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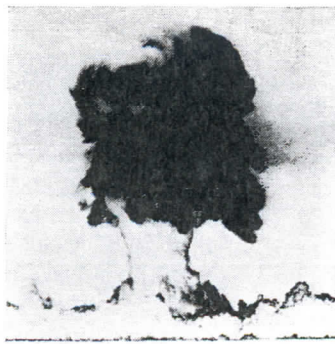
PEACE AND THE SCIENTIST



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THE CASE FOR ENDING NUCLEAR TESTS

BY HANS A. BETHE

The debate over whether or not to end nuclear testing has now reached international proportions. One of the most eminent scientists who believes that we can and should stop the tests is DR. HANS A. BETHE of Cornell Laboratory of Nuclear Studies.

Dr. Bethe, who was born in Strasbourg, became a naturalized citizen in 1941, and for his work in aiding the development of the A-bomb he received the President's Medal of Merit in 1946.

THE cessation of nuclear weapons tests has been debated in the newspapers, in Congress, and most of all, in Geneva, where there have been what I consider honest negotiations. Concrete proposals have been made by both sides, by the East and by the West; there has been a considerable measure of agreement between East and West; and a number of articles of a treaty have been accepted.

The fundamental points of view of the two sides on disarmament measures were quite different. The Soviet Union advocated just a piece of paper on which we would agree to reduce our armaments. The United States and Britain insisted on the verification of any treaty concerning the limitation of armaments.

Because of the Russian desire for secrecy, the West proposed that the verification of a test cessation agreement should be primarily by physical methods, which would mean less intrusion into the privacy of the Soviet Union. It is clear that the Russians have by now accepted the major principle on which the United States has insisted; namely, that there should be a control system for the test cessation agreement. This in itself is an important result of the negotiations, and we must not jeopardize this achievement by either breaking off the negotiations or by making unreasonable demands which we know Russia cannot fulfill.

The problem of detection of nuclear explosions varies with the medium in which the nuclear ex-

plosion is set off. Until recently, practically all the nuclear explosions were set off in the atmosphere, either on the ground or higher up. The best-known method for detection of nuclear explosions is the collection of radioactive debris, by planes flying in those regions where the debris is expected to arrive, or on the ground from fall-out. However, the collection of fall-out on the ground is quite unreliable, because the winds may carry the radioactive debris in one direction or another.

We can also detect a nuclear explosion by the acoustic method, which consists in recording the pressure wave created by the explosion. Though the pressure decreases as the wave passes through the atmosphere, it remains recordable to a distance of 10,000 miles. The wave is such a good indicator of nuclear explosions that the United States has usually announced Russian explosions very soon after they have taken place. We have announced far more Russian explosions than the Russians themselves. Similarly, the Russians have been able to detect our nuclear explosions.

To improve detection, it was proposed as part of a treaty on the cessation of nuclear tests to have a large number of stations in each country, especially in Russia, in the United States, and in the British Commonwealth, all equipped with detection instruments. With the network of stations worked out in the Geneva negotiations, it was generally agreed that we would be able to detect and

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identify explosions in air down to the level of one kiloton, or possibly lower.

The second medium in which nuclear explosions have been set off is underwater. Such explosions are, if anything, even easier to detect than those in air, because the pressure wave is very well propagated through water, so much so that even an explosion of a few tons, not kilotons, can be recorded through water for thousands of miles.

Another location where nuclear tests might be carried out is in outer space. Detection there is considerably more difficult than in the air or in water, but it is confidently expected that one could detect nuclear weapons tests to distances of at least a million miles, which is four times the distance from here to the moon.

UNDERGROUND testing is our most vexing problem and has received the most publicity. It has the obvious advantage that it does not contaminate the atmosphere, and therefore the great disadvantage, from a detection point of view, that radioactive air samples cannot be collected. From experience gained in Nevada, we know how deep an explosion has to be buried in order to prevent escape of radioactive material into the air. A kiloton bomb must be buried about four hundred feet underground; a twenty-kiloton bomb, about eleven hundred.

The displacement of the earth produced by an underground explosion is sufficiently great to be recorded easily by a seismograph, unless the explosion itself is very small. The two largest underground explosions to date were carried out in Nevada in the fall of 1958. One of these was five kilotons and the other twenty; they could be observed on the seismographs throughout the United States, and the larger one gave a clear signal in Russia.

Unfortunately, underground explosions produce the same type of record as earthquakes; namely, seismograms consisting of a series of perhaps twenty wiggles. There are very few ways to distinguish between the two types of seismogram. The best distinguishing mark that seismologists have been able to find is the direction of the so-called first motion — whether the first wiggle starts up or down.

The criteria for distinguishing earthquakes from explosions were discussed in detail in the Geneva negotiations. It was decided that control stations should be set up at regular intervals of about six hundred miles in seismic regions — that is, regions in which earthquakes normally occur — and about a thousand miles in aseismic regions. This figures out to about twenty stations in the U.S.S.R.

It is estimated that one to two hundred earthquakes with a force equivalent to that of an explosion of twenty kilotons occur in the Soviet Union every year. Of these, about half would be distinguished from explosions by first motion and other features in the seismograms obtained in the Geneva network of stations. This leaves about fifty to a hundred earthquakes a year which cannot be distinguished from explosions.

The only sure way to tell an earthquake from an explosion is to send an inspection team to the location of the earth disturbance. A combination of seismograms from several stations can determine the location to an accuracy of about five miles. Thus, one would have to send an inspection team to explore an area of about a hundred square miles for evidence of an explosion. A number of scientists have tried to work out procedures for such an inspection.

How many inspection teams would have to be sent out every year? Would one inspect every one of the fifty to a hundred questionable events? I do not think so. It is generally agreed that about 30 per cent would suffice. This would mean about twenty inspections in the Soviet Union annually in order to monitor possible nuclear tests above twenty kilotons.

A detailed study of the problem has been made by Dr. Richard Latter of the Rand Corporation. He finds that the capability of the control system would be greatly increased by distributing the stations somewhat differently from the pattern proposed in the Geneva negotiations and by increasing their number in Russia from twenty to thirty. This would make it much easier to distinguish earthquakes from explosions, so that only about ten earthquakes per year in the Soviet Union with a force equivalent to twenty kilotons or more will remain unidentified by their seismograms. Ten inspections would therefore cover all doubtful events equivalent to twenty kilotons or more. Forty inspections would make it possible to monitor all earthquakes above five kilotons. (A five-kiloton bomb is a small bomb. The Nagasaki bomb had a force of twenty kilotons.)

We must keep in mind, however, that our underground explosions in the past have been carried out in Nevada tuff, in a rock which is very soft and which therefore gives a relatively strong seismic signal. If the underground explosion is carried out in harder rock, such as salt, granite, or limestone, it creates a smaller signal. A signal which corresponds to a five-kiloton explosion in tuff may correspond to perhaps ten or fifteen kilotons in these harder types of rock. Even fifteen kilotons is not a very large atomic explosion.

Our capability of detection and inspection of underground explosions under the Geneva or the

Latter system would be quite satisfactory were it not for the possibility of deliberate concealment of explosions by a process known as decoupling, or muffling.

A very powerful method has been proposed by Dr. Albert Latter, the brother of Dr. Richard Latter. The method consists of making an enormous cavity underground and setting off the atomic bomb in the middle of the cavity. One can calculate that the apparent size of the explosion is thereby reduced by a factor of about 300.

Latter's decoupling theory was invented about January, 1959, and was then checked by many scientists, including me. It was experimentally verified with small explosions of conventional high explosive in Louisiana early this year. To decouple the explosion of a twenty-kiloton weapon, a spherical hole of about fifty million cubic feet, or nearly five hundred feet in diameter, is necessary. Moreover, the hole has to be three thousand feet below ground. The big room of Carlsbad Caverns is only big enough to muffle ten kilotons.

It would obviously be very slow and very expensive to excavate such a hole by a normal mining operation, with pick and shovel and high explosives. However, in salt domes, large holes can be made by washing out the salt; that is, by pumping water in and pumping brine out. Experts of the oil industry have estimated that to excavate a hole big enough to muffle a twenty-kiloton explosion would take more than two years and would cost about ten million dollars. This is quite a lot of money, but the time factor is probably more important. The actual washing operation has to be preceded by an engineering study, and after completion of the hole, considerable time is required to set up and complete an atomic test.

Whether a five-hundred-foot hole in a salt dome could be maintained is not known. Holes of about one tenth that volume are used to store oil and gasoline. It is also unknown whether a hole could be used repeatedly for nuclear testing.

I cannot imagine that the washing of a five-hundred-foot hole would go undetected, even in a closed country like the Soviet Union. Just the amount of salt water which would be carried up to the earth's surface is staggering, being many times the volume of the salt. Somehow this salt water must be disposed of. One possibility is to dump the brine directly into the sea or into depleted oil wells, but both of these methods severely limit the geographical areas in which the hole could be constructed. A more widely applicable method would be to dump it into a river. But even in a very big river, like the Ohio or the St. Lawrence, the salt excavated from one big hole would double the salt content for a year. The increase would be very easy to discover by making a

chemical analysis of the river water at regular intervals.

It is important that there are relatively few locations in which large holes can reasonably be dug; one needs salt domes and, in addition, ways to dispose of the salt water. In other types of rock, both excavation and disposal of the excavated material would be far more troublesome, and the resulting hole would probably be less safe and less reliable for decoupling. Luckily for inspection, the geographical regions where salt domes are known to exist are generally aseismic, so that any seismic signal originating from these regions would be suspicious. For the same reason, only a few inspections would be needed to guard against muffled shots. Of course, one first has to get a signal from a muffled explosion. How this can be done I shall discuss later.

THE main question is: Does any country want to go to such an extreme as constructing the big hole in order to cheat on a test ban? Can we really assume that the Russians would go to the trouble of negotiating a test cessation treaty just in order to turn around the next day and violate it?

Having participated in the negotiations with the Russian scientists at Geneva on three occasions, I believe that they are sincere in wanting the test cessation agreement and do not intend to cheat on it. For instance, in November, 1959, although the Russians were in many ways reluctant to agree with the American delegation, they were very eager to accept any improvements in detection apparatus suggested by the Americans. If the Russians wished to violate the treaty, they would have objected to these improvements.

Many other Americans, without disagreeing on any of the scientific facts, believe that the Russians are bent on violation, and they therefore oppose the cessation of testing. Dr. Edward Teller has argued this point repeatedly, and in particular in his television discussions with Lord Bertrand Russell. His line of reasoning runs as follows: "We cannot detect Russian underground tests of bombs of small yield; since we cannot detect these tests, we should assume that they are carrying out such tests. If they carry out such tests and we do not, then they will soon be ahead of us in the area of small nuclear weapons. When they are ahead of us in this area, they will have military superiority, and thereby they can blackmail us into complete submission. At that moment the whole free world will have to capitulate to Russian Communism."

It seems to me this is a series of non sequiturs. Every one of these steps, I think, is very unlikely. I do not think the Russians intend to violate a treaty banning weapons tests; I do not think that

the Russians could risk cheating, even if there is only a small likelihood of being detected. Even if we had no system of physical stations detecting nuclear tests, the Russians would not risk having some defector tell us about a clandestine nuclear explosion. If there were such a defector telling us of a Russian violation, it would not be very difficult to find physical evidence of it. I believe that the Soviet Union, which is posing as a peace-loving nation, whether rightly or wrongly, simply cannot afford to be caught in a violation, and therefore I think that it will not try to cheat.

But even supposing that the Russians wanted to cheat, what would they need to do? One violation, one nuclear test below ground, does not do much for the development of weapons. In the first place, they would have to develop entirely new methods to assess the results of a nuclear test. Most of the methods commonly used for observing the results of a test in air do not work underground. Probably several explosions of weapons whose performance is already known are required to develop methods of observation underground. Second, two or more test explosions are often needed to develop a single new weapon. Finally, a country which already has dozens of types of weapons will hardly be interested in developing just one more, in violation of a treaty. For all these reasons, a potential violator of the treaty would only be interested if he could perform a whole series of tests.

Now, if a series of tests were carried out, all at the same location, this would greatly simplify the work of the detecting agency. It would merely be necessary to detect the disturbances on the seismograph, not to distinguish them from earthquakes. The fact of repeated seismic disturbances originating from the same location (except as aftershocks of one big earthquake) would be sufficiently suspicious to warrant dispatching an inspection team to their site. With our accepted Geneva system of twenty stations in the Soviet Union, it is generally agreed that we could record disturbances underground of less than one kiloton. Thus, to violate the treaty without being detected, it would be necessary to find a new location for practically every test in the series. The development of a new test site would add enormously to the cost, complexity, and inconvenience of testing.

I HAD the doubtful honor of presenting the theory of the big hole to the Russians in Geneva in November, 1959. I felt deeply embarrassed in so doing, because it implied that we considered the Russians capable of cheating on a massive scale. I think that they would have been quite justified if

they had considered this an insult and had walked out of the negotiations in disgust.

The Russians seemed stunned by the theory of the big hole. In private, they took the Americans to task for having spent the last year inventing methods to cheat on a nuclear test cessation agreement. Officially, they spent considerable effort in trying to disprove the theory of the big hole. This is not the reaction of a country that is bent on cheating.

Two of the Russian scientists presented to the Geneva Conference their supposed proof that the big hole would not work. A day or two later, Dr. Latter and I gave the counterproof and showed, with the help of the Russian theory itself, that the Russian proof was wrong and that the theory of the big hole and the achievable decoupling factor were correct. We have been commended in the American press for this feat in theoretical physics. I am not proud of it.

In the recent hearings before the Joint Atomic Energy Committee of Congress, Dr. Teller recommended that we in the United States should continue determined research to find out further methods of decoupling, further methods of reducing the signal from an underground explosion. His argument is that we have to know all the possible methods of concealment if we are to develop a detection system which can deal with them. This may be so, but should we really spend our time and effort in drawing up a blueprint for a violator of the treaty, and also do the engineering development for him?

The Russians themselves have been quite consistent in their attitude toward decoupling. In negotiations in Geneva for joint research on improvement of seismic detection, they refused, as recently as May of this year, to participate in any research or decoupling or to permit the United States to engage in such research. "The Russian people," said Mr. Tsarapkin, the U.S.S.R. delegate, "will not understand it if research under the test ban treaty is conducted for the purpose of defeating the treaty."

Because of the difficulties of detecting small nuclear tests underground, President Eisenhower on February 11 proposed to the two other great nuclear powers to effect, for the time being, only a partial test ban treaty. Tests in the atmosphere and underwater, as well as in the nearer parts of outer space, would be discontinued. He proposed to ban all large nuclear explosions underground, those giving a signal equivalent to twenty kilotons or more under Nevada conditions. Smaller explosions and decoupled tests would be permitted, because they cannot be identified by the present system.

Further, the President proposed, the three pow-

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ers should start intensive research on the improvement of methods for detection and identification of underground explosions, so that in time the treaty could be extended to smaller underground explosions, and perhaps a complete ban could be effected in the end.

This proposal was accepted by the U.S.S.R. on March 19 with an important modification; namely, that there should be a moratorium on smaller nuclear tests for a number of years. While only the large tests would be prohibited in the treaty itself, the three powers would declare in a separate document that they would refrain from carrying out nuclear explosions under twenty kilotons. The Russians proposed four to five years as the duration of such a moratorium; the West, two to three years.

To pursue this proposal further, the seismologists of the three nuclear powers met in May in Geneva to make plans for joint research on seismic detection. A large measure of agreement was achieved, but there is still a question as to the number and type of nuclear explosions to be used in this research.

Somehow, the seismic research has become identified in the mind of the public with the setting off of underground test explosions. This is by no means correct. The main problem is to improve the instruments of detection. This can be done largely by utilizing signals from earthquakes. Few explosions will be needed.

We need instruments which will give us more diversified information. We want to eliminate from the seismograms as far as possible the "noise"; that is, the ever-present, minute, irregular motions of the earth. We need to learn to utilize calculating machines and mathematical tricks for the analysis of the records. We want to learn to deduce the shape and depth of the original earth displacement caused by a disturbance hundreds or thousands of miles distant from the recording instrument. At present, the depth can be deduced from the seismogram only if it is very great — about thirty miles or more. Perhaps we can learn to determine the depth of the source of the seismic signal to an accuracy of one mile. If this were possible, then signals originating from a depth of at least two miles could be attributed to earthquakes, because it is extremely difficult to drill holes that deep.

A NUMBER of promising ideas for improved detection were proposed in the spring of 1959 by the Berkner Panel, which was set up by the President's Science Advisory Committee to study the problem of detection of nuclear explosions. Some of these ideas were proposed to the Russians at the Techni-

cal Conference in November, 1959. With a lot of research there is good hope for substantial improvement of the art of detection during a two- or three-year moratorium.

Would it be possible by these improvements to detect a decoupled test of a twenty-kiloton explosion in a big hole, using only the twenty seismic stations provided in the Geneva system? We do not know. It must be remembered that, with a decoupling factor of 300, a twenty-kiloton explosion looks like only seventy tons, not kilotons, and this is a very small explosion indeed. With the present methods, the Geneva system can only detect and locate explosions down to about seven hundred tons, not identify them.

But suppose it is impossible to improve the seismic techniques sufficiently by research. We already know one method which would certainly enable us to detect even the fully decoupled tests. This method is to make the spacing between stations much smaller. My proposal would be to decrease the spacing from 600 miles, as agreed to in the Geneva negotiations, to 120 miles in the seismic regions, and also in those regions where there are salt domes. In the parts of the Soviet Union where there are neither earthquakes nor salt domes, the stations could be distributed at a much wider spacing — let us say, 250 miles. With such spacing, one would need about two hundred stations to cover the Soviet Union.

If the whole of the Soviet Union, seismic and aseismic regions alike, were to be covered by stations at 120-mile spacing, six hundred stations would be needed. I mentioned this number during the congressional hearings which were held in April, 1960, under the chairmanship of Mr. Hollifield. The number was then quoted out of context and without the proper qualifications in sensational press reports which implied that I no longer supported a test ban treaty. This, of course, did not correspond to the intention of my testimony.

The twenty stations in the U.S.S.R. which are provided by the Geneva system will be large, manned stations, each with about thirty technical people plus supporting personnel. They will have equipment to observe nuclear tests in the air as well as underground, and each station will have an array of a hundred seismographs in order to reduce the "noise."

The additional two hundred stations which I am proposing would be unmanned robot stations with one seismograph each, or possibly two. Such a system of robot stations would be simpler, cheaper, and, at the same time, more effective for seismic detection than the twenty large stations. I should think that these additional robot stations might well be acceptable to the Russians, especially if we do not demand them now but keep this idea in

mind as a way out if no better method is discovered to observe decoupled tests.

How much would such a system of small stations cost? Two estimates have arrived independently at a figure of about \$100,000 for each of these small stations. This includes provision for making the station "tamperproof." While one cannot expect such tamperproofing to be 100 per cent effective, one can expect to design the station in such a way that any tampering will be observable.

It is important to have reliable transmission of information from the robot stations to the large stations. Various methods of transmission have been considered by a group of communications experts. The total cost of the system of small stations in Russia, even with the most elaborate communication links, is estimated to be less than two hundred million dollars. Engineering estimates have also been made of the cost of the basic twenty-station net. No final figure has been given, but a total of half a billion for both the small and the large stations is probably the best conservative guess that can be made at present. This is not cheap, but it is a great deal less than the one to five billion dollars for the large stations alone which was mentioned in the Holifield hearings in April.

The system of robot stations is expected to detect and identify fully decoupled twenty-kiloton tests in the seismic regions. It is expected to detect and locate, but not identify, similar tests in the aseismic regions. I have previously shown that, once you get a signal, the number of inspections can be held within reasonable bounds. Of course, the robot stations would also greatly improve the detection of normal, not decoupled shots. It would be easy to detect and identify earthquakes down to one kiloton or less. Hence, the number of inspections could be greatly reduced.

It has been argued that several years will pass before we can build the system of small robot stations. This is true, but it would also take several years before a sufficiently large cavity could be constructed and successfully used.

In the meantime, there is a possibility of using already existing, smaller cavities in salt. There seem to exist, at least in this country, several holes which would fully decouple an explosion of two or three kilotons. If similar cavities exist in Russia, it must be admitted that it would be possible to use these for testing very small weapons; there will always be a threshold of detection, even with the best detection system. The question is whether such testing would be worth while. Moreover, a two-kiloton hole could be used to achieve partial decoupling for a larger explosion — say, twenty kilotons. From the Louisiana experiments, one may estimate that this proportion of hole size to explosion energy will give decoupling by a

factor of 30. The twenty-kiloton explosion then looks like two thirds of a kiloton. This is just detectable by the Geneva net of stations, although without the robot stations a signal of this size could not be distinguished from an earthquake. Thus, with the Geneva net alone, it would be risky for a violator to attempt a partially decoupled explosion of twenty kilotons. A ten-kiloton explosion, partially decoupled in an existing two-kiloton hole, could probably go undetected until either we have robot stations or significant improvements have been made in the art of detection. However, it seems from the Louisiana experiments that the cavity will suffer damage when it is used for partial decoupling of an oversized explosion. It is, then, very doubtful whether it could be used more than once. In this way, the few existing big holes would soon be used up.

I believe, therefore, that it is technically feasible to devise a system of detection stations and inspections which will give reasonable assurance against clandestine testing, with the possible exception of very small, decoupled tests.

A KEY point in the monitoring system is on-site inspection. This was recognized as necessary in the Experts Conference of the summer of 1958. The Russians agreed reluctantly, but they did agree, to a passage which says that "all events which are recorded by the control stations and which could be suspected of being nuclear explosions will have to be inspected on the site." This passage, which our negotiators insisted on, has been a very powerful argument for our side. I am sure that the Russians have often regretted that they agreed to it. On the other hand, our delegation would not have agreed to the final report of the conference without this passage.

Estimates made in Washington have ranged as high as from one to three hundred necessary inspections per year in the Soviet Union for a complete test ban. Obviously, the Soviet Union wishes to prevent such a large number of inspections. Soviet negotiators have objected time and time again that we would use the on-site inspections for espionage purposes.

To solve this impasse, Prime Minister Macmillan, on his visit to Moscow in the spring of 1959, proposed that there should be a fixed quota of inspections every year in each country and that, in exchange, each side should have free choice of the inspections to be made on the territory of the other.

In other words, if a suspicious event is recorded on the seismographs in Russia, then the West, which means essentially the United States and

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Britain, would have the right to choose whether or not to inspect this event. They would decide on the basis of other knowledge whether it is reasonable in that particular locality to suspect a nuclear explosion. If, for example, the seismic event is shown to originate from a completely trackless wilderness in the mountains, then it may be presumed by the West that it was not a nuclear explosion. If, however, the seismic event is recorded in an abandoned mining area where one might very easily dig a tunnel to put in a nuclear bomb for testing, or especially in a salt dome area, then we would presumably insist on inspecting that area.

It seems to me that this idea of a quota, combined with free choice by the West of the events to be inspected in Russia, is a good compromise. Russia has accepted this idea in principle; our government has not: it insists on inspection of a percentage of the suspicious events rather than a fixed number. This implies that the number of inspections would be determined on the basis of technical need. The Russian position is that the quota must be determined on the basis of political acceptability alone.

In practice, however, the U.S. government has adopted the quota idea as part of President Eisenhower's proposal of February 11, 1960, of a partial ban on nuclear tests. He proposed that this partial test ban be enforced by a quota of about twenty inspections per year in the U.S.S.R., a very reasonable number. The Russians, while accepting the February proposal with some modification, have not as yet responded to the proposed number of inspections. In fact, they have never officially mentioned any number and have given us to understand only that they are thinking of very small numbers of inspections. But one point is clear: The quota must be fixed by the negotiators before either Russia or the West will sign a treaty.

LET us assume the most unlikely and worst possible case; let us assume that the Russians have gone to all the trouble of negotiating a treaty only in order to violate it. It would take them a very long time to set off any significant number of explosions; it would take a tremendous effort. It is generally agreed that they could test only small nuclear weapons. Even in the area of small nuclear weapons, a test series would take a number of years. Now, let us even assume that the Russians wish to go to all this trouble just to develop further small nuclear weapons. Where do we stand?

At this time, it is generally agreed that we are far ahead of Russia in the development of small

nuclear weapons. We have nuclear weapons ranging from twenty kilotons down to a fraction of a kiloton. We have them in all different sizes. We have weapons which can be carried in big airplanes, in fighter planes, in ballistic missiles, in land-based rockets, and even in airborne rockets to bring down enemy planes. We have nuclear weapons which can be shot in short-range rockets, like Honest John; we have nuclear weapons so small that they can be carried by the infantry with relative ease. We have an enormous arsenal of such weapons. The Russians also have a number of such weapons, but their arsenal in the field of small weapons, as far as we know, is much more limited than ours, and probably their weapons are not quite as sophisticated. It would take them a long time to catch up with us.

What is the alternative? Suppose we resume tests only in the area of small weapons. Then we could be sure that it would not take the Russians very long to reach our present, very high-level technology in this field. But, it will be argued by Dr. Teller and his associates, in the meantime we also can make progress. Clearly, we could if we resumed nuclear tests. However, we have already gone far enough so that very little we can do in the future will be of great military significance.

While the Russians could gain considerably by the resumption of tests of small nuclear weapons, they also have enough such weapons to give them a sizable capability in case of a tactical nuclear war. Therefore, they do not have a desperate need for improving their weapons, and thus not enough incentive for testing to risk a violation. Yet, if nuclear tests were resumed legally, the Russians would probably make more rapid progress than we would.

It has been claimed that we still have a long way to go in nuclear weapons. There are two schools of thought on this: one essentially represented by the Livermore Laboratory, the other by the Los Alamos Laboratory. The Los Alamos Laboratory, our chief laboratory in the development of nuclear weapons, which has to its credit most of the weapons which have been developed up till now, is generally of the opinion that not much more can be obtained in the way of weapons improvement. They will admit, and I will admit, that there can always be some further improvement, but the question is, Is it worth while? Even if testing were allowed, would it be worth a great effort?

Let me repeat: If the Russians really want tactical nuclear weapons — that is, nuclear weapons of small yield — then the best thing for them to do would be to resume testing of such small weapons officially, exactly as was suggested in the original proposal by President Eisenhower on February 11.

The fact that they asked instead for a moratorium on small tests indicates to me that they do not put much weight on development of these weapons.

I believe that if tests were resumed, if the negotiations on test cessation were to break down, then the Russians would choose to test big weapons, hydrogen weapons, in the megaton class. I think that these are the weapons which are most dangerous to us; these are the weapons which the Soviets consider to be of the greatest military importance to them. I want to remind you of the situation in the fall of 1958. At that time the United States put in an extra test series, which is known as the Hardtack II series, carried out in Nevada. This test series consisted of a number of small nuclear explosions, from about twenty kilotons down to a fraction of a kiloton.

At the same time, the Russians tested the largest weapons they have ever tested, weapons of many megatons. They increased the yield from their weapons; they made them more efficient in the large-megaton class. They probably obtained in that test series the warhead for their big intercontinental ballistic missile. This is a tremendous weapon in their hands. If the Russians were to launch a determined attack on this country, perhaps a surprise attack, they would undoubtedly use these enormous weapons.

I believe that it was much to our disadvantage that the United States conducted the test series in the fall of 1958. It would have been in our power to declare in August of 1958 that we would stop testing from that moment on. If President Eisenhower had made this bold declaration, I do not believe that the Russians would have conducted their test series in September and October. They used our small test series as a very welcome excuse to conduct their own. The bold political decision to stop tests altogether would have been much more to our military advantage, since such a decision would have made it difficult for the Russians to resume testing and to test their big warheads. Had the Russians tested nevertheless, we would still have been free to conduct the small Hardtack II series. We got comparatively little from our small test series; they got a great deal, and very big weapons, out of theirs.

If we were now to resume testing, if we were to break off negotiations in Geneva, then we could not force the Russians to test only small weapons underground. While we might restrict our own testing in this manner, the Russians could test anything that they considered to be to their military advantage. Whether their tests would be in the multimegaton category, or whether they would try to decrease the weight for, let us say, a one-megaton weapon, I could not predict. But I strongly suspect that they would choose to test

large weapons rather than small ones, that they would choose to test strategic weapons, which they consider the most important, rather than the tactical weapons which have had such prominence in public discussions in the United States.

IF we had stopped nuclear testing when the Russians first suggested doing so, at the beginning of 1956, we would presumably have had a very great superiority in hydrogen bombs. We had tested at least half a dozen; they had tested one type only. We might possibly have a situation in which the Russians would not now have a hydrogen warhead for their ICBM. The missile gap has been a great worry to our military during the past two years. Without a hydrogen warhead, the ICBM would be much less important, and our superior position in planes might have remained of much greater significance.

The politically bold decision to accept the Russian offer to stop nuclear testing in 1956, either before or after our own 1956 test series, would then have given us considerable military advantage. Sometimes insistence on 100 per cent security actually impairs our security, while the bold decision — though at the time it seems to involve some risk — will give us more security in the long run.

There can be no doubt that, since 1956, the Russians have gained in nuclear weapons, relative to us. It is my belief that this is quite natural: the country that is behind will catch up; the country that is ahead will not make so much progress in the future. Dr. Teller has pointed out that our nuclear weapons today are about a thousand times as efficient as they were in 1945. He states, "In comparison with the nuclear weapons of 1960, those of 1950 appear completely obsolete. If the development should continue, there is no doubt that in 1970 nuclear explosives can be produced compared to which our present weapons will appear similarly outdated." The first sentence is clearly true. But if we want to increase the efficiency of our nuclear weapons by another factor of about ten — not a thousand — from the presently achievable, we come to a point where the entire material in the weapon must undergo a nuclear reaction. Since there must be assembly mechanism, triggers, bomb cases, and the like, this is clearly impossible. Further nuclear weapons development will be limited by the laws of physics.

This being so, further testing by both sides would bring the Russian capability closer and closer to ours. If we stop nuclear testing now, we may reserve at least the little bit of military advantage in nuclear weapons that we still possess.

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It is certainly late enough. So I come to the conclusion that, even from the purely military point of view, for our purely military strength compared with Russia's, we would gain by a test cessation agreement.

The political gain would be enormous. Basic to the accepted control system of a test ban are the control stations on the territory of the contracting parties. If the agreement becomes reality, the Russians will for the first time permit foreign international inspectors to go on their soil, to have the right to check up on their activities. This is the first time that the Russians have been willing to give up any part of their sovereignty. Of course, we are asked to give up the same part of our sovereignty too, but for the Russians, with their extreme desire for secrecy, it is a far more difficult thing to do, and it would be a real achievement of the negotiations.

The Russians have further admitted that there should be on-site inspections of suspicious events detected by the physical control stations. This is another major concession. So, in the test cessation agreement, we would get the first admission in principle of the rights of a foreign control organ on Russian soil, an admission which might be of the utmost importance for further disarmament agreements. It would be very dangerous indeed for us to jeopardize this achievement by not concluding the test cessation agreement.

The main importance of our negotiations on the test cessation agreement comes, I believe, not from this agreement itself, important as it is, but from further agreements which must follow. It has been recognized widely in the United States, and also in the Soviet Union, that the continued arms race makes no sense. The two countries are fully capable of destroying each other, in fact, of destroying each other several times over. This is an absurdity. Modern war simply does not make sense as an instrument of national policy. I believe that we should try to arrive at a situation of carefully controlled limitation of armaments. It is a difficult thing to achieve, and it will be a long road before we do.

However, if we want to stop the armaments race, then we have to make a start somewhere. It has to be made in a way consistent with United States policy, meaning that every limitation of armaments must be carefully controlled. We have to make a start in an area where it does not cost us too much, where we can back off again if the

first treaty doesn't work. With the test cessation agreement, this would be possible, because it covers a sufficiently restricted subject.

I have so far discussed this problem entirely in regard to the two powers, the United States and Russia. However, the effect on other powers is at least equally important. It is clear that other powers may also get nuclear weapons soon. In fact, if we wait long enough, they surely will do so. I do not know how long it will take for China to achieve this capability. I do not think it will be next year, but I will not be surprised if the Chinese develop nuclear weapons before another five years pass. It is to our interest to keep nuclear weapons out of China's possession. We have every interest in restricting the nuclear club to its present members, essentially three, with France a junior partner. If the three great nuclear powers continue nuclear testing, then there will be no pressure on the other countries to refrain from developing nuclear weapons. If, however, the three great powers give up nuclear testing, and give it up completely, then popular pressure, both from the great powers and from the small powers, will be very strong on the other countries to make them adhere to the treaty which the great powers have signed.

I cannot predict whether China will in fact adhere to a test cessation treaty. I think that both Russia and the United States would desire that China do so. But one thing seems to me certain: If we do not have a treaty on cessation of nuclear tests, then China will surely get nuclear weapons in a fairly short time. For this reason, it is imperative not only to have a treaty but to have it soon.

At this time we can still get something if we agree to stop nuclear testing. But we have a wasting asset here. Before long, I believe, public opinion in the world will force us to stop nuclear testing without our getting anything in exchange. At present we get in exchange recognition by Russia of stations on Russian soil and of the principle of controlled disarmament. We may further get in exchange the restriction of the nuclear club to three members.

Opponents of the test cessation agreement want to have a perfect agreement; they want to have an agreement in which we can be sure to detect each and every violation, no matter how small. I think that by insisting on perfection we shall end up with nothing.