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TESTING AND TAMING OF NUCLEAR WEAPONS

BY DAVID R. INGLIS

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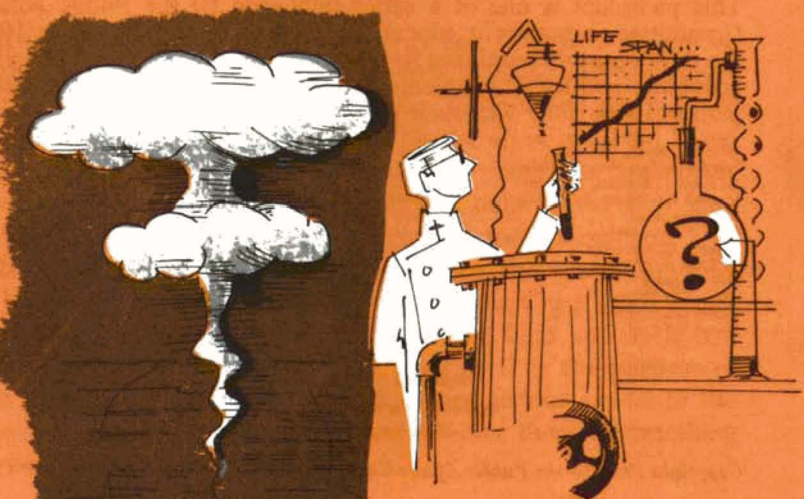

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TESTING AND TAMING OF NUCLEAR WEAPONS

BY DAVID R. INGLIS

The author of this timely pamphlet is Senior Physicist of the Argonne National Laboratory, chairman of the Federation of American Scientists, and a former editor of the Bulletin of Atomic Scientists. . . . *Illustrations are by Bill Dove of Visual Services, Inc.*

Everyone knows that nuclear energy has brought a revolution in the life of man. It is a dual challenge, a threat and a promise. The threat is of utter destruction by the nuclear weapons of war. The promise is of an abundant life for all of mankind based on nuclear power and nuclear aids to medicine and other sciences. The promise will be fulfilled only if we live long enough, somehow evading the threat of destruction.

It would be more pleasant to dwell on the promising side, to hope that by emphasis on "atoms for peace" we could somehow push the threat into the background. That approach is a little like sweeping the dirt under the rug. It is the purpose of this pamphlet to look instead at the more serious aspect of the atomic age, at the threat and to see whether there is something we can do to ameliorate it.

threat of nuclear weapons

The big bombs of past wars destroyed mainly by blast, the sudden pressure wave in the air capable of pushing over brick walls and twisting the landscape. There were special bombs for shrapnel, and special fairly small "incendiary bombs" used in great numbers for starting fires, but most of the big-bomb damage was done by blast.

A nuclear weapon, too, inflicts much of its damage by blast, but the same weapon also inflicts great damage in its vicinity by an immediate flash of intense radiation. In addition to this it sends up a great cloud of radioactive material which trickles down to earth many miles away and contaminates great areas with delayed and biologically harmful radiation, or fallout.

what war means

Blast and the immediate radiation from the bomb are its punch as a weapon of war, by which it can destroy whole cities or knock out even hardened missile bases if it hits close enough. These effects can be isolated in peace-time testing of nuclear weapons to sea or desert where they will do no serious harm. But only the nearby and most intense part of the fallout can be isolated in this way. Some of the fallout comes down thousands of miles from the site of the test, some of it years later, and small amounts of it enter into our food and affect us all. Fortunately, it is only a very small part of the total fury of a bomb that affects us as a result of tests, but the number of bombs tested is very small compared to the number that would be used in a nuclear war. The total of almost a hundred megatons of fission yield of all bombs which have been tested by all four nuclear nations probably amounts to less than 1 per cent of our stockpile. Thus, while we study the effects of peace-time fallout, we must bear in mind that whatever harm might be done by fallout is extremely small indeed compared to the havoc of the nuclear war we must prevent.

TESTING AND FALLOUT

Nuclear weapons cannot be developed to any great extent without testing. Small improvements can presumably be made by the present nuclear powers on the basis of theoretical calculations alone, building on the experience of past tests. But making big advances and establishing confidence in newly designed weapons requires tests. Such advances in the past have required not single tests but whole series of tests. A non-nuclear nation will require quite a series of tests to gain experience and become a nuclear power, unless it is supplied with very detailed weapons information or with the weapons themselves by one of the present nuclear powers.

Almost all nuclear tests have been carried out in the atmospere. Six were carried out underground in Nevada in 1957-58. These were quite small tests. Two have been carried out above the atmosphere about three hundred miles above the South Atlantic in 1958.

Tests in the atmosphere (and those immediately above the atmosphere) deposit great quantities of radioactive materials in the air, in the form of fine dust. Eventually this falls to the ground, mainly brought down by rain or snow. But it may reside in the atmosphere a long time before it reaches the ground. This is fortunate, because many of the radioactive materials are so short-lived that they have lost most of their radioactivity before they fall.

A one-megaton bomb produces as much energy as the explosion of a million tons of TNT. That's a lot of TNT. It would fill a trench six feet wide and six feet deep ten miles long. Now think of a third as much radium, a third of a million tons of it. Radium is a very radioactive substance. The radiation (counting gamma rays only) from the products of a one-megaton bomb one hour after it explodes is equivalent to that of all that radium. If the material from the bomb could be kept in one place, its radioactivity would rapidly become weaker: after a day, it would be only one-fiftieth as strong, after a week, one five-hundredth. A year after the explosion, the radioactivity would be equivalent to about six tons of radium, which is still a lot – far more than the world's supply of radium.

local fallout

But while its radioactivity is decaying, it is also being diluted by spreading out into the atmosphere in various ways. It spreads in different ways for bombs of different sizes. Most A-Bombs have enough power to push their mushroom clouds of hot radioactive gasses seven to ten miles high. The part of the cloud that gets up there may stay there for something like a month or more. That is time enough for it to be blown around the world in an east-west band – it doesn't spread far north or south. Somewhere in this band within a couple of months most of it comes down in rain. But part of the radioactive material is too coarse to get well mixed with the lofty winds and comes down much sooner as "local fallout". This is particularly strong if the bomb is exploded near enough to the ground to suck up a lot of neutron-irradiated earth.

Local fallout spreads on the ground in what may be lethal intensities for many miles downwind, perhaps hundreds of miles if it is a big bomb. In war, this would mean that many millions of people not within the range of the blast and immediate radiation of any of the bombs would nevertheless be killed or very seriously injured. In most of the area the injury to a person would come from several hours of exposure to the radiation coming from the surface of the ground about him.

Shielding by several feet of earth or concrete would provide protection against this, but being in an ordinary house above the level of the ground wouldn't help. Being in the basement below ground level would provide protection if one could stay there for several weeks while the intensity of the radiation decays. After that, if (optimistically) the war should stop with one attack, one of the most urgent problems would be how to provide food from the contaminated soil. The fallout in war, in addition to all the other damage, would be so enormously much worse than fallout from testing that our primary concern, as we discuss the testing of nuclear weapons, must be to avoid war.

The local fallout from testing is deliberately confined to relatively uninhabited areas. Even so, it has caused trouble. The unlucky crew of the Japanese fishing vessel "Lucky Dragon" received a serious dose of radiation, fatal to one of them, about one hundred miles away from a Bikini H-bomb test in 1954. A group of Marshall Island natives, even though evacuated quickly, were sadly injured. At our continental proving grounds in a Nevada desert, comparatively small bombs have been tested, a fraction of one per cent of the big H-bombs in power. Serious trouble with local fallout has thus been avoided. But the radiation levels for a few arid towns have been high enough to cause some concern.

worldwide fallout

A big H-bomb produces such an immense body of hot air that its mushroom cloud rises quickly up into the stratosphere, perhaps 25 miles above the earth. If the bomb is burst several miles above the earth, almost all of its radioactivity is carried up into the stratosphere, where it mixes with worldwide air currents and stays for many months. If the bomb bursts less than two or three miles above the earth, as would be more usual in warfare, the intensely bright and radioactive "ball of fire" which forms at the time of the burst would be large enough to reach the ground. Earth would be vaporized and local fallout would be intense.

But in either case, much of the radioactivity is carried aloft for worldwide distribution. Up there, high above the weather, the air circulation is more regularly east-and-west than it is with the prevailing winds near the ground. However, it also seems to spiral gradually from near the equator towards the poles. The gradual mixing of the air from the stratosphere into the lower regions seems to take place mostly near the poles, where cold

air descends. The radioactive material may spend a month or more in the troposphere getting mixed up with the weather before it starts to come down in rain. Most of it falls in the north-temperate zone, including the northern half of the United States.

The nice thing about this arrangement is that practically none of this worldwide fallout comes down very soon, and there is time for the very intense and short-lived part of the radioactivity to die. The long-lived radioactive elements of the bomb debris are the ones which cause concern. The most important of these are known as Strontium 90, and Cesium 137. It takes about thirty years for these materials to lose half of their radioactivity.

present and future fallout

The increase of radioactivity from fallout in the past few years is shown by measurements of the Strontium 90 in the soil near New York City. The measurements are in a unit called millicuries per square mile, and the increase is interesting. At the end of 1954, the level of radioactivity was 7 units, at the end of 1956, it was 25 units, and at the end of 1958, when testing had just stopped by mutual consent of the US and the USSR, it was 50 units. But the intensity of Strontium 90 radiation has kept right on going up, because this material is stored for years in the upper atmosphere and falls out slowly.

how fallout injures people

There is a great deal of confusion in people's minds about how much harm may be done by fallout from testing. The confusion arises because the technical facts are meager and they are interpreted by people who take different attitudes towards uncertainties. These attitudes vary all the way from "what we don't know won't hurt us" to "better safe than sorry." Unfortunately, there's a lot we don't know for sure. The best scientists can do in this new and insufficiently explored field is to give probable results and limits of uncertainty.

More specifically, nuclear testing affects future human life in two important ways. It has bearing on the likelihood of war, and it produces fallout which is harmful to an uncertain degree. If one judges that testing makes war less likely, he must consider whether a possible saving of life in this way counterbalances an inevitable but lesser harm to life through fallout. Some who hold this view tend to minimize fallout damage and emphasize the small end of the range of uncertainty. An opposing point of view is that each big bomb tested in the atmosphere condemns a number of people around the world to death – we don't know whom nor how many – and holds that no nation has the right to do this to other people.

There are others who are convinced that continued testing would make war more likely. For these there is no conflict between the two considerations. Both lead to the conclusion that worldwide abstinence from testing is desirable if attainable. With this perspective, let us examine the nature of the harm done by fallout from tests.

injury caused by fallout

Radiation from fallout hurts people in two ways. It causes diseases in people now living and shortens their life span. By causing changes in the reproductive cells of people now living it causes genetic damage to people of future generations. By way of slight reassurance, it may at least be said that the total amount of both kinds of trouble expected as a result of past bomb tests is very small compared to the total amount of such trouble in the world. There are many thousands of cases of radiation-induced disease in the world every year and the amount of misery involved is tremendous. Yet the population of the world is so large that the number seems small on a percentage basis.

These *Effects of Radiation and Fallout* have been discussed in a pamphlet of that title by James F. Crow in somewhat more detail than is possible here.* There has been no change in fundamental knowledge since the publication of this pamphlet, only in some detailed estimates which remain uncertain.

THE HORROR OF NUCLEAR WAR

It is very difficult to grasp the horrible destruction which would come with nuclear war. We seem to have a mental barrier that protects us from the unpleasantness of contemplating human grief on so vast a scale. We should at least be aware that the scale of pain and death and desolation would be vast indeed, and that it can happen here. It would not be like the bombing of England or Germany in the last war, when in two or three years as much explosive energy was delivered as would be carried today in a single medium-sized H-bomb. Those raids were terrible enough, but they were small and innocuous compared to what would happen today. The destruction was spotty and there was time for succor and reorganization between raids.

Today whole cities would go out in a flash, the entire organization of our society would disappear over night. The instantly

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**Effects of Radiation and Fallout*. Public Affairs Pamphlet No. 256, 25¢.

dead within two miles of a bomb would be lucky compared with those farther away whose skin might peel off from flesh burns, or who might be incinerated in the firestorm. There would be little or no chance for care of the wounded, for they would be legion and in most places the healthy people who were further from the bombs would have to hide in holes and cellars to avoid the radiation from "local" fallout, extending in a wide swath hundreds of miles downwind from each big bomb burst. When they would emerge weeks later, they would face the problem of controlling the panic of desperate mobs fighting for the remaining food supplies, and of raising food fit to eat from contaminated soil.

That it would be terrible beyond imagination there is no doubt, but it is impossible to say just how bad it would be, how many would survive the direct effects of the initial attack, how many would survive the ensuing panic and turmoil and disease, how many might resume an orderly and productive existence, and to what extent some remnants of civilization might survive. We have no experience with human behavior under such extreme circumstances of terror and universal bereavement.

Studies have been made of what might happen if we *assume* an attack of a certain intensity, but it would be a mistake to consider the result a prediction of what will happen. There was in

1959 a hearing of a congressional committee investigating the results of a single attack with a total of 1,466 megatons distributed in a particular way over the United States. The results were discussed as though this is what we could expect from a nuclear war: thirty million people killed outright and many more seriously injured. The catch is that this is probably a small fraction of the present Soviet stockpile, and an attack either now or within a very few years could be many times that intense.

need for a changed attitude

This is not only what *could* happen here in our beloved country, to end all that we know and cherish. If we look at the repeated wars of history, if we examine how little we have done to change the competitive ways of nations, we may reasonably judge that this is what probably *will* happen here. Yet it's unthinkable that it should. Throughout history there always have been wars. Suddenly, in the middle of the twentieth century, the very meaning of the word "war" has completely changed. There must be no more war, not even one. If this is to be so, we must examine how the ways of mankind can be changed to accomplish it. Though everything is in a state of flux, the change in our political thinking tends to be gradual. It seems doubtful whether the ways of mankind can be changed quickly enough to keep pace with the rapidity of technological change. An idea for a small change capable of reducing the likelihood of war may be more valuable now than an idea for a big change which would eventually make war impossible but leave a serious risk of war in the immediate future.

reducing the likelihood of war

Compared with other sorts of disarmament or arms control, a worldwide cessation of tests on the basis of a reasonable control agreement is a step which requires only a small change in international political thinking. It would not make war impossible. It would not make it appreciably less horrible if it should occur.

But it should considerably reduce the danger that war will break out by accident or design. This is the great benefit which would be expected to follow from a good test ban agreement, no matter whether or not further steps of arms control would follow. An added benefit is that such an agreement would set the stage for further agreement, not only by giving the world experience with enforcing an agreement, but also by keeping the techniques of nuclear warfare from developing to such a refined stage that it might become impossible to bring them under effective control.

TESTING AND WEAPONS DEVELOPMENT

To attain its present advanced state of nuclear technology the United States has carried out about a hundred and thirty nuclear tests, and the Soviet Union has carried out about sixty. You may ask why these nations would want to carry out more tests when they have made so many? One answer is that it is the nature of military competition always to require more and better weapons. We have now come to the point where one bomber carrying one single bomb (a twenty megaton H-bomb) can deliver more explosive power than was used by all nations throughout all of World War II. The present military desire is not for a still bigger explosive but for ability to deliver it with a more convenient vehicle than a big bomber. There is a similar desire for more compactness and greater ease of delivery on down the line of less powerful weapons.

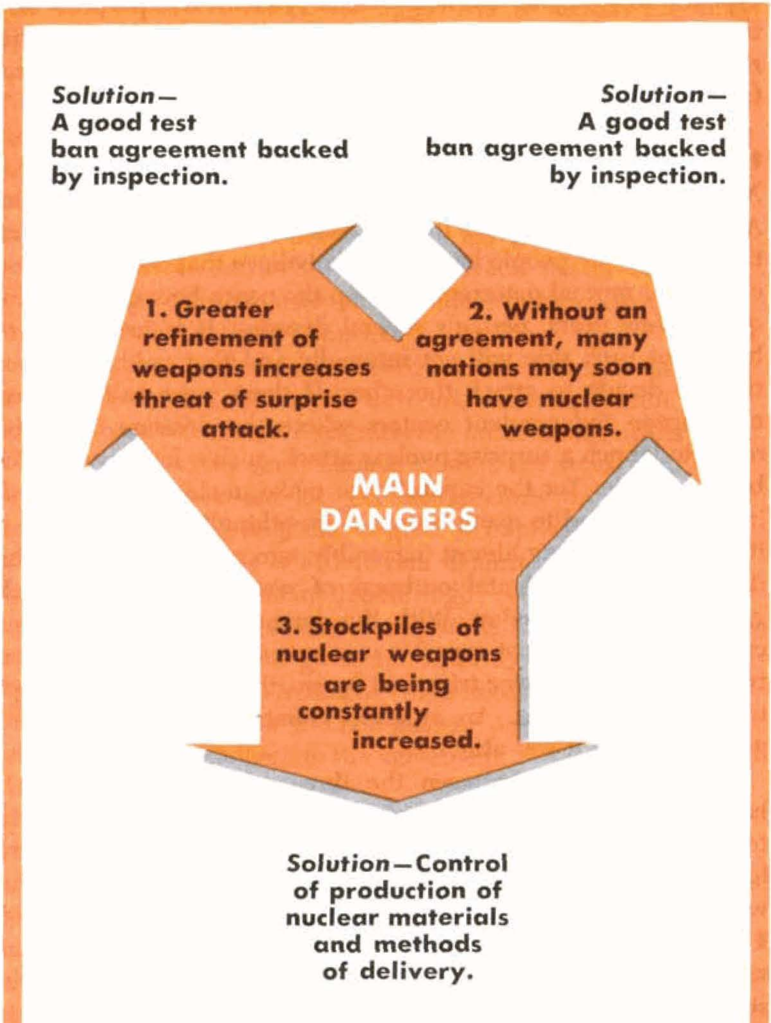
The nuclear arms race has three separate phases: (1) The nuclear nations are developing their arms to attain a greater degree of refinement. This tends to make a surprise attack more devastating and swift. (2) The non-nuclear nations are working toward the development of their own nuclear arms. (3) The nuclear nations are increasing the stockpiles of the weapons they already know how to make.

A good test ban agreement would put a lid on the first two efforts, but not on the third. In this sense, a controlled test ban would begin to "taper off" the arms race, but would not end it. It would prevent its spreading and growing with ever greater refinement. It would at least raise prospect of something better than the infinite upward spiral until the ultimate explosion.

There are a number of causes of international tensions. But anxiety over the future of the arms race is perhaps the most dangerous. No one knows when some national leader, stirred up over some real or fancied issue and unable to foresee anything but ultimate disaster, may in desperation decide to provoke a showdown when he can have the advantage of surprise attack. If, in the see-saw of competing developments, he should feel he had a temporary advantage in weapons' techniques, he might feel particularly tempted to strike. It is in this sense that a successful test ban could bring a valuable reduction of tensions. It would greatly slow down the development of ever more insidious weapons. It would level off the upward spiral of the arms development race. And it would remove the basis for the desperate decision that one might as well get the war over with, come what may.

A test ban agreement need not lead to any relaxation of national effort to maintain a successful deterrent, and there is no logical reason why it should. For that reason it does not require any great change in our political thinking. There is nothing unilateral about it (aside from the possibility of one side cheating in the realm of very small tests). It hampers new military developments of both sides alike. It leaves each side free and, within the context of mutual deterrents, obligated to maintain a military force adequate to make it unprofitable for the other to attack.

Two points must then be quite clear. First, an agreement to ban tests does not mean an end to the arms race. Whatever need there may be for building more weapons or perfecting the nonnuclear components of weapons is not altered. Second, we cannot expect great economies from a test ban agreement alone. Any saving there might be in not carrying out some aspects of testing and associated development may be more than offset by


Solution— A good test ban agreement backed by inspection.
Solution— A good test ban agreement backed by inspection.
1. Greater refinement of weapons increases threat of surprise attack.
2. Without an agreement, many nations may soon have nuclear weapons.
MAIN DANGERS
3. Stockpiles of nuclear weapons are being constantly increased.
Solution—Control of production of nuclear materials and methods of delivery.

expenditures on the test-ban control system. The purpose of a test ban is economy of risk, not economy of dollars. Substantial reduction of military budgets would be expected only after further steps of arms control.

the many-nuclear-nation problem

As long as the competition remains between the tight Anglo-American partnership on the one side and the Soviet Union on the other, many people have come to believe that there is a good chance for mutual deterrents to keep the peace between them for quite a few years, perhaps several decades. It is reasonable to hope that each side will act rationally and that neither can rationally decide to attack the other. If there were half a dozen or a dozen independent centers where the decision could be made to launch a surprise nuclear attack, such a hope would not be reasonable. Yet the capability to make nuclear weapons will inevitably spread to many countries if nothing is done to prevent it. We are marching almost inexorably into a world in which the danger of an accidental outbreak of war will be even much greater than it is today. With the spread of nuclear weapons capabilities, we cannot expect a war to remain confined between two belligerents. A war triggered by small nuclear nations is apt to engulf large ones. An attacked country may even have to guess by whom it was attacked.

The negotiations between the three nuclear powers which have been progressing at Geneva since 1958 have been working toward an initial agreement between these three powers. They have discussed a network of 170 control stations throughout the world, of which 21 would be in the U.S.S.R., 19 in the U.S., and 4 in Great Britain. The immediate difficulty has been one of working out a satisfactory compromise between the western desire to have adequate control and the Soviet reluctance to admit inspectors. Once this difficulty is overcome and an agreement can be signed between these three powers, work at installing the inspection stations in their territories can commence. It will then be necessary to extend the agreement to include the other important countries of the world.

Many of them will be easy to persuade, particularly those which have not yet made substantial investments in a nuclear arms program, if we may judge by the attitudes shown in United Nations debates of nuclear testing. The attitude of France shows that persuasion may be difficult after a nation is thoroughly committed to a development program. She has used her prestige as a nascent nuclear nation to try to persuade the great nuclear powers to go further with disarmament rather than simply banning tests, but resisted a test ban.

A non-nuclear nation might feel it unfair that it is asked to renounce something that others have and intend to retain. Here, one must be a realist and recognize the unpleasant nuclear facts of life. In a sense the great nuclear powers are stuck with what they have, and dare not let go. Each realizes that its nuclear might is a mixed blessing, that it gives it unprecedented power, but no real security. It is a deterrent against attack and an invitation to attack, but the invitation might be greater if it would let down its guard. The non-nuclear powers should rejoice if the great nuclear powers can go so far as to agree on an effective test ban. Since such an agreement could not be effective for long without the adherence of the non-nuclear powers, each of them should be willing to adhere to the agreement.

withholding nuclear weapons information

In building up alliances to bolster the positions of the two great power centers, the great nuclear powers are tempted to strengthen the ground armies of their non-nuclear allies by giving them nuclear weapons. If one side does this, the other feels forced to, and there is no great net gain on either side. Yet, there can be a serious net loss because of the diffusion of nuclear weapons information to other countries.

United States policy, as established in 1958, is to provide the armies of our NATO allies with nuclear weapons, but with a string attached. The nuclear warheads themselves remain in U.S. possession, under the control of an American officer on the spot, until the emergency arises in which they are to be used. Although it is hard to know whether security arrangements are effective, this has the purpose of preventing the transfer of detailed weapons information to the other country. Such information would make it significantly easier for that country to design nuclear weapons of its own, and might even make it possible for it to become a nuclear nation on a modest scale without carrying out any tests. It is evident, then, that our present policy should be administered with the utmost caution, and should be retracted rather than extended in scope, if we are to retain freedom of action in seeking worldwide arms development control.

Another aspect of the problem is the need to avoid the possession of dangerous fissionable materials by the non-nuclear nations. Such materials are made in bulk but are not refined to the required quality in the nuclear reactors being installed to produce industrial power in various countries. Such reactors are built and operated on the basis of bilateral agreements between a nuclear and a non-nuclear country. The fuel is ultimately returned to the nuclear country for refining, and this provides a control on the availability of such material for nuclear weapons. This function might well be carried out by the International Atomic Energy Agency under the auspices of the U.N.

stopping tests to avoid fallout

As we have seen, another incentive for stopping tests, but a less urgent one, is the desire to avoid the radioactive contamination of the atmosphere. While almost all tests in the past have been carried out above ground, it seems likely that in the future many of them will be carried out underground if there should be no test-ban agreement. The fallout incentive applies only to the atmospheric tests. But the desire to control arms development in order to make war less likely provides a strong incentive for a test-ban agreement applying to all kinds of tests.

TECHNIQUES OF TEST CONTROL

The first Soviet atomic bomb test somewhere in Siberia in 1949 was detected by means of airplanes flying over northwestern United States. Filters are used to collect radioactive samples from the air for laboratory analysis. By this method it is even possible to tell what the bomb was made of and a good deal about its effectiveness. Thus it would not be hard to set up an effective control system to monitor a worldwide ban on tests in the atmosphere. Part of it is operating under national auspices already.

underground tests

It was discovered by means of a test in Nevada in 1957 that the energy and the radioactivity of an atomic bomb can be contained by the weight of the earth if it is detonated deep underground. In this test, the bomb was placed at the end of a tunnel far into the side of a mesa, placing it under about 800 feet of rock. The tunnel was curved near the bomb, in such a way that the shock wave from the explosion collapsed and sealed off the tunnel before any gasses could escape. Rock was suddenly vaporized and the surrounding rock compressed to form a spherical cavity. Most of the radioactivity was sealed in a glassy inner lining formed from melted rock. The roof of the cavity soon caved in and the radioactive glass was concentrated in a heap at the bottom, covered by a pile of loose rock. The cave-in left a partially empty space far above the original sphere, but not extending to the surface. Although the largest bomb tested underground was a 19-kilotons, about the size of the Hiroshima bomb, larger explosions might be contained at greater depths.

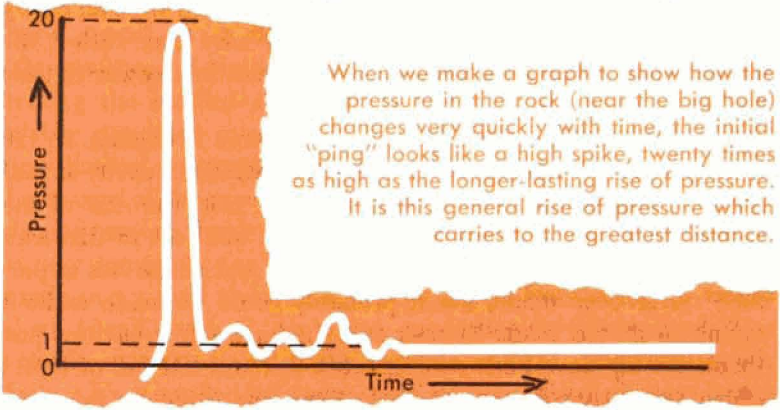
In establishing a control system to monitor a nuclear test ban, the main problem is to provide assurance that no underground tests are being carried out in secret. They can be detected by observing vibrations, known as seismic waves, which they send out through the earth. The trouble is that earthquakes send out rather similar signals. These have been observed on recording seismographs for a long time, but seismologists have not had much experience in trying to distinguish between earthquakes and underground blasts. One method we already know about is based on the fact that the blast makes sudden outward pressure in all directions, whereas an earthquake does not. Thus seismographs in four directions from a blast under appropriate conditions would each give a signal with an upward first motion, as compared to two upward and two downward around a normal earthquake. A few earthquakes are abnormal in this respect and might be suspected of being blasts. For this reason an ideal control system based on present technology would include both a network of seismographic detection stations and an arrangement whereby suspicious signals would be followed up by a careful inspection of all clues on the spot where the signals originated.

Between the summer of 1958 and the summer of 1960 there have been a long series of meetings at Geneva to discuss the details of an agreement to set up such a control system. Important progress has been made in reconciling differences between the Soviets and ourselves, but substantial differences remain. It appears as though a new awareness of the importance of agreement will have to be born on both sides before the final points can be settled. The most important question still to be worked out is the number of on-site inspections to be authorized. The Soviet Union would like to limit the number of its territory to three a year. The United States is insisting on more.

The necessity of having a control system capable of detecting serious violations of a nuclear test ban arises from the distrust of one nation by another when they are in the throes of a highly competitive arms race. Each wants assurance that the other is not obtaining some crucial military advantage by carrying out weapons development involving secret tests. A control system is to be judged, therefore, not only by its ability to detect tests that we know how to make, but also to direct them if special ways are devised to hide them. But even if we are suspicious to the extent of believing that another nation might go to some trouble to hide tests, we must be reasonable in judging how much effort they might decide to expend.

muffling tests in big holes

The method of hiding tests so far discussed which seems the least implausible involves preparing a very large round cavity deep underground and detonating the bomb at its center. The air space around the bomb muffles the shock transmitted to the surrounding rock. Two very different kinds of vibrations go out into the rock, along with various intermediate varieties. The first is a sharp "ping" made when the shock wave in the air meets the rock. It remains quite strong for two or three hundred miles, but becomes rapidly weaker at greater distances. The second is a dull "thud", a slow outward shift of the rock to make room for the expansion of the cavity when the air in it is made extremely hot by the energy of the bomb. This dull signal dies



When we make a graph to show how the pressure in the rock (near the big hole) changes very quickly with time, the initial "ping" looks like a high spike, twenty times as high as the longer-lasting rise of pressure. It is this general rise of pressure which carries to the greatest distance.

off more gradually at greater distances, and in most cases it can be observed thousands of miles away. Because it travels so far, it has been considered to be the most useful basis for monitoring, and the control system which has been discussed at Geneva depends entirely on this low-frequency signal. Seismologists have been accustomed to observing distant earthquakes with such low-frequency signals. It seems quite certain that future research work will find new ways of distinguishing between earthquakes and blasts, making use of other parts of the signal. The "ping" from a test in a cavity is probably unlike anything from an earthquake.

We come next to the questions "How big a cavity is needed and how deep underground?" and "Might it be practical or worthwhile to prepare so big a hole?" Up to a certain size, the bigger the hole is made, the better it muffles an explosion, but beyond that size it doesn't help to make it bigger. To do a good job, it has to be enormous, and a good job is pretty good. It is good enough to make the bomb seem 120 times smaller than it is. That is, the bomb in the big cavity can be 120 times as powerful as the one that gives the same "dull thud" when it is exploded in the rock with no cavity around it. The strength of the thud also depends on the kind of rock. If the cavity is made in a hard rock like rock salt and the thud compared with a bomb with no cavity in Nevada-type rock where bombs already have been tested, the muffled shot would seem three hundred times less powerful than it is.

But this takes a very big hole. It requires a volume of 110 cubic yards for each ton of TNT equivalent, if the cavity is half a mile underground. For a twenty-kiloton test, the size of the Hiroshima bomb, this would mean a hole 500 feet in diameter at that depth. An empty hole of that size and shape has apparently never been made, but it probably could be made without caving in if it is made in rock salt. In fact, a few cavities just about this big have been made in rock salt and left full of liquid which helps to hold up the roof. They are made by pumping water through for some years to dissolve out the salt and then used for storing petroleum products. But these were not made in defiance of a control system. If the brine were dumped in a river it would be fairly easily detected, and it would be very difficult to carry out such a construction job in secret.

Any deep man-made cavities in other kinds of rock are very much smaller than that. It is doubtful that they could be made much larger. Natural caves are not the right shape and not deep enough underground to be much good. Carlsbad Cavern, if available from the National Park Service, would be good for about ten kilotons and caverns as big as that are extremely rare. There is only one other in North America, for example, and the next below these in size is only about a tenth as big.

If a hole were used of smaller volume than we have been talking about, the muffling would be proportionately less effective. If for a twenty kiloton bomb, for example, we were to use a hole of half the diameter, 250 feet across instead of 500, the volume would be eight times smaller and the bomb would seem only 15 times less powerful than it is, not 120 times. That's still a big hole. A control system would perhaps have to be more alert for such "partial muffling" than for the most effective muffling because it would be less difficult to construct a smaller hole.

how good is a control network?

The problem of detecting the construction of big holes or detecting the muffled signals from blasts in big holes is considerably simplified by the fact that salt formations occur in only very limited geographical regions. Such regions occupy less than 1 per cent of the area of the Soviet Union, for example, and they do not overlap the regions where earthquakes are frequent. This is very important for it means that an on-site inspection can be made every time there is a seismic signal from a region where there is salt, even if only a few inspections are permitted. The seismic network needs to be capable only of *detecting* signals from a blast muffled by such a hole, not capable of *distinguishing* it from an earthquake. For this, quite weak signals reaching the apparatus should suffice.

The network including seismic stations in the Soviet Union, for example, was first seriously considered as a part of a control system for unmuffled tests. It would be able to detect and locate very small tests, down to one kiloton, but not to distinguish all these from earthquakes.

It is considered desirable that this be supplemented by a reasonable number of on-site inspections, so that the control organization can sample the suspicious signals by arbitrary choice, to determine whether they were earthquakes, and thus make it very likely that a violator would be caught if he should make several clandestine tests of even fairly small bombs. The risk of being caught and exposed before world opinion should be a strong deterrent to a potential violator.

There are many weak earthquake tremors which might be confused with a small underground test, fewer strong enough to be confused with a larger test. In an average year there are probably about 100 per year in the Soviet Union strong enough to be confused with a 20-kiloton test. With the pattern for distributing the 21 stations as discussed at Geneva, the control network would be capable of identifying some of these earthquakes, but leave something like 60 per year unidentified and therefore suspicious. Twenty inspections per year, giving a sampling of about one out of three, would probably be ample to discourage violations. Practically all of these earthquakes are in the "seismic regions" which constitute only about one-tenth of the area of the country. If one occurs outside this region, there would be no question of sampling; it would be inspected.

Some reports about Congressional hearings have exaggerated the difficulties of monitoring a test ban. If an evader should go to a great deal of trouble and is able to hide the preparation of big holes that might be practical to construct, the 21-station network discussed at Geneva would permit some rather considerable evasions – up to perhaps ½ of 1 per cent of the size of a big H-bomb, but a rather modest extension of the 21-station network would make it quite effective and bring this figure down to well under 1/10 of 1 per cent.

The reason for emphasis on the 21-station network in the U.S.S.R. is historical. It has been favorably discussed and even tentatively agreed upon in the Geneva discussions, and there is a tendency for negotiators to be tenacious on such points. Important technical improvements in monitoring effectiveness are to be expected in the future without increasing the number of stations, and much greater improvements will be possible if the number of stations can be increased.

There is an important tie-in between numbers of stations and area covered by on-site inspection. This might make it seem reasonable to the Soviets as well as to us to establish considerably greater numbers of stations, mostly robot stations. If the stations were closer, as they would be with about 100 stations in the U.S.S.R. concentrated particularly in the seismic and salt regions, it would be possible to locate the source of earthquake signals much more accurately. The technique of making a comparison signal by going out and exploding a chemical charge near the site of the suspicious event can be used more effectively with the stations closer together and is expected to be very useful both for locating the event accurately and for determining whether it is an earthquake.

Much of the seismic region is wild mountain country where a rather simple on-site inspection would show there had been no human activity. In other cases a refined search would be required. One promising method is similar to that used by oil prospectors to locate special layers in the rock. Small blasts are set off in a small hole in the ground, and seismographs set up nearby record the reflections of the waves it sends out. As we have seen, an underground nuclear blast in the solid rock leaves a large cavity filled with loose rock, and this cavity would be readily found by this method.

developing arms-control techniques

Considering the importance of the subject, it seems unfortunate that so little research and development has been done on the technical problems that arise in controlling a test ban. The State Department has a small group dealing with the problem of negotiation. It solicits technical help from other agencies and the Defense Department lets out contracts for rather modest investigations. Back in the early 1940's, when it was thought possible to develop an atomic bomb, though it looked extremely difficult, a cooperative project was set up with large laboratories where specialists with various backgrounds could exchange ideas while working toward a common goal. The same was true of radar and other important developments. It is to be hoped that we will soon have such an imaginative and cooperative project in the broad field of arms control, covering all its political and psychological aspects as well as its technical aspects, with the goal of devising the best possible agreements from the point of view of reducing the likelihood of war and being acceptable to all nations. The contracts already started on specific problems of nuclear test control, and international collaboration on this subject which may soon be undertaken, would be usefully supplemented by such a general project to explore the future needs of more far-reaching steps of arms control.

ARMS CONTROL AND DISARMAMENT

A worldwide cessation of nuclear tests is a step of arms development control. It doesn't control arms themselves, but it puts a lid on their future development. It could be a useful step even if it remains a long time the only step in this direction. It not only tends to preserve the technical possibility of arms control but it provides experience and confidence to encourage taking further steps.

controlling production of nuclear materials

Stopping production of the special materials needed for the construction of nuclear weapons would be another step which might soon be practical. The degree of inspection is modest enough that it might be tolerated under present conditions by the Soviet Union. In fact, if the Soviets would agree, it would be sensible to take this action at the same time as the test ban. Stopping tests requires a detection network which is rather elaborate technically. But it does not interfere seriously with military secrecy because on-site inspections would have to cover only relatively small areas, mainly in wild regions. Stopping production requires a different sort of inspection—sending inspectors to factories to find out what is being made. The great nuclear powers have already produced so much material that they would not feel it a great military hardship to desist from further production, and the non-nuclear nations might feel better about joining an agreement which includes control of nuclear production by the big powers. Control of production in the non-nuclear nations would provide an additional check on the spread of nuclear weapons.

difficulty of eliminating stockpiles

After stopping production, what next? Some glib proposals have been made which include getting rid of all nuclear materials, or of large parts of the stockpiles. Unfortunately, it is not possible to verify by technical means whether a nation has gotten rid of all its fissionable material. It has been aptly said that the best instrument for such detection is a screwdriver to open every packing case!

From examination of the history and the present condition of all production facilities, it would be possible to make a rough estimate of the amount of material that has been produced. But if the estimated amount were delivered and destroyed according to an agreement, other countries would remain uncertain how much might be left over. This would be a way to reduce quite drastically the amount of material available, but some form of assurance against hidden stockpiles would probably be required, such as an overwhelming U.N. military capability. It might also be possible to establish control of stockpiles by questioning the people who should know about them. But the control of the stockpiles already produced is so difficult that it is not promising as an early step in arms control.

control of delivery vehicles

Control or elimination of the vehicles of delivery of nuclear weapons is a much more promising possibility. If we could become sufficiently alarmed by the continued arms race to become seriously interested in actual disarmament, we should try to make agreements for the controlled elimination of long-range missiles, bombing airplanes, rocket-launching submarines, etc. Submarines can be controlled through inspection of their bases, and bombing planes are easy to find. Missiles present the chief problem. If we could reach an agreement fairly soon to eliminate them, it should be possible by careful inspection to make sure that none are missed. But if several years pass during which solid-fuel missiles can be installed in inconspicuous holes in the ground, it will become much more difficult to enforce a ban.

no need for secrecy

If we could eliminate all vehicles for the delivery of nuclear weapons, we would at the same time practically eliminate the need for military secrecy. If there could be complete disarmament, even Khrushchev has pointed out that there would be no further need for secrecy. But inspection is needed to verify compliance in most minor steps of disarmament, no matter how small. And the Soviet Union has a special reason to resist roving inspectors because it has presumably been successful in hiding the exact location of its missile bases. Elimination of practically all delivery vehicles, particularly all missiles, would be about the least that could be done to get past this difficulty.

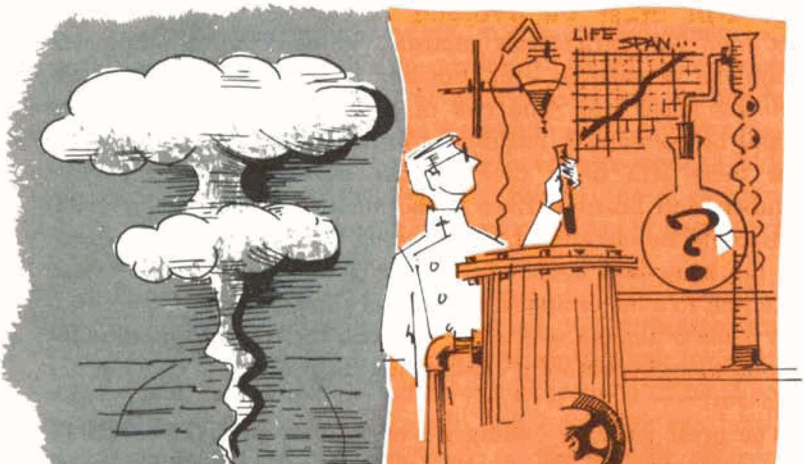
Such a substantial step of disarmament would be valuable not only in getting rid of the missiles that are poised to exterminate our cities, but would provide improved atmosphere for settling other world problems. Yet caution would seem to demand some instrument of force, either a world police force or residual national armament, to take the place of the nuclear deterrence being given up. Before 1945, war was accepted as a reasonable extension of diplomacy as an instrument of national policy. There were circumstances in which war might pay. With the nuclear threat, this is no longer true. In a nuclear war, both sides would lose. (There are still those who argue that we must have a plausible *threat* of nuclear war as an instrument of national policy, but not war itself.)

If we get rid of vehicles for nuclear delivery, or take further steps to tame the sudden nuclear threat, there will be problems of arranging some kind of balance to discourage aggression. With nuclear bombs still in existence, perhaps only in hidden stockpiles, the possibility of delivery by commercial aircraft would constitute a mild threat. Inspection at airports could guard against this, and ground-to-air missiles and other purely defensive systems might be retained which could be very effective against such an improvised attack. The prospects of attacking would not be likely to tempt a serious military planner. U.N. troops at key trouble spots would probably also be used as an important new element of world stability.

war still must be avoided

But even with strict arms controls, the need for avoiding war would be as great as ever. For any big war would soon grow into a nuclear war. The risk of a devastating surprise attack would be eliminated, but during initial stages of a conventional war there will be a race for the development of effective bombers and missiles. Even if the nuclear warheads and materials could be eliminated, there would be a race to make these, for the know-how cannot be erased. There would still be some deterrent to a major attack. And if war should occur out of a sudden flame of temper over some incident, there would be time for second thoughts before it could reach the proportion of a nuclear holocaust.

The great gains in getting rid of delivery vehicles would be the elimination of the danger of an accidental attack which could touch off sudden devastation and the elimination of the temptation to seek the advantage of an overwhelming surprise attack. If we could fully appreciate the uncertainties of the situation, we would probably insist that our government pursue more seriously the possibility of such a step of disarmament. We would surely cease to tolerate our decade-long failure to establish a vigorous agency with adequate laboratory and development facilities dedicated solely to devising and assessing possible paths to a more stable peace through various degrees of arms control.



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