THE NRDC/SOVIET ACADEMY OF SCIENCES JOINT NUCLEAR TEST BAN VERIFICATION PROJECT

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[Thomas B. Cochran received the Forum's 1987 Leo Szilard Award for his role in the project described here. This article is the author's talk given at the Forum's Awards Session, 20 April 1987, at the Crystal City, VA, APS meeting. For more about the history and personnel of the project, and for the official text of the agreement, see *Physics and Society*, September 1987, pp.6-7.]

I am deeply honored to have been chosen to be the recipient of the 1987 Leo Szilard Award for my negotiation and implementation of a May 1986 Agreement with the Soviet Academy of Sciences for demonstration of in-country seismic verification of a nuclear test ban. I am, of course, very pleased to be now added to the list of great individual physicists who have received this award, but the credit for the NRDC/Soviet Academy project must be shared among the number of individuals who have played an important role in this historic initiative - the largest privately funded scientific exchange ever between the U.S. and the U.S.S.R..

On the Soviet side, Academician Evgeny P. Velikhov, Vice President of the Soviet Academy of Sciences and Academician M.A. Sadovsky, Director of the Institute of Physics of the Earth (IPE) agreed to the project in Moscow last May when I first formally presented the concept at an Academy-sponsored Workshop on Verification of a Comprehensive Test Ban. At what must have been considerable political risk, they showed great political courage in seeking and obtaining Soviet government approval for this unprecedented project. Professor Mikhail Gokhberg, Deputy Director of IPE, is responsible for the overall management of the Soviet component of the project and Dr. Igor Nersesov, Chief of Seismology at IPE, oversees the Soviet field team.

On the American side, Dr. Charles Archambeau of the University of Colorado has overall technical responsibility for seismic research and is Chairman of the NRDC Seismic Monitoring Advisory Committee. Dr. Jonathan Berger of Scripps Institution of Oceanography, University of California, San Diego and Professor Jim Brune of Scripps and who is also Director of the Seismological Laboratory at the University of Nevada, Reno are co-investigators responsible for the American field teams and the installation and operation of the seismic equipment.

The project represents the largest single program NRDC has ever undertaken in its 17-year history. Adrian DeWind, chairman of NRDC, participated in the Moscow Workshop, signed the agreement with the Soviet Academy on behalf of NRDC, and has played an active role in its implementation. John Adams, Executive Director of NRDC, has made a major contribution, including his tireless efforts to raise the funds for NRDC's participation in this exchange. My colleague S. Jacob Scherr, NRDC Staff Attorney, has worked closely with me on a day-to-day basis in the management of the project.

There are numerous other Americans and Soviets on what we think of as our Test Ban Verification Team, making this project a success. And finally, this effort would never have gotten off the ground without the very generous support from American foundations, individual funders, and the public.

The United States has sought a Comprehensive Test Ban Treaty (CTBT) since the mid-1950s - through every Administration from Eisenhower to Carter. From a U.S. perspective, at least up until the Reagan Administration, achieving adequate verification was the principal obstacle. Ultimately, negotiations toward a CTBT were broken off by the Carter Administration following the Soviet invasion of Afghanistan. Negotiations were not resumed during the Reagan Administration. Reagan is the only President to actively oppose a CTB.

General Secretary Gorbachev made clear his interest in a test ban when he unilaterally suspended Soviet testing in July 1985. He also announced that verification would not be an obstacle to a test ban. It is in this setting on May 22 of last year that NRDC proposed to the Soviet Academy of Sciences to establish and jointly staff seismic monitoring stations adjacent to each of the principal nuclear weapons testing sites in the two countries: in eastern Kazakhstan in the Soviet Union and the Nevada Test Site in the United States. As you know, seismology provides the main tools for detecting and discriminating underground nuclear tests and for accurate estimates of their yields. The objectives of the project as originally envisioned are:

- to demonstrate that in-country nuclear weapons test verification is not an obstacle to a comprehensive test ban (CTB) or a moratorium on testing;
- to demonstrate that scientists of the United States and the Soviet Union are prepared to cooperate to work toward a common goal of a CTB; and
- to obtain baseline seismic data that would be useful in designing and operating a seismic verification network.

We agreed that we need not wait until a treaty was negotiated but could place equipment in the field to demonstrate verification procedures and find out what problems might arise. By May 28, Velikhov had obtained Soviet government approval for the basic idea and the historic agreement was signed by Evgeny P. Velikhov on behalf of the Academy and by Adrian DeWind on behalf of NRDC.

In the past ten months, NRDC and the Academy have made substantial progress in implementing the NRDC/Academy agreement.

Under the Agreement, we had a single month in which to launch the project. In just three weeks, NRDC raised about $1 million. Dr. Archambeau persuaded Drs. Berger and Brune at Scripps to agree on extremely short notice to equip and send a team

seismologists to the Soviet Union. In a little more than a week, e were able to obtain the necessary export license.

The U.S. team of seismologists arrived in Moscow on July 4. Vith IPE, we established the first station at Karkaralinsk on July 9 f last year. By the end of August the U.S. and Soviet teams had stablished three stations around the Kazakh test site about 200 ilometers distant. The stations were located at Karkaralinsk, Bayanaul and Karasu in the Kazakh Republic.

It was decided to equip the stations in two phases. The stations were initially equipped (Phase I) with short period (Teledyne Geotech S-13) and intermediate period (Kinemetrics S-1) surface seismometers and battery operated portable digital recorders. Most of this equipment was loaned by Scripps. Over the last ten months rotating teams of two seismologists from Scripps and the University of Nevada have joined with their IPE counterparts in operating this Phase I equipment.

In late July, Scripps also began the procurement of over $600,000 worth of state-of-the-art seismic and computer data recording equipment for Phase II. This included high frequency down-hole seismometers which had to be custom manufactured by Teledyne Geotech.

Construction of facilities to house the Phase II equipment were completed by the Soviets by early November 1986. The sites at Karkaralinsk, Bayanaul and Karasu, are all located in granite massifs that rise several hundred meters above the surrounding Kazakh steppe. In order to reduce the surface noise, boreholes with 20 cm diameters, which would eventually house the high frequency seismometers, were drilled to depths of 70 to 100 meters, cased, and sealed. Wellhead vaults were set in the surrounding rock, just below the earth's surface. The interiors of these vaults measure approximately 3X4 meters with a 1X2 meter pier situated next to the borehole. At each site a large trailer was situated approximately 300 meters from the vault to house recording instruments. One or two additional trailers at each site provide accommodations for Soviet and American personnel. High-voltage power lines were installed
at each site along with backup diesel generators.

During the past two months the two teams have been installing and calibrating the instruments at the three Kazakh stations. At each station there are three component high-frequency accelerometers (Teledyne Geotech 54100) in the borehole, augmented by six surface seismometers on the pier, three component short period instruments (Teledyne GS-13) and three component intermediate period instruments (Kinemetrics S-1). There are also plans to install three broadband seismometers (Streckeison STS-VBB). When fully equipped these stations will each cover a frequency band from 100 Hertz down to a period of about 3000 seconds. The seismic signals are to be recorded locally on magnetic tape. The data recording system (designed and assembled by Scripps) at each station in cludes signal digitizers and a PDP 11/73 computer.

Ths Soviet Union ended its nineteen-month unilaterial testing moratorium on February 26, 1987. At the insistence of the Soviet Government, the Kazakh stations are required to be turned off for a short period surrounding each of their tests. A military official flies into each station a few days prior to a test, and a protocol is followed to shut down and seal the instruments. The day after the test an official returns and the stations can be turned on. During the first few tests thus far, this procedure has not worked well due to the difficulty of transporting our team to each of the stations to turn them back on. Since February 26, the stations have been down about 50 percent of the time. Provided we can reduce the delay in restarting our stations, the scientific objectives of the project should not be compromised by the inability to record Soviet tests. The primary purpose of the project is to demonstrate technology to verify the absence of clandestine, or unannounced, tests. In the past Soviet tests were not announced, either before or after the shot. NRDC is now in the unprecedented position of receiving formal advanced notice of Soviet tests.

While operating, the Kazakh stations will continue to collect seismic data from U.S. nuclear tests in Nevada,teleseismic and regional earthquakes, and industrial explosions in the region, as well as background noise. Our best scientific results, associated with verification of test limitations or bans, will come from the anlayses of these data.

The ambient ground noise level is being recorded and its frequency dependence measured. The noise levels obviously control the magnitude of events that can be detected and the accuracy with which signals can be characterized by any given station configuration.

Analysis of regional earthquakes and explosions (out to 2000 km) can be used to study the source properties and transmission efficiencies of various seismic wave types, which are usually termed seismic "phases," in the Kazakh area and thereby reduce uncertainties in the quantitative description of seismic wave propagation characteristics. Numerous studies of this kind have been conducted in Nevada, but this provides the first opportunity for U.S. seismologists to study the Kazakh test site area. These studies will be particularly useful in reducing the uncertainties of important parameters of models used to estimate the capability of in-country seismic stations to verify a low threshold test ban treaty.

Evernden, Archambeau and Cranswic (*Review of Geophysics* 24, May 1986, pp. 143-215), for example, argue that 40 high-frequency stations, including 25 in-country stations in the Soviet Union of the type being operated under the NRDC/Soviet Academy project, would be sufficient to verify a 1 kiloton threshold test ban. A similar number would be required to monitor the U.S. They assume the possibility of evasion by fully decoupling the underground explosion, that is, they assume attempts might be made to muffle the seismic signal from the explosion by exploding the nuclear device in a large underground cavity. Their model assumes sufficiently quiet sites can be found in the Soviet Union and efficient transmission of high-frequency (30 to 40 Hz) seismic compression and shear waves at regional distances in stable continental shield areas. Preliminary analysis of the data from our Kazakh stations is consistent with these assumptions.

The velocity and attenuation of compression and shear waves depend on the temperature and composition of the medium. It is now well known that the upper mantle attentuation below the Kazakh test site is low compared to the attentuation below the Nevada test site. Thus, for the same yield, the amplitude of the compression body wave (the so-called P-wave) recorded at a distant station from a nuclear test in Nevada is smaller than for a test in Kazakh. Consequently, if no correction is made for these differences, the explosion in Kazakh will appear larger than the equivalent explosion in Nevada.

Failure to properly correct for the m_b bias for P-waves leaving the Nevada and Kazakh test sites, in years past, has led to over-

estimates of Soviet test yields and has resulted in U.S. Government claims that the Soviets have violated the 150 kiloton limit under the Threshold Test Ban Treaty. As reviewed by Sykes ("Underground Nuclear Explosions: Verifying Limits on Underground Testing, Yield Estimates and Public Policy," in Press, U.S. Report to IUGG, 1987), more exhaustive analyses in recent years indicate that the m_b bias is higher than that previously assumed by the U.S. Government, and the evidence for Soviet non-compliance with the 150 kt limit has evaporated.

Some of the best data for reducing the uncertainty in the m_b bias, and thus for determining the m_b versus yield relationship for the Kazakh test site, will come from seismic measurements of Nevada nuclear tests by our stations near the Kazakh test site. This is accomplished by comparing the m_b as measured near the Kazakh test site with the values from well calibrated recording stations elsewhere in the world. Specifically, the attenuation of a body wave (i.e., the direct compressional P-wave) traveling from Nevada to Kazakh is the same as that for a signal traveling in the reverse direction. Since the yield of U.S. tests are known to the U.S. Government, the P-wave amplitudes for Nevada tests recorded at our Kazakh stations gives a direct measure of the attenuation and this in turn can be used to normalize Soviet tests recorded at stations in Nevada.

The bias can also be measured, albeit not as accurately, by comparing the P-wave amplitude of teleseismic earthquakes simultaneously recorded at our Kazakh stations and at our Nevada stations. The Soviets can of course use these same proceudres to improve their estimates of the yields of U.S. tests. Hopefully, we can put to rest the issue of whether the Soviets have violated the 150 kiloton limit. Preliminary analysis of our data, incidently, is consistent with Soviet compliance.

We have been delayed in establishing the Nevada station and our Soviet colleagues have been unable to staff them due to successful efforts by the Reagan Administration to obstruct our joint research program. In September 1986 we invited five Soviet seismologists to come to the United States to assist in selecting locations for the three seismic monitoring stations around the Nevada Test Site (NTS). The Reagan Administration first delayed action of the visa request until after their scheduled departure and then placed restrictions on their visas. The Soviets were told that they would not be permitted to visit the proposed sites without first going to the Nevada Test Site and witnessing a nuclear explosion and a demonstration of CORRTEX. CORRTEX, the acronym for "continuous reflectometry for radius versus time," is a device for indirectly measuring the yield of an explosion by measuring the speed of the shock wave in a narrow radial distance range at the edge of the hydrodynamic zone. For tamped explosions in the 75 to 150 kiloton range, this range is a few tens of meters away from the explosion source. President Reagan had previously invited the Soviet Government to send their experts to Nevada for such a demonstration in response to General Secretary Gorbachev's Administration's strategy has been to deflect Congressional interest in a nuclear test ban or moratorium by insisting that the Soviets have probably violated the Threshold Test Ban Treaty and that better verification methods are required before the Treaty is ratified. The extension of the Soviet test moratorium last April. The Reagan Reagan Administration wants the Soviets to agree that each side be permitted to measure, using the CORRTEX technique, the yield of all nuclear tests above 75 kilotons conducted by the other side. (CORRTEX does not work well at lower yields because the distance range for the measurement of the shock speed is too close to the source.)

The Soviet position is that while the CORRTEX method is useful for measuring the yield of one's own tests, it is not a practical method of monitoring the yields of tests by a second party, since confidence in yield estimates would be low because of uncertainties in the reliability of information required to properly emplace the CORRTEX system and interpret the recorded data. For example, the uncertainty in the yield estimate could be a factor of two or more at the 95 percent confidence level if the emplacement geometry, and the local rock properties, were not well known. Thus, CORRTEX is unworkable under a scenario which assumes cheating. The Soviets, moreover, do not wish to establish the precedent of renegotiating a treaty which both countries have signed, as a precondition to ratification. The Soviets, rightfully I believe, also see CORRTEX as yet another attempt by Administration officials, who are actually opposed to arms control, to foster the impression of movement in discussions with the Soviet Union.

Presumably for all of these reasons, the Soviets have refused to permit the seismologists associated with the NRDC/Academy project to participate in a CORRTEX demonstration at the Nevada Test Site. Without visiting the test site the Soviet seismologists were permitted to stay in the U.S. only seven days. We were permitted to take them to LaJolla, California , where the two teams, relying on slides, rock samples and geologic maps, selected the three station sites around the Nevada Test Site.

In February, a team from the Seismological Laboratory at the University of Nevada, Reno, established temporary surface seismometers at these three locations and began recording data. We invited three Soviet seismologists to the U.S. to work for two months with our seismologists at Scripps and the University of Nevada and to assist in the construction and installation of the Phase II stations. Again, the Reagan Administration placed the same restrictions on their visas. Their stay in the U.S. would be limited to seven days and they could not go to our stations in Nevada or California unless they first went to NTS and witnessed a test and CORRTEX demonstration.

In an effort to break the visa impasse, Academician Velikhov convened a workshop on Nuclear Test Yield Estimation in Moscow on February 12, 1987. This workshop was attended by over two dozen scientists from eight countries. Two methods of yield estimation were considered: the CORRTEX method and several new seismic techniques. Soviet experts from the Academy presented technical papers on CORRTEX. Velikhov invited U.S. Government experts on CORRTEX from Los Alamos National Laboratory and experts on seismic techniques from Lawrence Livermore National Laboratory. They did not attend. Following the workshop Velikhov telexed the U.S. weapons laboratories offering to continue the discussions to identify the best method that can be employed for yield estimation. He asked whether the Los Alamos and Livermore experts could participate in such a workshop and, if so, what would be a convenient time and place for a meeting.

Upon returning from Moscow, we brought these new developments to the attention of the State Department pointing out that the Academy has agreed to have its CORRTEX experts participate in technical discussions at a time and place of U.S. choosing, and

that no useful purpose can be served by forcing the young seismologists associated with the NRDC/Academy project to go to the Nevada Test Site to witness an explosion and a demonstration of CORRTEX about which they have no expertise. Moreover, assuming the Administration was interested in resolving technical issues surrounding CORRTEX, an opportunity existed to host the Soviet Academy's experts.

Despite these efforts by the Soviet Academy, the Reagan Administration continues to refuse to lift the visa restrictions of our Soviet colleagues. To continue to prohibit the Soviet seismologists from visiting our joint seismic monitoring stations without first witnessing a CORRTEX demonstration about which they have no expertise makes it clear the Administration is only using them for its own propaganda purposes.

We have all been taught the virtues of living in a free society. It is appalling to find that our American scientists have more freedom to travel and conduct scientific research in the Soviet Union, than our Soviet colleagues have in the United States. American physicists are not free to engage in privately funded, unclassified research where it is seen by the Executive Branch as threatening to its own policy preferences.

The Reagan Administration seems to be afraid of scientific truth. The Administration stands in fear of a research program designed to demonstrate verification of a comprehensive test ban; a program which in fact improves its own capabilities to verify the existing Threshold Test Ban Treaty.

SDI PROGRESS

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[The author was formerly Chief Scientist of the SDI Organization. This paper was originally presented at the Arms Control and Verification Technology Symposium in Albuquerque, New Mexico, on 14 April 1987.]

In spite of the rhetoric, the SDI is a research and technology program to provide the basis for a future deployment decision, although it is not a deployment program. A decision-driven program is very different from a deployment program where well-defined goals, schedules and budgets can be turned over to a program manager. To such a program manager, innovation will be the enemy, in SDI it is still an ally. Within the SDI there still is flexibility, as well there should be. In the decision process one has to not only deal with defined technical requirements, but we must also understand the possibility that as time proceeds, the Soviets can anticipate our future capabilities and we must cope with a changing set of requirements. For this reason, managing a decision-driven program places severe demands on planning and communicating the nature of the program to the public.

One of the most frequently posed questions to the SDI is to its state of progress. The most extensive advances have been in rocket-launched, maneuvering exoatmospheric interceptors with precision homing that can destroy targets by direct collision. The progress is a result of miniaturized sensors, computers, and propulsion. There has been a series of very impressive intercept experiments beginning with the HOE program in 1984 that demonstrated interception and destruction of an RV in outer space, the development and successful testing in 1985 of a much smaller antisatellite weapon launched from an aircraft, and then most recently in September 1986 the Delta 180 experiment in which two space test platforms tracked and observed each other giving an extensive amount of tracking and homing information. The Delta 180 experiment emphasized the appearance or optical signature of rocket powered flight as needed to define the sensor requirements for boost-or post-boost-phase intercept.

Substantial progress has also been made with endoatmospheric interceptors. Recent demonstrations of small, agile, homing missiles offer the possibility of developing an ability to intercept and destroy, by direct collision, high velocity attacking missiles within the atmosphere.

The second vital area of progress is in our ability to track and discriminate re-entry vehicles above the earth's atmosphere far from their intended targets. The most likely near-term approach to accomplish this intercept is with sensors and missiles launched from the ground, and carrying out their surveillance, tracking, and intercepts in the late mid-course part of the flight. In order to succeed with this kind of intercept in the face of a responsive threat where we must expect chaff, decoys, and anti-simulation, we have to find a solution to the problem of discriminating the heavy objects. Here there has been progress using passive, active, and interactive techniques to acquire, track, and interrogate this complex threat cloud and provide defined tracks for interception of the real RV's. Many years of prior investment in long wave infra-red sensors and recent advances in laser radars are beginning to pay dividends.

The third area is the survivability of our predeployed assets in and surveillance capabilities that must survive a determined attack. We have greatly improved our understanding of the components and tactics of a survivable system, although we realize that in an attack we would certainly lose many important assets. The issue here is to define a system concept that continues to function and never presents an attractive target to an attacker. In this area we are faced with the task of defining the threat and predicting its evolution, and our activities have been greatly accelerated. Studies thus far