For the kind of explosiveness that man will be able to contrive by 1980, the globe is dangerously small, its political units dangerously unstable.

CAN WE SURVIVE TECHNOLOGY?

by John von Neumann
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"The great globe itself" is in a rapidly maturing crisis —a crisis attributable to the fact that the environment in which technological progress must occur has become both undersized and underorganized. To define the crisis with any accuracy, and to explore possibilities of dealing with it, we must not only look at relevant facts, but also engage in some speculation. The process will illuminate some potential technological developments of the next quarter-century.

In the first half of this century the accelerating industrial revolution encountered an absolute limitation—not on technological progress as such but on an essential safety factor. This safety factor, which had permitted the industrial revolution to roll on from the mid-eighteenth to the early twentieth century, was essentially a matter of geographical and political *Lebensraum:* an ever broader geographical scope for technological activi-

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ties, combined with an ever broader political integration of the world. Within this expanding framework it was possible to accommodate the major tensions created by technological progress.

Now this safety mechanism is being sharply inhibited; literally and figuratively, we are running out of room. At long last, we begin to feel the effects of the finite, actual size of the earth in a critical way.

Thus the crisis does not arise from accidental events or human errors. It is inherent in technology's relation to geography on the one hand and to political organization on the other. The crisis was developing visibly in the 1940's, and some phases can be traced back to 1914. In the years between now and 1980 the crisis will probably develop far beyond all earlier patterns. When or how it will end—or to what state of affairs it will yield—nobody can say.

Dangers—present and coming

In all its stages the industrial revolution consisted of making available more and cheaper energy, more and easier controls of human actions and reactions, and more and faster communications. Each development increased the effectiveness of the other two. All three factors increased the speed of performing large-scale operations—industrial, mercantile, political, and migratory. But throughout the development, increased speed did not so much shorten time requirements of processes as extend the areas of the earth affected by them. The reason is clear. Since most *time* scales are fixed by human reaction times, habits, and other physiological and psychological factors, the effect of the increased speed of technological processes was to enlarge the *size* of units

— political, organizational, economic, and cultural — affected by technological operations. That is, instead of performing the same operations as before in less time, now larger-scale operations were performed in the same time. This important evolution has a natural limit, that of the earth's actual size. The limit is now being reached, or at least closely approached.

Indications of this appeared early and with dramatic force in the military sphere. By 1940 even the larger countries of continental Western Europe were inadequate as military units. Only Russia could sustain a major military reverse without collapsing. Since 1945, improved aeronautics and communications alone might have sufficed to make any geographical unit, including Russia, inadequate in a future war. The advent of nuclear weapons merely climaxes the development. Now the effectiveness of offensive weapons is such as to stultify all plausible defensive time scales. As early as World War I, it was observed that the admiral commanding the battle fleet could "lose the British Empire in one afternoon." Yet navies of that epoch were relatively stable entities, tolerably safe against technological surprises. Today there is every reason to fear that even minor inventions and feints in the field of nuclear weapons can be decisive in less time than would be required to devise specific countermeasures. Soon existing nations will be as unstable in war as a nation the size of Manhattan Island would have been in a contest fought with the weapons of 1900.

Such military instability has already found its political expression. Two superpowers, the U.S. and U.S.S.R., represent such enormous destructive potentials as to afford little chance of a purely passive equilibrium. Other countries, including possible "neutrals," are militarily defenseless in the ordinary sense. At best they will acquire destructive capabilities of their own, as Britain is now doing. Consequently, the "concert of powers"—or its equivalent international organization—rests on a basis much more fragile than ever before. The situation is further embroiled by the newly achieved political effectiveness of non-European nationalisms.

These factors would "normally"—that is, in any recent century—have led to war. Will they lead to war before 1980? Or soon thereafter? It would be presumptuous to try to answer such a question firmly. In any case, the present and the near future are both dangerous. While the immediate problem is to cope with the actual danger, it is also essential to envisage how the problem is going to evolve in the 1955-80 period, even assuming that all will go reasonably well for the moment. This does not mean belittling immediate problems of weaponry, of U.S.-U.S.S.R. tensions, of the evolution and revolutions of Asia. These first things must come first. But we must be ready for the follow-up, lest possible immediate successes prove futile. We must think beyond the present forms of problems to those of later decades.

When reactors grow up

Technological evolution is still accelerating. Technologies are always constructive and beneficial, directly or indirectly. Yet their consequences tend to increase instability—a point that will get closer attention after we have had a look at certain aspects of continuing technological evolution.

First of all, there is a rapidly expanding supply of energy. It is generally agreed that even conventional, chemical fuel—coal or oil—will be available in increased quantity in the next two decades. Increasing demand tends to keep fuel prices high, yet improvements in methods of generation seem to bring the price of power down. There is little doubt that the most significant event affecting energy is the advent of nuclear power. Its only available controlled source today is the nuclear-fission reactor. Reactor techniques appear to be approaching a condition in which they will be competitive with conventional (chemical) power sources within the U.S.; however, because of generally higher fuel prices abroad, they could already be more than competitive in many important foreign areas. Yet reactor technology is but a decade and a half old, during most of which period effort has been directed primarily not toward power but toward plutonium production. Given a decade of really large-scale industrial effort, the economic characteristics of reactors will undoubtedly surpass those of the present by far.

Moreover, it is not a law of nature that all controlled release of nuclear energy should be tied to fission reactions as it has been thus far. It is true that nuclear energy appears to be the primary source of practically all energy now visible in nature. Furthermore, it is not surprising that the first break into the intranuclear domain occurred at the unstable "high end" of the system of nuclei (that is, by fission). Yet fission is not nature's normal way of releasing nuclear energy. In the long run, systematic industrial exploitation of nuclear energy may shift reliance onto other and still more abundant modes. Again, reactors have been bound thus far to the traditional heat-steam-generator-electricity cycle, just as automobiles were at first constructed to look like buggies. It is likely that we shall gradually develop procedures more naturally and effectively adjusted to the new source of energy, abandoning the conventional kinks and detours inherited from chemical-fuel processes. Consequently, a few decades hence energy may be free—just like the unmetered air—with coal and oil used mainly as raw materials for organic chemical synthesis, to which, as experience has shown, their properties are best suited.

"Alchemy" and automation

It is worth emphasizing that the main trend will be systematic exploration of nuclear reactions—that is, the transmutation of elements, or alchemy rather than chemistry. The main point in developing the industrial use of nuclear processes is to make them suitable for large-scale exploitation on the relatively small site that is the earth or, rather, any plausible terrestrial industrial establishment. Nature has, of course, been operating nuclear processes all along, well and massively, but her "natural" sites for this industry are entire stars. There is reason to believe that the minimum space requirements for her way of operating are the minimum sizes of stars. Forced by the limitations of our real estate, we must in this respect do much better than nature. That this may not be impossible has been demonstrated in the somewhat extreme and unnatural instance of fission, that remarkable breakthrough of the past decade.

What massive transmutation of elements will do to technology in general is hard to imagine, but the effects will be radical indeed. This can already be sensed in related fields. The general revolution clearly under way in the military sphere, and its already realized special aspect, the terrible possibilities of mass destruction, should not be viewed as typical of what the nuclear revolution stands for. Yet they may well be typical of how deeply that revolution will transform whatever it touches. And the revolution will probably touch most things technological.

Also likely to evolve fast—and quite apart from nuclear evolution—is automation. Interesting analyses of recent developments in this field, and of near-future potentialities, have appeared in the last few years. Automatic control, of course, is as old as the industrial revolution, for the decisive new feature of Watt's steam engine was its automatic valve control, including speed control by a "governor." In our century, however, small electric amplifying and switching devices put automation on an entirely new footing. This development began with the electromechanical (telephone) relay, continued and unfolded with the vacuum tube, and appears to accelerate with various solid-state devices (semi-conductor crystals, ferromagnetic cores, etc.). The last decade or two has also witnessed an increasing ability to control and "discipline" large numbers of such devices within one machine. Even in an airplane the number of vacuum tubes now approaches or exceeds a thousand. Other machines, containing up to 10,000 vacuum tubes, up to five times more crystals, and possibly more than 100,000 cores, now operate faultlessly over long periods, performing many millions of regulated, preplanned actions per second, with an expectation of only a few errors per day or week.

Many such machines have been built to perform complicated scientific and engineering calculations and large-scale accounting and logistical surveys. There is no doubt that they will be used for elaborate industrial process control, logistical, economic, and other planning, and many other purposes heretofore lying entirely outside the compass of quantitative and automatic control and preplanning. Thanks to simplified forms of automatic or semi-automatic control, the efficiency of some important branches of industry has increased considerably during recent decades. It is therefore to be expected that the considerably elaborated newer forms, now becoming increasingly available, will effect much more along these lines.

Fundamentally, improvements in control are really improvements in communicating information within an organization or mechanism. The sum total of progress in this sphere is explosive. Improvements in communication in its direct, physical sense—transportation—while less dramatic, have been considerable and steady. If nuclear developments make energy unrestrictedly available, transportation developments are likely to accelerate even more. But even "normal" progress in sea, land, and air media is extremely important. Just such "normal" progress molded the world's economic development, producing the present global ideas in politics and economics.

Controlled climate

Let us now consider a thoroughly "abnormal" industry and its potentialities—that is, an industry as yet without a place in any list of major activities: the control of weather or, to use a more ambitious but justified term, climate. One phase of this activity that has received a good deal of public attention is "rain making." The present technique assumes extensive rain clouds, and forces precipitation by applying small amounts of chemical agents. While it is not easy to evaluate the significance of the efforts made thus far, the evidence seems to indicate that the aim is an attainable one.

But weather control and climate control are really much broader than rain making. All major weather phenomena, as well as climate as such, are ultimately controlled by the solar energy that falls on the earth. To modify the amount of solar energy, is, of course, beyond human power. But what really matters is not the amount that hits the earth, but the fraction retained by the earth, since that reflected back into space is no more useful than if it had never arrived. Now, the amount absorbed by the solid earth, the sea, or the atmosphere seems to be subject to delicate influences. True, none of these has so far been substantially controlled by human will, but there are strong indications of control possibilities.

The carbon dioxide released into the atmosphere by industry's burning of coal and oil—more than half of it during the last generation—may have changed the atmosphere's composition sufficiently to account for a general warming of the world by about one degree Fahrenheit. The volcano Krakatao erupted in 1883 and released an amount of energy by no means exorbitant. Had the dust of the eruption stayed in the stratosphere for fifteen years, reflecting sunlight away from the earth, it might have sufficed to lower the world's temperature by six degrees (in fact, it stayed for about three years, and five such eruptions would probably have achieved the result mentioned). This would have been a substantial cooling; the last Ice Age, when half of North America and all of northern and western Europe were under an ice cap like that of Greenland or Antarctica, was only fifteen degrees colder than the present age. On the other hand, another fifteen degrees of warming would probably melt the ice of Greenland and Antarctica and produce world-wide tropical to semi-tropical climate.

"Rather fantastic effects"

Furthermore, it is known that the persistence of large ice fields is due to the fact that ice both reflects sunlight energy and radiates away terrestrial energy at an even higher rate than ordinary soil. Microscopic layers of colored matter spread on an icy surface, or in the atmosphere above one, could inhibit the reflection-radiation process, melt the ice, and change the local climate. Measures that would effect such changes are technically possible, and the amount of investment required would be only of the order of magnitude that sufficed to develop rail systems and other major industries. The main difficulty lies in predicting in detail the effects of any such drastic intervention. But our knowledge of the dynamics and the controlling processes in the atmosphere is rapidly approaching a level that would permit such prediction. Probably intervention in atmospheric and climatic matters will come in a few decades, and will unfold on a scale difficult to imagine at present.

What could be done, of course, is no index to what should be done; to make a new ice age in order to annoy others, or a new tropical, "interglacial" age in order to please everybody, is not necessarily a rational program. In fact, to evaluate the ultimate consequences of either a general cooling or a general heating would be a complex matter. Changes would affect the level of the seas, and hence the habitability of the continental coastal shelves; the evaporation of the seas, and hence general precipitation and glaciation levels; and so on. What would be harmful and what beneficial–and to which regions of the earth — is not immediately obvious. But there is little doubt that one *could* carry out analyses needed to predict results, intervene on any desired scale, and ultimately achieve rather fantastic effects. The climate of specific regions and levels of precipitation might be altered. For example, temporary disturbances —including invasions of cold (polar) air that constitute the typical winter of the middle latitudes, and tropical storms (hurricanes) — might be corrected or at least depressed.

There is no need to detail what such things would mean to agriculture or, indeed, to all phases of human, animal, and plant ecology. What power over our environment, over all nature, is implied!

Such actions would be more directly and truly worldwide than recent or, presumably, future wars, or than the economy at any time. Extensive human intervention would deeply affect the atmosphere's general circulation, which depends on the earth's rotation and intensive solar heating of the tropics. Measures in the arctic may control the weather in temperate regions, or measures in one temperate region critically affect another, one-quarter around the globe. All this will merge each nation's affairs with those of every other, more thoroughly than the threat of a nuclear or any other war may already have done.

The indifferent controls

Such developments as free energy, greater automation, improved communications, partial or total climate control have common traits deserving special mention. First, though all are intrinsically useful, they can lend themselves to destruction. Even the most formidable tools of nuclear destruction are only extreme members of a genus that includes useful methods of energy release or element transmutation. The most constructive schemes for climate control would have to be based on insights and techniques that would also lend themselves to forms of climatic warfare as yet unimagined. Technology—like science—is neutral all through, providing only means of control applicable to any purpose, indifferent to all.

Second, there is in most of these developments a trend toward affecting the earth as a whole, or to be more exact, toward producing effects that can be projected from any one to any other point on the earth. There is an intrinsic conflict with geography — and institutions based thereon — as understood today. Of course, any technology interacts with geography, and each imposes its own geographical rules and modalities. The technology that is now developing and that will dominate the next decades seems to be in total conflict with traditional and, in the main, momentarily still valid, geographical and political units and concepts. This is the maturing crisis of technology.

What kind of action does this situation call for? *Whatever* one feels inclined to do, one decisive trait must be considered: the very techniques that create the dangers and the instabilities are in themselves useful, or closely related to the useful. In fact, the more useful they could be, the more unstabilizing their effects can also be. It is not a particular perverse destructiveness of one particular invention that creates danger. Technological power, technological efficiency as such, is an ambivalent achievement. Its danger is intrinsic.

Science the indivisible

In looking for a solution, it is well to exclude one pseudosolution at the start. The crisis will not be resolved by inhibiting this or that apparently particularly obnoxious form of technology. For one thing, the parts of technology, as well as of the underlying sciences, are so intertwined that in the long run nothing less than a total elimination of all technological progress would suffice for inhibition. Also, on a more pedestrian and immediate basis, useful and harmful techniques lie everywhere so close together that it is never possible to separate the lions from the lambs. This is known to all who have so laboriously tried to separate secret, "classified" science or technology (military) from the "open" kind; success is never more—nor intended to be more—than transient, lasting perhaps half a decade. Similarly, a separation into useful and harmful subjects in any technological sphere would probably diffuse into nothing in a decade.

Moreover, in this case successful separation would have to be enduring (unlike the case of military "classification," in which even a few years' gain may be important). Also, the proximity of useful techniques to harmful ones, and the possibility of putting the harmful ones to military use, puts a competitive premium on infringement. Hence the banning of particular technologies would have to be enforced on a worldwide basis. But the only authority that could do this effectively would have to be of such scope and perfection as to signal the *resolution* of international problems rather than the discovery of a *means* to resolve them.

Finally and, I believe, most importantly, prohibition of technology (invention and development, which are hardly separable from underlying scientific inquiry), is contrary to the whole ethos of the industrial age. It is irreconcilable with a major mode of intellectuality as our age understands it. It is hard to imagine such a restraint successfully imposed in our civilization. Only if those disasters that we fear had already occurred, only if humanity were already completely disillusioned about technological civilization, could such a step be taken. But not even the disasters of recent wars have produced that degree of disillusionment, as is proved by the phenomenal resiliency with which the industrial way of life recovered even—or particularly—in the worst-hit areas. The technological system retains enormous vitality, probably more than ever before, and the counsel of restraint is unlikely to be heeded.

Survival–a possibility

A much more satisfactory solution than technological prohibition would be eliminating war as "a means of national policy." The desire to do this is as old as any part of the ethical system by which we profess to be governed. The intensity of the sentiment fluctuates, increasing greatly after major wars. How strong is it now and is it on the up or the downgrade? It is certainly strong, for practical as well as for emotional reasons, all quite obvious. At least in individuals, it seems worldwide, transcending differences of political systems. Yet in evaluating its durability and effectiveness a certain caution is justified.

One can hardly quarrel with the "practical" arguments against war, but the emotional factors are probably less stable. Memories of the 1939-45 war are fresh, but it is not easy to estimate what will happen to popular sentiment as they recede. The revulsion that followed 1914-18 did not stand up twenty years later under the strain of a serious political crisis. The elements of a future international conflict are clearly present today and even more explicit than after 1914-18. Whether the "practical" considerations, without the emotional counterpart, will suffice to restrain the human species is dubious since the past record is so spotty. True, "practical" reasons are stronger than ever before, since war could be vastly more destructive than formerly. But that very *appearance* has been observed several times in the past without being decisive. True, this time the danger of destruction seems to be real rather than apparent, but there is no guarantee that a real danger can control human actions better than a convincing appearance of danger.

What safeguard remains? Apparently only day-to-day — or perhaps year-to-year — opportunistic measures, a long sequence of small, correct decisions. And this is not surprising. After all, the crisis is due to the rapidity of progress, to the probable further acceleration thereof, and to the reaching of certain critical relationships. Specifically, the effects that we are now beginning to produce are of the same order of magnitude as that of "the great globe itself." Indeed, they affect the earth as an entity. Hence further acceleration can no longer be absorbed as in the past by an extension of the area of operations. Under present conditions it is unreasonable to expect a novel cure-all.

For progress there is no cure. Any attempt to find automatically safe channels for the present explosive variety of progress must lead to frustration. The only safety possible is relative, and it lies in an intelligent exercise of day-to-day judgment.

Awful and more awful

The problems created by the combination of the presently possible forms of nuclear warfare and the rather unusually unstable international situation are formidable and not to be solved easily. Those of the next decades are likely to be similarly vexing, "only more so." The U.S.-U.S.S.R. tension is bad, but when other nations begin to make felt their full offensive potential weight, things will not become simpler.

Present awful possibilities of nuclear warfare may give way to others even more awful. After global climate control becomes possible, perhaps all our present involvements will seem simple. We should not deceive ourselves: once such possibilities become actual, they will be exploited. It will, therefore, be necessary to develop suitable new political forms and procedures. All experience shows that even smaller technological changes than those now in the cards profoundly transform political and social relationships. Experience also shows that these transformations are not a *priori* predictable and that most contemporary "first guesses" concerning them are wrong. For all these reasons, one should take neither present difficulties nor presently proposed reforms too seriously.

The one solid fact is that the difficulties are due to an evolution that, while useful and constructive, is also dangerous. Can we produce the required adjustments with the necessary speed? The most hopeful answer is that the human species has been subjected to similar tests before and seems to have a congenital ability to come through, after varying amounts of trouble. To ask in advance for a complete recipe would be unreasonable. We can specify only the human qualities required: patience, flexibility, intelligence.

DEFENSE IN ATOMIC WAR

It will not be sufficient to know that the enemy has only fifty possible tricks and that we can counter every one of them, but we must be able to counter them almost at the very instant they occur

Dr. John von Neumann

THE introduction to any and all applied science via the channel of military science, while it was rare in the one or two generations that came before us, is not so paradoxical. Without trying to reminisce about things long past, this particular circumstance has had, since Archimedes and Leonardo da Vinci, a very long pedigree.

I would like nevertheless to reminisce just a little. My particular introduction occurred at the Ballistic Research Labortories in the early years of World War II. It is remarkable to consider today how small in numbers was the manpower trained for this kind of applied science, and in particular for military matters. This was especially true in the theoretical field and more especially in my field—mathematics.

It was astounding that there were considerable numbers of supposedly very sophisticated specialists in very highly complicated fields of effort, and yet how very little we knew about the matters to which we were to be introduced.

THERE the guidance and the example of somebody who knew what this was all about were tremendously valuable. This whole relationship of being supposedly an expert in one way and yet a complete ignoramus in the way which happened to matter at that time is hard to describe.

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I assume it is best illustrated by a story which I heard recently about the American Indian who registered at a New York hotel and made two X's for his name. When asked what this signified, he said that the first X meant "Chief Bald Eagle." When asked what the second X meant, he said, "Ph.D." We were all making our X's in this fashion!

The other thing which was very remarkable was how this transformation took place in other fields and specifically how the institutions expanded which were connected with the Ballistic Research Laboratories.

The first vista I got of this was at the Ballistic Research Laboratories, where, first under Colonel Zornig and then under Colonel Simon, and always under the guidance of Dr. Kent, the institution expanded fiftyfold. And how the complexity of what went on grew!

Quite apart from facts referred to, it was very remarkable that the laboratory was one of the pioneers in supersonic wind tunnel building in America. It was absolutely the pioneer in the field which concerned me very closely afterward—the building of modern electronic computing machines.

The first modern electronic full-scale computing machine was built at the University of Pennsylvania for the Ballistic Research Laboratories, and for years afterward the only ones that could operate on the scale required were available there, and only there. It took quite some time before a really high speed machine was developed independently elsewhere.

Since then, the complexity and the sophistication of the weapons business has been increasing very rapidly from year to year. I should like to mention, as an example of this, the phase of computing machines. It is probably true that since 1945 the over-all capacity of these machines has nearly doubled every year.

This is astounding because over a period of ten years it means a thousandfold increase. Yet it is true that the increase that has occurred is a thousandfold in certain respects. I know of one instance where it actually has been three or four thousandfold since 1946.

IT is astounding to what extent the use of the computing machine has spread, and in some fields today it is very hard to imagine how one would go on working without such machines.

One of them is, of course, ballistics in the very complicated forms it now has assumed. Ballistics has progressed from the calculation of firing tables for more or less conventional use into the calculation of firing tables for antiaircraft artillery, then into the more complicated field of air-to-air firings, and now into the peculiar and complicated field of missile-trajectories guidance.

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