons of the member nations ready for use in case of emergency.

As thus envisaged, the military strength of the Commission would be great enough to make hopeless the effort of any individual nation or group of nations to challenge its power. At first, all the strength in atomic weapons would be contributed by the United States. The other member nations would, however, contribute armies and aeroplanes and guns according to their proportionate share.

When the agreement is made to the satisfaction of the member nations, the details of producing atomic weapons would be passed on to the Commission which these nations entrust with their united military power. From then on there would be no reason why atomic bombs should be made by any other group, in the United States or in any other country. Nor is there any reason why, until such an agreement is reached, the technical secrets of atomic weapons should be released from the countries that now have them.

In the exploitation of the peace-time uses of atomic energy, each nation will need to give suitable assurance to the others that its own control of its atomic industry is such as to prevent the malevolent development of weapons by any group within its borders. It is essential that such assurance include provision for the inspection to any extent that may be necessary by representatives of the international Commission.

If the nations follow such a procedure with courage and determination, it would seem possible to ensure the banishment of international wars. It will then be possible to develop with assurance the peaceful fruits of atomic energy.

Two alternatives have been suggested to this idea of an armed international Commission. One is atomic disarmament. The other is maintaining American strength on a conclusively higher level than can be attained by any combination of other nations.

I am convinced that atomic disarmament would be a fatal mistake. An agreement to stop producing atomic bombs would only make it possible for some ambitious nation to develop them with the hope of gaining the mastery of the world, and the destruction of other nations would be the result.

For a number of years I believe the United States could as a nation maintain military strength greater than any group that might oppose her. Such a policy would, however, tend to unite the world against America, which would in the long run be disastrous. It is, furthermore, doubtful whether over some peaceful decades the United States would continue support of armed forces adequate to maintain a high level of superiority. She would then become vulnerable to the nation with the long-harboured grudge or the newly developed commercial rivalry. Even should she win, the next war would be disastrous.

The answer is rather to outlaw war itself. This can be done by a strong world 'police' which has at its disposal more powerful weapons than any recalcitrant nation can hope to acquire.

There is thus real hope that another atomic bomb may never be used in war, and thanks in part to atomic weapons that international war itself may already be obsolete.

Peacetime Implications of the Release of Atomic Energy

Enough regarding the destructive uses of atomic energy. Of much more interest is its use as man's willing servant. In the long run it can scarcely be questioned that the peaceful applications of atomic energy will be those that will most profoundly affect our lives. What these important applications will be is, however, as difficult to predict as it would have been a century ago, just after Faraday laid the scientific basis for electrical engineering, to tell the future meaning of electricity. At this moment the obviously great field open to atomic energy is that of production of useful heat and power. We also see important though limited medical and industrial applications of radioactive materials, artificially produced by atomic chain-reactions. Perhaps more significant than either are the new vistas that will be opened up by scientific experiments that make use of the by-products of atomic fission.

This has indeed been the case with such discoveries as X-rays. Fifty years ago it was evident that X-rays were useful for 'seeing' through objects, such as the human body, which are opaque to ordinary light. It could not be predicted that X-rays would become a powerful weapon in the fight against cancer, or that researches made possible by X-rays would reveal the electron and with it give us the radio and a host of electronic devices.

Such unforeseen developments are the result of every great discovery of science. It will nevertheless be worth noting some of the definite practical applications of atomic energy that we can now see clearly before us.

At present, controlled atomic power in the form of heat is in continuous production in large quantities at several plants, especially those at Oak Ridge, Tennessee, and at Hanford, Washington. The heat from these plants is a by-product, and is carried away in one case by air and in the other by a stream of water. The useful product is neutrons, which are used in the plants as a means of transmuting certain chemical elements to others of specially useful characteristics. Of these transmutation processes the most important one is that of uranium into plutonium. Previous to the fission chain-reaction, the most abundant source of neutrons was the cyclotron, which operates on electric power. Per kilowatt of energy used, the fission chain-reaction gives some ten thousand times as many neutrons as a cyclotron, and it is not difficult to make a fission chain-reaction plant that delivers a hundred times as much power as is used by a cyclotron. This means that even now we are using large amounts of atomic power many times more efficiently for the particular process of producing neutrons than the best electrical machine that we have been able to devise.

Looking to the future, we may expect the use of neutrons as a means of producing new elements by transmutation to become of increasing importance. Plutonium is a concentrated source of available energy, and will be a valuable material for peaceful purposes as well as for building weapons.

Other artificially produced elements, especially radioactive ones, will also find use in medicine, in industry, and in many branches of science. It is yet too early to see clearly how important these uses may become.

We have not yet built an atomic power plant that is generating electrical power. This is merely because we have been engaged in winning a war, and there has been no serious shortage of electric power. If there were sufficient demand for a demonstration, a reasonably efficient plant using super-heated steam for driving a turbine could be put into operation within a year. Before, however, such plants can be made economical competitors with existing practice, a number of years development will be required.

While there are several other possibilities, the most obvious method of producing power from atomic fission is to heat a cooling agent such as air or steam or liquid metal in the chain-reactor unit, and pass this heated coolant through a heat exchanger which heats the steam for driving a turbine. Beyond the heat exchanger of such a plant everything would be done according to standard practice. Up to the heat exchanger all the design requires new features, among them protection against the extreme radioactivity of everything, including the coolant, that has been exposed to the neutrons.

The chain-reacting unit itself can assume many forms. The one essential is that it shall contain a fissionable substance such as uranium, either in its natural state, or if a small unit is desired, enriched with additional U^{235} or plutonium. H. D. Smyth, in his official report, has described in some detail how this active material can be combined with a moderator such as carbon or beryllium or heavy water so as to bring about the chain-reaction.

The large atomic-power plants now used for producing plutonium have in them many tons of natural uranium and graphite. By using uranium containing more than the usual fraction of U^{235}, chain-reacting units have been built that are of much smaller size.

There is, however, a lower limit to the size and weight of an atomic power plant that is imposed by the massive shield needed to prevent the neutrons and other dangerous radiations from getting out. Next to cosmic rays, these radiations are the most penetrating that we know, and for a plant designed to deliver, for example, no more than a hundred horse-power, are enormously more intense than the rays from a large supply of radium or an X-ray tube. To stop them, a shield equivalent in weight to at least 2–3 ft. of solid steel is needed. There are basic laws of physics that make it appear very unlikely that a lighter shield can be devised. This means that there is no reason for hoping that atomic power units for normal uses can be built that will weigh less than perhaps fifty tons. Driving motor-cars or aeroplanes of ordinary size by atomic power must thus be counted out.

Prominent among the advantages of atomic power are the extraordinarily low rate of fuel consumption and consequent low cost of fuel, the wide flexibility and easy control of the rate at which power is developed; and the complete absence at the power plant of smoke or noxious fumes. With regard to fuel consumption, when completely consumed, the fission energy available from a pound of uranium is equivalent to burning more than a thousand tons of coal. With the pre-war price of uranium oxide at roughly 3.00 dollars per pound and of coal at 3.00 dollars per ton, this would mean the economical use of uranium as fuel if only one part in a thousand of its available energy is used. Actually, we should expect the first plants built for producing atomic power to be considerably more efficient than this in their use of the fission energy, which would mean a substantial cost advantage in favour of uranium. One must consider also, however, the need to purify and fabricate the uranium into the desired form. For certain types of power plants under consideration, some separated U^{235} is required, and this is expensive. Attempting to consider all such factors, it appears that the fuel cost of the atomic power plant of the future will nevertheless be small as compared with the corresponding fuel cost of a coal-burning plant.

In considering the economic aspects, there are, however, many other factors. It is not really possible for these to be explored until we have actual experience with atomic power plants. First is the capital cost. Clearly if one must charge against the capital cost what is spent in research and development, this cost is very high indeed. If, however, one looks down the line to a thousand million dollars a year national industry based on atomic power, the nation can afford a considerable investment in the research and development required to bring this industry into being. When this development is completed, it appears not unlikely that the cost of building and maintaining a large-scale atomic power plant may compare favourably with that of a coal-consuming plant of the same capacity.

Much remains to be learned, however, regarding the metallurgical and other technical problems involved in constructing a successful plant to transform fission energy efficiently into high-temperature heat. The materials to be used may be expensive. The designs are, nevertheless, essentially simple. An inherent advantage of the atomic power unit is that the heat sources, that is, the uranium blocks, can readily be maintained at any desired temperature regardless of how rapidly the heat is being removed. This means that a relatively small-size heater unit will be needed, and that corrosion due to excessive heating is controllable.

The terrific blasts produced by the atomic bombs have led to unwarranted fear of accidental explosions resulting from the normal use of atomic power. Explosions such as destroyed Hiroshima cannot occur accidentally. Such explosions must be carefully planned. The dangers of explosions of the 'boiler' type with an atomic power plant are about the same as with a steam plant, which is to say they are practically negligible if the plants are designed and handled by competent engineers.

There is, nevertheless, real possibility of damage to health of the operating personnel from rays emitted by the plant itself and by all materials that are taken out of the plant. These materials could also become a public hazard. This is the problem of the health of radium and X-ray workers on a grand scale. That the problem can be solved is shown by the fact that in all the operations of the existing half-dozen or more such plants, some of which have now been working for years, not a single serious exposure has occurred. This, however, is due to the thorough inspection and vigilant care given by the health staff headed by Dr. Robert Stone. In some of the experimental work we have not been so fortunate. Until we become much more familiar with nucleonics than we are at present, atomic power plants can be safely operated and serviced only with the help of health supervisors who are familiar with radiological hazards.

All this points toward using atomic power first in relatively large units where careful engineering and health supervision can be given. An obvious suggestion is its application to the power and heat supply of cities and of large industrial plants. Within ten years it is not unlikely that the power companies designing new plants for city service will be considering favourably the use of uranium instead of coal for purely economic reasons.

This, of course, does not mean that atomic power will put coal out of business. Each will have its own field. For small heating units, such as the kitchen stove, atomic power has no place. If our national economy grows as it should, coal as a chemical agent, as for example in blast furnaces and preparation of organic chemicals, will increase in importance.

From the point of view of the national economy the introduction of such a new source of power is a clear gain. If it will lessen the cost of heat and power to our cities, it will be a stimulus to every industry. If it reduces the pall of winter smoke, it will be a boon to all. If it gives cheap power where industry and agriculture need it but cannot now get it, it will extend the economic frontiers of any country. These are possibilities that lie immediately before us.

Atomic Energy and our Way of Life

Atomic energy is just one more step along the path of technological progress. It may, however, be the supreme gift of physical science to the modern age. Clearly its value will be determined by the use to which it is put. It is especially worthy of note that, along with other technical advances, the effect of atomic power is to force human society into new patterns. This need for human growth to meet the responsibility of atomic power is the basis of Norman Cousins' striking statement that "modern man is obsolete".

Let me note briefly three such effects of technology on society that can be clearly recognized. These are, first, toward greater *co-operation*, secondly, toward more *training and education*, and thirdly, toward evaluating one's life in terms of *service* rendered to the community. First, the society that is adapted for survival in the modern world is one in which an increasing degree of *co-operation* occurs between diverse groups spread over ever larger areas. As an example, consider the atomic bomb project, in which about a million people of all types and descriptions worked together to gain a needed result that could be achieved only by a great co-ordinated community.

In no field is the growing importance of such co-operation more evident than in that of scientific research. Faraday, a century ago, was one of the first professional scientists. Working by himself, he covered the whole field of electricity and much more besides. Sixty years ago, Thomas Edison organized what was perhaps the first research team to work with him at Menlo Park. Now America has thousands of research laboratories. From 1900 until 1940 her universities developed organized research groups for studying specific problems. Astronomers built specialized observatories. Research centres grew for studying diseases. Teams of physicists built cyclotrons and surveyed cosmic rays over the world. When the War came, co-operative research became of greatly increased size and effectiveness.

The development of the methods for producing plutonium is typical. At the peak there were engaged on this one problem roughly five thousand laboratory workers in seventy odd locations studying different aspects of this single problem. Not only theoretical physicists and nuclear chemists were needed; but equally vital were corrosion experts and metallurgists and hæmatologists and meteorologists, laboratory technicians, mechanics and office workers. No one person could be skilled in every field or understand even the meaning of the answers to the many problems. But somehow the group-mind integrates such knowledge into the useful form that results in a process that successfully produces plutonium.

There remains, happily, a valuable place for the individual research man who masters and advances his own limited field of study. His specialty, however, is of little value except as a part of a broader field. More and more we find that even in a limited field a team of men with different specialties working together does the most effective work. New thoughts develop in their discussions. More refined techniques are available. A team which thus supplies a combination of originality and special skills is the pattern toward which research is moving.

Co-operation is the very life-blood of a society based on science and technology. Such a society is necessarily made up of specialists, not only men of science and engineers, but also skilled labourers, salesmen, administrators, educators, and legislators. Working alone, such specialists are useless. When their work is co-ordinated they form a society of enormous strength. What the society of an atomic age cannot permit is the development of antagonisms between these groups that will prevent effective co-operation. To love our neighbours is becoming the condition of survival; and our neighbours with whom we work are to be found in all divisions of society throughout the entire world.

As the second evident effect of technology on society, consider the need for ever-increasing training and education. It is no disparagement of engineers to point out that most of the new war-time developments that have led to Allied victory, such as radar, submarine detection, rockets, and the atomic bomb, have had to be led by men whose scientific knowledge is far in advance of that supplied by our technical schools and industries in the training of engineers. To compete in the modern world, more people need more training. Nor is technical training all that is required. Of greater importance is more education for leadership. In a democratic society that is forced into a position of world prominence, citizens as well as their leaders need to understand the problems and human needs of all the nations.

This pressure for more training and education applies at all levels. Automatic machinery performs an increasing number of routine jobs. The demand for skilled mechanics to make the machines is thus increasing while that for unskilled labour falls off. The growing complexity of society multiplies rapidly the demand for all kinds of persons trained to keep the work co-ordinated. These range from typists to administrators. Of those whose overall view of the needs of society is adequate to guide wisely an industry or the growth of a community there is an acute shortage.

The result is more students wanting more extensive education in schools and colleges. Professional schools are becoming graduate schools. More research men will need to carry their studies beyond the thesis for the doctorate. The interruption of college education during the War places a nation at a temporary disadvantage with regard to highly trained young men and women, and is for the moment keeping down the enrolment in advanced classes. All indications are, however, that the post-war pressure on the institutions of higher learning will increase and continue. There is growing interest likewise in all aspects of adult education as people strive to keep themselves abreast of the rapid changes of the times.

The third, and perhaps the most remarkable, trend is an increasing concern that one's activities shall *contribute to the welfare of society*. It is more difficult to establish this trend by citing examples than it is to show the increase of co-operation and of education. But it is, I believe, no less real. The ancient high regard for the 'holy man' who retired to a monastery and separated himself from society finds little sympathy in modern life. Reading of American colonial history shows that the freedom for which our forbears fought was primarily the right to live their own lives in the pursuit of happiness without unnecessary restrictions, not primarily the opportunity to shape a better society. Now both capital and labour strive to justify their position in terms of the usefulness of their contribution to society, and the United States have fought a war with unparalleled unanimity because loyalty to the common cause made her citizens ready for any sacrifice.

There have not been in the United States prominent movements similar to that in Germany, where the youth was whipped to patriotic ardour by the call to lose one's self in the greater good of the State. Nor has any 'cause' in America perhaps met with the wide response the Russians have given to communism as a political system, in which each person consciously works for the good of all. Yet Americans respond to many calls to service. As members of scientific societies we are aware of our own increasing attention during the past generation to the social responsibilities of science and scientists. The present active concern of men of science about the political disposition of the atomic energy problem is apparently only a representative example of the anxiety of every American that, with the great issues with which humanity is faced, his own actions may help rather than hinder a good solution. The greater powers placed in our hands by technology seem indeed to make us more acutely aware of our responsibility to use these powers for human ends that go beyond ourselves. Typical of the forces working in this direction is the recognized need that the democratic form of society must attain its fullest strength if it is to survive in the fierce competition of the post-war world.

The evolutionary law of the survival of the fittest applies to societies as well as to individuals. According to this law, the society of the future will inevitably advance along these lines of co-operativeness, of education, and of individual concern with service toward the common welfare. If selfish interests or an ill-adapted form of government should prevent the growth of one nation along these lines, some other nation or group that can develop thus more rapidly will pass it by.

These factors which give strength to society are precisely those that characterize the highest type of citizen. *Co-operation:* he likes to work with others on a common task. *Education:* he has learned to do his own useful task and to share intelligently in solving public problems. *Service:* the central objective of his life is to contribute to the common welfare the maximum that his abilities make possible. These also are the factors which make life of greatest value to the individual himself.

My point is that the release of atomic energy is merely the most recent important step of that steady progression of science that is compelling man to become human. He must pay careful attention to co-operation, education and service for the welfare of society if he is to thrive under the conditions that science imposes. If we will let ourselves grow as thus indicated, the civilization of the atomic age promises to be the richest that history has known, not only with regard to material bounty but also in its cultivation and appreciation of the truest human values.

How then are we justified in describing atomic energy as a human asset? First, atomic energy now supplies for the first time weapons which make it possible for a centralized world government to prevent wars between nations. Having made war intolerable because of its enormous destructive power, it thus opens the way for an international organisation to prevent war from ever occurring again.

Secondly, atomic energy is now a source of useful new materials produced by transmutation. It promises to supply us with heat and power, available in large quantities wherever needed, and thus to open new economic frontiers. New advances in medicine, in industry and in science are on the horizon.

Thirdly, as the most recent great step in the long progression of advances in science and technology, the advent of atomic energy is forcing mankind along the difficult road to greater humanity. Growing co-operation, education and spirit of service are evident trends.

In the fierce competition between social systems in the atomic age, the need for strength demands that we enable every citizen to contribute to the common welfare as his abilities may permit. Permanent peace can now be secured if we will work for it. Increased prosperity, with broader horizons, lies before us. Greater development of the human spirit is the inevitable consequence of the increased responsibility for using our new powers. These are among the greatest of human goods.

RADAR FOR CIVIL AVIATION

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THE story of the development of radar during the War is now well known—how it started as a defensive measure to give warning of the approach of enemy aircraft to the coasts of Britain, and grew finally to take an important offensive role in almost every form of warfare. An outline of the history of this remarkable development has been given in *Nature* by Sir Robert Watson-Watt*. One of the fields in which radar technique has made very large contributions is that of air navigation. In war-time, aircraft must fly in all kinds of weather, by day and by night, and the development of radio aids to replace those visual aids available in clear weather was of paramount importance. In peace-time it is just as important that aircraft should be able to fly with safety in all kinds of weather if aviation is to give regular and reliable passenger and freight service. It is still true, however, that the weather is the main limitation on flying, and although much has been accomplished, much remains to be done.

Advances made in war should become available at once for use in peace. It is therefore to be expected that radar should quickly begin to contribute towards safe and reliable civil aviation. That the immediate application of radar to civil flying has been slower than some would have hoped has been largely due to essential differences between civil and military flying. In order to understand the application of radar to the former, we must examine the most important of these differences. The most obvious difference is that of 'pay-load'. One may be prepared to spend a lot more to deliver a load of bombs on a vital objective than to deliver a load of passengers or freight. Again, one will be prepared to sacrifice a considerable portion of bomb-load for radio equipment if this will ensure that the remainder of the load falls on the target. In civil flying, however, weight and bulk of radio equipment must be kept to a minimum, otherwise flying will become uneconomic. Military aircraft must be able to navigate at will over most of the country at home and over enemy territory, expecting not co-operation but hostility over the latter. Civil aircraft are expected to keep rigidly to well-defined routes along which they can expect active co-operation from the ground most of the way.

It is not surprising then that much military equipment is not suitable for civil aviation. The fundamental scientific and technical principles learned during the War are, however, applicable, but some time must elapse before they can be used to create equipment specially designed for civil aviation. Nevertheless, there are several radar equipments in the navigational field which are immediately applicable to civil aviation and, if not now in ideal form, can at least be employed until more suitable versions are developed.

* *Nature*, 156, 319 (Sept. 15, 1945).

Advantages of Radar

It must not be supposed that only radar technique can provide answers to the problems of radio navigation. Indeed, in many cases ordinary continuous-wave (C.W.) techniques will provide a simpler solution than radar. Radar has, however, two outstanding characteristics which may enable it to succeed where continuous-wave technique would fail. The first is its ability to measure distance simply and accurately; and when this is required, radar has no serious competitor. The second arises through the fact that if short pulses are used, reflexions from the ionosphere and local objects near the transmitter may be separated from the direct pulses and so may be ignored. With continuous-wave systems, such reflexions frequently destroy the accuracy of the information obtainable from the system. Thus we shall see that for precise long-range navigation, radar techniques alone are likely to provide a satisfactory answer.

Radar Beacons

Very soon after radar had been developed for use in aircraft, mainly to detect ships (ASV) and hostile aircraft (AI), it was realized that by the use of repeaters to send back an amplified and coded form of the pulses received from the radar, an excellent navigational aid would be obtained. The radar set measures the range of the repeater, or 'responder beacon' as such devices are called, and by means of directional aerials enables the aircraft to home to it. This type of radar is known as secondary radar, primary radar being dependent on energy reflected from the target. When two beacons are within range, the aircraft may find its position by means of range cuts.

So successful was this form of navigation that it was desired to use it for aircraft which would not carry search radar. This is quite possible because the high-power transmitter of the search radar is unnecessary for navigation by responder beacons, since the 'echo' received is the retransmitted pulse from the responder and not the weak reflexion as from an aircraft or ship. Thus the radar beacon system of navigation was developed in its own right in the form known as *Rebecca-Eureka*. It became the basic radio aid for dropping paratroops, and its vital role on D-day has been told elsewhere. Thereafter a wide experience of the use of the system grew up in Transport Command and, as a result, its immediate application to civil aviation is possible.

One of the outstanding requirements for civil aviation is the measurement of distance along an air-route. The radar beacon system supplies this at once. In addition, homing to an airfield is simple and