

Comprehensive Test Ban Treaty: Grounds for Objection Diminish

Attainment of a treaty banning all nuclear weapons tests has been a stated policy objective of the United States and Russia since 1958. Partial success was achieved in 1963 with the prohibition of all but underground tests.

The failure to ban underground explosions was an indication of the force of the argument that, as long as national defense depended upon the availability of a varied and reliable stockpile of nuclear weapons, it would be foolhardy to stop testing. A further obstacle was the need to lessen widespread fears concerning the dangers inherent in cheating by other countries.

To minimize these fears, the United States said it would insist on measures that would deter a potential violator and provide assurance that a treaty was being adhered to. Such measures have included on-site inspection of the area of origin of certain unidentified seismic signals, and seismic observatories in the Soviet Union. Yet these have always been anathema to the Russians, who claim that a country could obtain adequate assurance through its own information systems. It is not clear how much of the Soviet objection has been based on its unwillingness to accept even minimal intrusions upon its sovereignty and how much has been a useful pretext for not agreeing to a nuclear test ban, which is probably opposed by influential groups within Russia. Nor is it clear how much of the United States' insistence upon inspections is inspired by domestic opponents of restrictions on testing.

In the 14 January issue of *Science*, Robert Neild and J. P. Ruina suggest that an overall examination of the matter shows that certain impediments to a ban on underground testing that had existed in 1963 are now much less severe. Their conclusion is based on what appears to them to be a greatly diminished relevance of nuclear testing and an increased ease in obtaining assurance that an agreement is being observed. The Neild-Ruina thesis may gain widespread acceptance as a con-

sequence of two happenings of the last 18 months.

The first was a meeting of seismologists that was convened for the purpose of discussing the use of seismological data to discriminate between earthquakes and underground explosions. The meeting was sponsored by the Advanced Research Projects Agency (ARPA) of the Department of Defense. It was held at Woods Hole, Massachusetts, in the summer of 1970. The second important event was the Cannikin nuclear weapons test, which was conducted last November on Amchitka Island.

The 5-megaton Cannikin explosion was related to the development of the warhead for the Spartan interceptor missile, an element of the Safeguard Ballistic Missile Defense system. The furor over this experiment originated mainly in the worry that the explosion would trigger a very large earthquake and tidal wave. It was also feared that a substantial amount of radioactivity might be released or that the local wildlife would be seriously affected.

The principal reasons for the test, as put forth in a letter to Senator John Pastore (D-R.I.) by the then Deputy Defense Secretary David Packard, were to minimize the possibility of stockpiling a defective design, to measure the explosive yield, and to measure the emitted flux and spectrum of x-rays. Packard also took note of the extensive environmental studies and experiments that had convinced him that Cannikin could be undertaken "without important environmental impact."

There was, in fact, not much disagreement among experts concerning the magnitude of the environmental risk associated with Cannikin; the disagreement was whether the benefits to be derived from the experiment warranted incurring the risk, even though it might be small.

Packard's letter did not make an overwhelming case for the need and, in fact, raised more questions than it answered. Just how important was it to resolve uncertainties that would exist

without the full-yield test? What was the plan if the design were defective? Did the fact that the Spartan warhead was designed to have low fission output in order to reduce radar blackout imply that the Safeguard radars would be blacked out by incoming, high fission warheads detonated at great altitudes?

In a letter to Senator Edmund Muskie (D-Maine), three members of the Federation of American Scientists Strategic Weapons Committee (Herbert Scoville, Marvin Goldberger, and Morton Halperin) noted that, in any event, the Spartan missile would play only a minor role in the defense of the Minuteman missiles, which was supposedly the major function of the Safeguard antiballistic missile.

In sum, the Administration seemed convincing in its contention that the environmental fears about Cannikin were overblown, but it was not very persuasive in justifying the experiment itself. As a consequence, doubts concerning the need not only for Cannikin, but for nuclear weapons tests in general were expressed in quarters heretofore silent. Interestingly, the lasting impact of the episode may have been to undermine substantially the rationale for the entire nuclear weapons test program.

The Woods Hole conference raised a different issue. On 11 April last year, the *Washington Post* carried an article based on the proceedings of that meeting. It suggested that very substantial progress had been made in seismological research related to the test ban verification problem. This was important because of its potential impact upon the requirement for on-site inspections. Whether or not the need for inspections is genuine, anything that makes the verification problem more tractable will ease the demand for them. This in turn will tend to push the United States toward a more negotiable position, even though neither American nor Russian nuclear weapons enthusiasts would welcome such a turn of events.

At Woods Hole the conferees focused upon the technique of differentiating between earthquake-generated seismic signals and explosion signals on the basis of the ratio of energy in the seismic waves that travel along the earth's surface to that in the waves that travel through the earth. It had been determined that, in comparison to the great majority of earthquakes, explosions produce substantially smaller

surface waves. It had also been demonstrated that surface waves from small earthquakes could be detected at great distances from the event. The implication of these findings was that it would be possible to construct a network of seismological observatories outside Russia which would be able to identify at least 90 percent of Russian earthquakes having a body-wave magnitude in excess of that associated with a typical low-kiloton underground explosion.

The immediate Defense Department response to the 11 April article was a statement implying that there had been a gross exaggeration concerning the amount of progress in seismological research and the impact such progress might have upon the U.S. test ban position. The Pentagon said that the Woods Hole report was not actually a report, but a collection of technical papers presented at the conference and circulated for review by the participants. Furthermore, the views expressed in these papers did not reflect those of ARPA, the sponsoring agency.

The Defense Department stand was that all low-kiloton tests could not be detected; that not all events that might be detected could be identified; that there were several ways of concealing tests so that they would not produce suspicious seismic evidence; and that on-site inspections were still necessary to allay doubts about those earthquakes that could not be identified and to differentiate between chemical and nuclear explosions.

Neither in this statement nor in others that would be made in the following months did Defense officials make any allowance for what intelligence-gathering systems might contribute to the identification of earthquakes or the differentiation between nuclear and chemical explosions. The reason for not mentioning intelligence was presumably that it was too highly classified. But if President Johnson could say in 1967 that reconnaissance satellites were useful for counting Russian missiles, it seemed to some that it should have been possible at least to admit in 1971 that such satellites would provide information with regard to the simpler task of indicating the chemical or nuclear nature of an explosion.

Moreover, since there could never be absolute assurance that clandestine tests were not being conducted, the Defense Department's response did not address the more pertinent questions. Had there been sufficient prog-

ress in developing detection and identification techniques for the United States to be confident, without inspections, that its security was not being jeopardized by those violations that might be unnoticed? Even if there were provisions for inspections, how much useful information would they provide in addition to that acquired by unilateral means?

As a result of the *Washington Post* article, senators and foreign embassies requested that they be sent the Woods Hole documents. After a delay, some of the requesting parties received the report, only to find that the summary had been removed. In expressing regret at this omission, Senator Clifford Case (R-N.J.) said that "it [the summary] was the only portion of the report comprehensible to the layman."

Summary Troubles

Apparently unhappy with the original summary, ARPA then produced a substantially revised version which was much less sanguine than the original. According to the 13 June *Washington Post*, a Pentagon spokesman had explained that the first summary had not been cleared for publication, that it had expressed the views of only one person, and that the second version reflected the "consensus of the 'entire' meeting" rather than the "views of one man." Some Woods Hole attendees wrote to Senator Case that the first they had heard of the revised summary was from the press. Others said that the original summary better represented their views than did the new version.

On 22 and 23 July, the Arms Control Subcommittee of the Senate Foreign Relations Committee held hearings chaired by Senator Muskie on the prospects for a Comprehensive Nuclear Test Ban Treaty. These hearings had been requested in May by Senator Case, who had inferred from reports of the Woods Hole discussion that the United States might adopt a more negotiable test ban position.

Several nongovernment experts on arms control presented testimony to the effect that they believed on-site inspections were not necessary, because there would be only an insignificant number of events of meaningful size that could not be identified on the basis of seismic data and intelligence information. Government witnesses were more pessimistic, although they were more forthcoming than the Pentagon had been in response to the 11 April *Washington Post* article. The Defense

Department's position was that, under the most optimistic assumptions, it would be possible to collect enough data from seismic stations outside Russia to identify all but 25 events with a body-wave magnitude in excess of 4.0. At the same time, the government witnesses cautioned that this ability to identify earthquakes would not eliminate problems arising from the use of such evasion techniques as concealing explosion signals in the waves generated by a large earthquake, or by testing in big holes or dry alluvium.

The Administration also took the position that 25 unidentified earthquakes, the minimum number that might be expected under the best of circumstances, was too large to be tolerated—that on-site inspections would still be required to resolve ambiguities about these events. James Brune, a seismologist at the University of California at San Diego, said that he did not know where the number 25 came from and that there were some seismologists who believed that this number would be closer to zero. (It is the understanding of one Senate aide that the 25 is based on the fact that, at present, 10 percent of the events above magnitude 4.5, the current "identification threshold," are unidentified. The inference drawn from this fact is that, if the "identification threshold" were lowered to 4.0, 10 percent of the 250 seismic events in the Soviet Union above this magnitude would be unidentified.)

In October, the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy conducted its own hearings on seismic discrimination between earthquakes and explosions. The joint committee has traditionally been more hard-nosed toward bans on nuclear tests than has the Senate Foreign Relations Committee. There seemed to be some feeling among members of the joint committee that there had been too much loose talk in the Senate concerning the ease with which a complete test ban might be monitored. It would not have been surprising, therefore, if these hearings had produced a much more conservative appraisal of progress in attacking the verification problem. As it turned out, the testimony and ensuing discussion substantially undercut many of the maxims upon which the U.S. test ban position had long rested.

In the first place, Defense scientists were much more positive than they had been to date concerning the ability to

identify seismic events with body-wave magnitude above 4.0. The thrust of their testimony in this regard was virtually indistinguishable from the conclusions contained in the original and repudiated summary of the Woods Hole report.

The most significant revelation, however, had to do with the utility of on-site inspections. After years of its being implied that on-site inspections would play a crucial role, the report now was that a determined violator could conduct a test in such a way as to prevent effects that might be uncovered by inspectors. In addition, certain of the proposed methods of carrying out violations (for example, testing in large cavities, in alluvium, or in the aftermath of an earthquake) would produce no seismic indication that an explosion had occurred; thus there would be no seismological evidence on which to base a demand for an inspection. (It has always been assumed that inspection requests would be grounded on ambiguous seismic data.) This pessimistic prognosis concerning the overall utility of inspections prompted Senator Pastore to ask where we were in light of the fact "that even with on-site inspection you cannot assuredly detect and identify." The Defense Department position was that on-site inspections would have a deterrent value because a violator would be aware that he might make a mistake which would allow the inspectors to obtain conclusive evidence of cheating. He would then have to choose between the undesirable alternatives of not allowing an inspection or running the risk of having incriminating evidence found. In response to this contention, it might be noted that a violator would, in any case, act with the knowledge that he might make a mistake which would be detected by other countries' detection systems operating solely outside his boundaries. The essential, but unasked question, is how much added deterrence would be derived from the threat of on-site inspections.

The third important piece of information developed at the joint committee hearings concerned the prevalence in Russia of dry alluvium. Because explosions detonated in this material produce seismic signals that are approximately 10 times smaller than the signals associated with explosions of equivalent size in more common materials, dry alluvium has been considered useful for concealing illicit nuclear explosions. The rub has

New Science Minister for Canada

Canada, in its most recent move toward developing a coherent national science policy, has established a new cabinet-level department, the Ministry of State for Science and Technology. The new minister is Alastair Gillespie, an economist and businessman who was elected to the Canadian House of Commons in 1968.

The creation of the ministry is the latest in a series of steps the Canadian government has taken over the past half-dozen years to develop a centralized science advisory structure. The first was the creation in 1964 of the Science Secretariat, a small office roughly equivalent to the U.S. Office of Science and Technology. Two years later came the Science Council, an independent advisory body appointed by the prime minister, which functions along the lines of the National Academy of Sciences Committee on Science and Public Policy (*Science*, 2 August 1968).

The Science Secretariat has been absorbed as the nucleus of the new ministry, and the Science Council now reports directly to the science minister instead of to the prime minister. The ministry has no operational or grant-giving functions—rather, it is a top-level policy-formulating body. Ultimately, the staff will be several dozen, with about half the professionals serving on a part-time contract basis.

Two primary issues confront Gillespie. Foremost is the need to stimulate more research and development within industry rather than government, which presently funds some 75 percent of the nation's total annual \$1-billion R & D output. Science-based industry in Canada has been in a state of relative stagnation over the past decade, while manufacturing has increased steadily and service industries have flourished.

The Science Council in a report last fall (No. 15) expressed "alarm" over the deterioration of technology-based industry and warned that, unless Canada carves a place for itself in the world market, it is in danger of falling back into its old role of being primarily an exporter of raw materials.

The total rate of unemployment in Canada is over 6 percent, and the job situation for scientists and engineers is believed to be at least as bad as it is in the United States. The creation of new jobs is urgent, because the supply of technical manpower is increasing by 9 percent per year (augmented by steady immigration), while the demand over the past 3 years has been static.

Another issue the new ministry is concerned with is one that affects the entire Canadian economy. Since Canada is too small—its population is one-tenth that of the United States—to support large-scale technological ventures on its own, it has welcomed the subsidiaries of many foreign-based corporations, notably those from the United States. At this point, 50 to 75 percent of the Canadian manufacturing industry is foreign-owned, and the proportion is extremely high in the automobile, chemical, and petroleum industries, where much R & D is concentrated.

Now, with the new mood of nationalism prevailing in Canada, the government is looking for ways to develop more native capability and independence. Officialdom is well aware, though, that actions resulting in the loss of foreign R & D capability would be a staggering blow to the economy. (Thus they are acutely interested in the new initiatives William M. Magruder is cooking up, for fear that the United States may decide to entice some of its R & D back onto home ground.)

Canada is in the unique position of being the only industrialized country that is neither a major producer of technology nor part of a large trading bloc. Thus it has been forced to limit itself to areas of specialization that can be feasibly supported—such as the development of heavy water reactors fueled by natural uranium. Part of Canada's new industrial strategy will be to encourage the development of more Canadian-based multinational corporations to create a market large enough to support innovative R & D. This is related to the nation's new foreign policy which is aimed at expansion of world trade ties and decreased vulnerability to the fluctuations in the U.S. economy.—C.H.

been that dry alluvium is only rarely found in sufficient depth to conceal the effects of explosions of significant size. It must be deep enough not only to contain radioactive materials, but also to prevent the formation of collapse craters of the type that usually occur at the test ground in Nevada.

ARPA has funded studies to examine the extent to which sufficiently deep and dry alluvium might be found in Russia. As recently as the July Senate hearings, it had been implied that tests of up to 45 kilotons could be concealed by testing in this material. But in October, the testimony was that it would probably not be useful for tests above 1 or 2 kilotons, which happens to be the yield below which explosions in any kind of earth materials might have a good chance of escaping detection. The implication was that dry alluvium of sufficient depth for greater-yield tests probably does not exist in Russia.

The testimony also addressed other possibilities for concealing tests. One method was to test in large, approximately spherical holes. It was suggested that it would be technically feasible to conceal an explosion of as much as 50 kilotons by this method. According to the decoupling theory, 50 kilotons detonated in a cavity 475 feet in diameter and about 4000 feet below the earth's surface would produce approx-

imately the same size seismic signals as a 0.5-kiloton explosion detonated in the conventional manner in hard rock. It was also implied that signals from 50- to 100-kiloton explosions could be concealed in seismic waves generated by a large earthquake. Another hypothesized evasion technique involves setting off in rapid succession a series of explosions; thus the composite seismic signal would have the character of earthquake signals.

There is little basis for determining the amount of credence that should be given such evasion possibilities. All assertions about what might be done to conceal explosions are based on little or no experimental data at explosion yields that might be significant.

The Pentagon's backing and filling as to whether anything new has happened with regard to the ability to detect violations was indicative of a mood within the Pentagon. Advances in seismological research are not welcomed by officials who believe continued testing is more important than the treaty. Defense Department scientists, who manage test detection research, are thus subjected to conflicting pressures. Senator Pastore took note of the problem and suggested that the management of test detection research be transferred from the Pentagon to the Office of Science and Technology in the White House.

In noting the flurry of talk about the test ban, Stephen Rosenfeld suggested recently in the *Washington Post* that the interest was not shared by those in government who were in a position to make test ban policy. And indeed it may be that the matter has come full circle—that doubts have been raised about the need for tests and that the verification problem had been eased—but there has been no essential change. However, it is more likely that things are not the same. The Woods Hole conference and the Cannikin episode have probably triggered a permanent movement to new ground.

The most significant changes of 1971 appeared to be the rather widespread willingness to cast a skeptical eye upon such sacred cows as the relevance of any nuclear tests, the ease of concealing violations, the dangers inherent in undetected clandestine activity, and the need for on-site inspections. Such changes will probably assure a more rational dialog, if not a treaty banning all nuclear weapons tests.

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RESEARCH TOPICS

Mars as an Active Planet: The View from Mariner 9

Only in recent years have ground-based optical and radar studies of Mars, and now spacecraft observations, made available pictures and maps of sufficient clarity to rule out some of the scientific speculations and popular fantasies of the past. The new evidence, however, is only slightly less interesting than the old stories of canals and dying civilizations. Far from being a dying planet, Mars turns out to have many features that appear to be, on geological time scales, of recent origin. The preliminary reports of the Mariner 9 findings on pages 293–320 of this issue of *Science* provide evidence of past volcanic activity, of faulting and other indications of major tectonic zones, and of geochemical differentiation. Observations of the dust storm that initially obscured most

of the Martian surface have led to the conviction that the dust is more prevalent than had been expected and that dust, rather than biological phenomena, may be the cause of the seasonal and secular changes in the appearance of the planet as seen through telescopes.

When the Mariner 9 spacecraft went into orbit around Mars last 13 November, the dust storm was still so intense that only the south polar cap and the tops of a few high mountains could be seen. During December, however, visibility improved noticeably, and, by 29 December, when the spacecraft's orbit was adjusted slightly to prepare for photographic mapping of the planet, the dust had cleared enough to reveal many additional features. The dust settled first around Mars's south pole, and is

gradually clearing in more northerly regions, fortuitously the same sequence as the mapping pattern decreed by the Mariner orbit.

Mapping of the Martian surface is now under way, and the Mariner scientists expect to complete most of the observations originally planned for the mission. The spacecraft carries two television cameras, ultraviolet and infrared spectrometers, and an infrared radiometer, and the telemetry signals from the spacecraft to Earth are being used for an occultation experiment and a celestial mechanics experiment. The most dramatic findings have come from the television pictures, but all experiments are working well and are returning large amounts of data. The two Soviet spacecraft in orbit around Mars