CTBT ISSUE

IRIS Newsletter

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CTBT... *At last !*

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The forty-year battle to stop the testing of nuclear weapons was won on September 24, 1996 when President Clinton signed the Comprehensive Test Ban Treaty (CTBT) at the United Nations. With the same pen President Kennedy used in 1963 to ban testing above ground and underwater, President Clinton effectively extended the ban to include underground tests; and in doing so, limited the future development of nuclear weapons.

Although it has been known from the beginning that testing is not necessary for the development of simple fission bombs, testing is recognized as the means for developing more advanced thermonuclear weapons, and thus fueling regional arms races. Despite attempts by the nuclear nations to argue that testing is necessary to maintain the safety and reliability of the nuclear stockpile, non-nuclear nations linked the 1995 extension of the Non-Proliferation Treaty to the successful negotiation of a CTBT by the end of 1996. Through a series of complex political maneuvers, a moratorium originally proposed by Congress and signed into law by President Bush was

> **"..the longest-sought, hardest fought prize in arms control history."**
> **—President Clinton**
> ***United Nations, Sept.24, 1996***

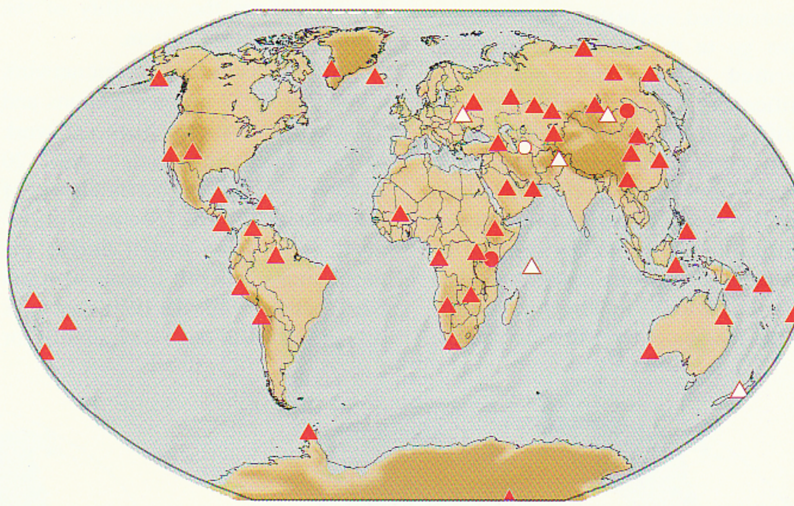

Figure 1. Over 50 stations of the IRIS GSN are currently part of the CTBT verification system. GSN stations being used in the primary network are shown as circles, auxiliary stations are shown as triangles. White symbols are GSN stations for which the GSE recommends continuing operation until other stations are installed. Between the time that the United States began negotiations on the CTBT in January 1994 to the signing of the treaty in September 1996, the IRIS Consortium completed the installation of 44 Global Seismographic Network stations to support the treaty's international verification regime. Working with the USGS, UCSD, and our local operating partners through scientific channels, IRIS independently encouraged countries to contribute GSN stations to the development of the International Monitoring System, thus greatly expanding global participation.

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extended by President Clinton, and ultimately lead to the achievement of what President Clinton is calling "the longest sought, hardest fought prize in arms control history."

Like the 1974 Threshold Test Ban Treaty, however, the CTBT is almost certainly destined to languish for years in legal "no-mans land". India has announced its intention not to sign the treaty, thus hindering achievement of one of the current requirements for ratification. The treaty is signed and therefore binding. The treaty, however, is not ratified, and in the United States it must go to the Senate for approval (termed 'advice and consent' to ratification). Without ratification, the verification provisions called for in the treaty may not necessarily come into force. In the case of the 1974 Threshold Test Ban Treaty, the failure to implement verification provisions that included the exchange of seismic calibration data contributed to the incorrect accusation by the Reagan Administration that the Soviet's had violated the threshold limit of the treaty.

Seismic Verification

The CTBT calls for an International Monitoring System (IMS) consisting of: a primary and auxiliary seismic network, a radionuclide monitoring network, a hydroacoustic network, an infrasound network, and on-site inspections. Although the combined interaction of these systems results in an enhanced level of deterrence, it is the capability of the seismic networks that largely defines the capability of the overall monitoring system.

The CTBT calls for a seismic network consisting of 50 primary stations and 120 auxiliary stations. Such a network of 170 stations (50 primary plus 120 auxiliary) is hauntingly reminiscent of the proposal of "160-170 control posts" made forty years earlier during the negotiations between Eisenhower and Khrushchev. While the 1950's network was projected to have a capability for detecting events only down to a magnitude 4.75, the goal of the 1990's network is to have a detection threshold of around magnitude 4.25 with location uncertainty of less than 1000 square kilometers. As illustrated by the following article by Harvey, however, a significant amount of calibration work needs to be done if this goal is to be achieved.

Verification, of course, can never be 100%. In the case of the seismic monitoring system, for example, it is theoretically possible to evade the monitoring system by decoupling a nuclear explosion of say one or two kilotons in a large underground cavity. That cavity could muffle the strength of the seismic signal and reduce the magnitude of the generated seismic signal down below the magnitude 4.25 detection threshold attributed to the monitoring system. Debate, both genuine and disingenuous, over the credibility of such evasion scenarios and the required levels of confidence

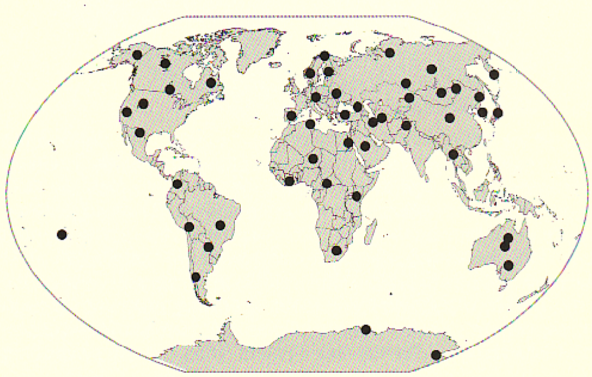


Figure 2: The primary network of the International Seismic Monitoring System consists of 50 stations, approximately 60% of which are intended to be, or are currently, arrays. The primary network is distinguished from the auxiliary network in that the stations will transmit data continuously in near real-time to the International Data Center where they are used for the initial event detection.

Figure 3: The auxiliary network of the International Seismic Monitoring System consists of 120 stations. These stations will be used to refine the parameters (location, depth, magnitude, etc.) of the events detected by the primary network.

This issue's bannergram: The last nuclear weapon test was conducted by China on 29 July 1996. The bannergram illustrates the explosion recorded at the closest IRIS GSN station in Ala-Archa (AAK), Kyrgyzstan, part of the International Monitoring System for the Comprehensive Test Ban Treaty. The magnitude of the event was mb = 5.2, corresponding to a yield of approximately 10 kilotons. The strong Lg arrival illustrates the value of regional recording for nuclear monitoring. Discriminants based on P to Lg ratios are effective for identifying Chinese tests at AAK. (see p. 4)

for the verification system has been a persistent barrier to the CTBT since 1970.

Although the official monitoring system is important, particularly for a) the rapid exchange and processing of 'official' data, and b) maintaining a political commitment to the monitoring regime; it is only the "tip of the iceberg" in terms of facilities that have the potential to record the seismic signals from a secret underground nuclear explosion. Many nations have, and will presumably continue to have, significant national means. And more important, perhaps, is that international cooperation in seismic monitoring in the form of earthquake reporting long predates concerns about nuclear tests. For many areas of the world, the dense coverage of regional networks developed by scientists provides a detection capability far better than that of the monitoring systems.

Today, in an era of digital data, low-cost modems, global telecommunications networks, and global computer communications systems (the World Wide Web), all of these scientific and environmental resources create the technological equivalent of a global *neighborhood watch* program that will enhance the CTBT verification regime at little or no additional cost. These resources will provide strong additional deterrent to any country considering violating the CTBT below the threshold of the monitoring system.

At some level, we will not be able to demonstrate with high confidence that the monitoring system would catch extremely small nuclear tests, if they were to occur. In this context, the sensitive issue of verification becomes a value judgment about the costs of violations weighed against the benefits of the treaty. With superpower competition being replaced by concerns over the proliferation of nuclear weapons, a consensus has emerged that the CTBT is now verifiable.

IRIS' Role

In response to Congressional and Executive Branch requests, IRIS accelerated the installation of the Global Seismographic Network beginning in 1994. In what the Director of the National Science Foundation has called "a blueprint for the support of multi-use scientific programs that serve the national interest," IRIS expanded the Global Seismographic Network with special Congressional funding so that it would contribute not only to scientific endeavors but also to the monitoring of a CTBT.

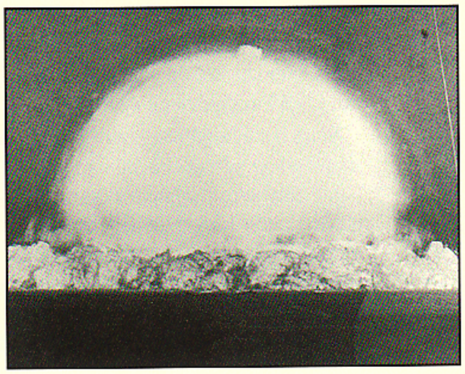
When diplomatic efforts were unable to expand participation in the International Seismic Monitoring System, IRIS worked with the USGS and UCSD through scientific channels, to encourage nations with GSN stations to contribute to the international verification regime. Through such direct contact, IRIS greatly expanded participation in the international monitoring system and over 50 of the IRIS Global Seismographic Network stations are now part of the International Seismic Monitoring System. Following the recommendation of the White House National Science and Technology Council, the National Science Foundation has enhanced its support of IRIS over the next 5 years for its role in the CTBT monitoring system.

With the establishment of the official monitoring system being caught in the legal limbo of signed but unratified treaties, it is fortunate that much of the monitoring system is composed of multi-use stations. Such stations are supported not only for treaty verification but also for the scientific exploration of the Earth's interior and the mitigation of earthquake hazards. With such a broad base of support, the operation of the IRIS Global Seismographic Network stations will almost certainly continue, now relatively impervious to political fluctuations in the diplomatic community. •

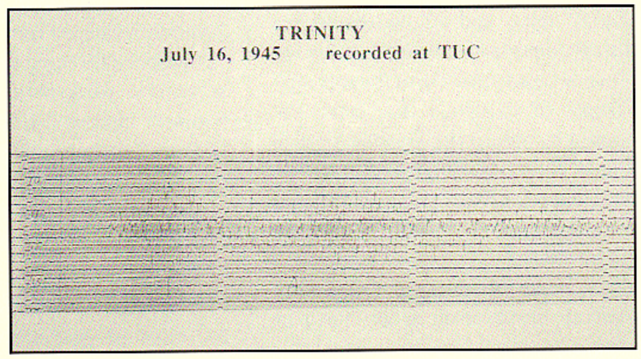
President Clinton signing the Comprehensive Test Ban Treaty at the United Nations in New York on Tuesday, September 24, 1996. Clinton signed the treaty with the same pen President John F. Kennedy used to sign the 1963 Limited Test Ban Treaty. (AP Photo/Greg Gibson)

The Beginning and the End

The First Test - 1945

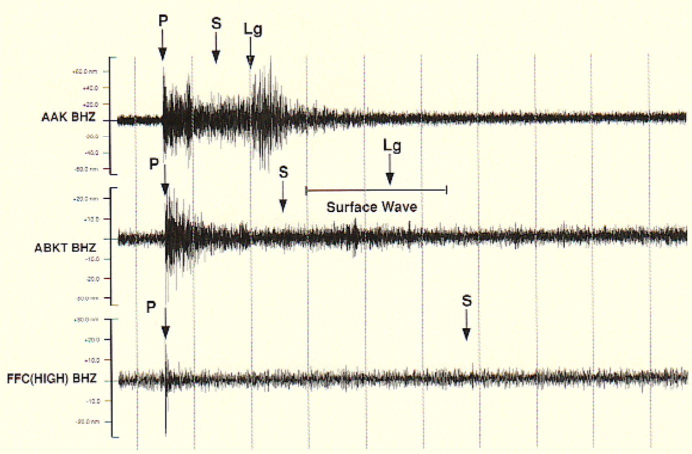


Early Phase of Trinity Test - July 16, 1945



Seismic Recording of Trinity at Tucson

The Last Test - 1996



Recordings of the last Chinese nuclear test at three IRIS GSN stations, AAK (10 degrees), ABKT (23 degrees) and FFC (83 degrees). The three seismograms were all passed through a 0.5 hz high pass filter and are all plotted with the same time window of 20 minutes. All of the traces have been approximately time aligned to the first P arrival. The seismic P, S and Lg arrival times are indicated by the arrows. The time range for expected Rayleigh surface waves are also indicated.

The last Chinese test was relatively small with an estimated yield of 10 KT. This figure shows the importance of regional distance recordings for discrimination of nuclear tests with yields of tens of KTs, a likely scenario for an emerging nuclear program testing a first generation nuclear device. The traditional discriminant used for many years is based upon teleseismic recordings of the P wave and surface wave expressed as a ratio of body wave magnitude, Mb, to surface wave magnitude, Ms. It is clear that for this last test we cannot see the surface wave in either of the teleseismic recordings shown in this figure. This is a common problem with the Mb/Ms teleseismic discriminant for smaller events and the lack of observable teleseismic surface waves for small events limits the usefulness of teleseismic monitoring. The regional distance station AAK shows a strong Lg arrival. This arrival is commonly attributed to a crustal waveguide effect and is normally seen in the distance range of 3 to 15 degrees. Discriminants based upon P to Lg ratios have been shown to be effective for Chinese tests recorded at AAK. There is evidence that this regional distance discriminant can be effective in a wide range of geologic settings throughout the world. - *Danny Harvey, University of Colorado*

Comparative Seismic Detection and Location Capabilities of IRIS and GSETT-3 Stations Within Central Asia

Danny Harvey, University of Colorado, Boulder

Our ability to confidently detect and accurately locate seismic events will form the backbone of the International Monitoring System, known as the IMS. This system will provide the crucial verification element of the new comprehensive test ban treaty. Stations of the Global Seismographic Network will be an important component of the IMS. In addition to providing an operational IMS component, IRIS, through its Joint Seismic Program, has conducted network and array deployments in Central Asia. These deployments have been used to evaluate a proposed IMS primary array site and, as described here, to evaluate overall IMS detection and location capabilities within a region of the world that will be important for the CTBT.

The final technical test of the IMS, known as GSETT-3, started on January 1, 1995 and has been operating continuously since that time. The final seismic product of GSETT-3 is known as the Reviewed Event Bulletin (REB) which is intended to be a comprehensive and accurate listing of worldwide seismic activity produced within 48 hours of real time. This bulletin would be used by the international community to detect potential treaty violators and it would set into motion the treaty enforcement procedures, starting with on-sight inspection. An accurate determination of worldwide REB detection thresholds and true location errors is critical for assessing overall IMS monitoring capabilities and effectiveness.

Although many network simulation studies have been done to estimate IMS detection and location capabilities, the most reliable and straightforward method for making these assessments is to compare the REB with bulletins determined from other networks. When local or regional networks are used for the comparison, we can get a good fix on the local seismicity characteristics and use this to pin down the REB capabilities within the region.

Even in cases where the reference network is global in scale, a direct comparison of the REB with the reference bulletin can be useful. This can be seen in Figure 1 which shows worldwide seismicity for 11 months of 1995 using the GSETT-3 REB and the USGS Preliminary Determination of Epicenters (PDE) bulletin. We compared the two bulletins and only plot events that were seen in one bulletin but not the other, with red indicating events that were in the REB but missing from the PDE and green visa versa. We can see that in comparison the PDE has a lower detection threshold than the REB in certain areas of the world, such as Southern Europe and Western US, and the REB has a lower detection threshold than the PDE throughout most of the world generally.

The IRIS JSP has operated several networks in Central Asia over the last five years. We have used the data recorded by these networks, along with GSN and CDSN data within and around Asia, to compile a regional bulletin which we call the Central Asian Bulletin (CAB). Because of the relatively high density of stations within Central Asia, the CAB can be used as a reference bulletin for determining the REB detection and location characteristics for the region. Figure 2 shows a direct comparison of REB and CAB bulletins for the month of February, 1995. Green symbols represent events that are in the CAB and not in the REB and red visa versa, with the common events not plotted. It is apparent that the CAB has a lower detection threshold than the REB over a large region of Central Asia.

A more quantitative determination of Mb detection threshold values can be seen in Figure 3. This figure shows the numbers of events as a function of Mb magnitude for all shallow events (depth ≤ 50 km) within a 10 degree radius of the Kyrgyz station at Ala-Archa. The fall off in numbers with decreasing

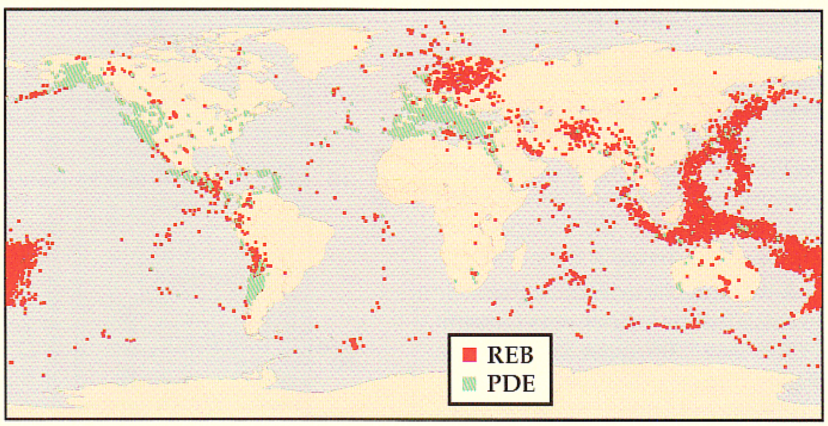


Figure 1. A comparison of REB and PDE bulletins for 11 months of 1995. Only events that appear in one bulletin but not the other are shown.

magnitude indicates the detection threshold value. For the REB this detection threshold is about 4.3 and for the CAB it is about 3.5.

Detection threshold characteristics are important performance parameters for a network. Equally important for nuclear monitoring are the location error characteristics. A large error in estimating source depth can put a legitimate suspect event out of consideration. Large errors or uncertainties in the geographic location can make on-sight inspection difficult or impossible. In Figure 4 we show a comparison of event locations for February, 1995 between the CAB and the REB. The location error ellipses are plotted with the REB ellipses not filled and the CAB ellipses filled with green. A line is drawn between the CAB and REB hypocenters for each event.

We note that the location error ellipses are much larger for the REB than for the CAB. In some cases the REB error ellipses are so large that making an on-sight inspection would be practically impossible. Also we note that in many cases the error ellipses for the REB and CAB locations do not intersect, indicating that one or both location and/or error estimates are inaccurate. In particular, the event that lies closest to the Kyrgyz Network, the cluster of triangles (stations) in northern Kyrgyzstan, shows a small CAB error ellipse and a much larger REB error ellipse that does not contain the CAB error ellipse. Because of the proximity to the Kyrgyz Network, in this case we feel certain that the CAB location and error estimate are more accurate and that, consequently, the REB location and/or error estimate is inaccurate.

A stated goal for monitoring of seismic events is that the location error footprint be less than 1000 square km in area. In Figure 5 we show the location error area as a function of Mb magnitude for events within the REB and CAB. The symbols in green are the CAB events, which represent events in February, 1995, and the events in red are the REB events in the same month. Only shallow events (depth ≤ 50 km) that are within 10 degrees of the station at Ala-Archa, Kyrgyzstan are plotted. Since there were relatively few REB events during the month, all of the REB events for the year of 1995 are also plotted as light red squares. The triangles show mean log statistics with the dark green and dark red vertical bars showing the standard deviations.

Although many individual CAB events exceed the 1000 square km threshold, the CAB mean statistics stay within the threshold throughout the magnitude range. For the REB, both individual events and the mean statistics exceed the threshold for events below magnitude 5. A curious feature of Figure 5 is the final upturn of the CAB mean error for the largest magnitude events. This comes about because of the increased numbers of stations that contribute to the locations for large events. These stations become distributed over a worldwide region and as they start to see the larger events they

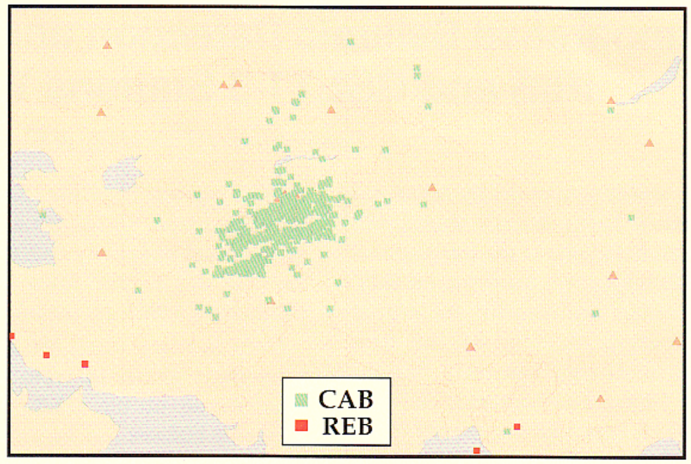


Figure 2. A comparison of CAB and REB bulletins for February, 1995. Only events that appear in one bulletin but not the other are shown.

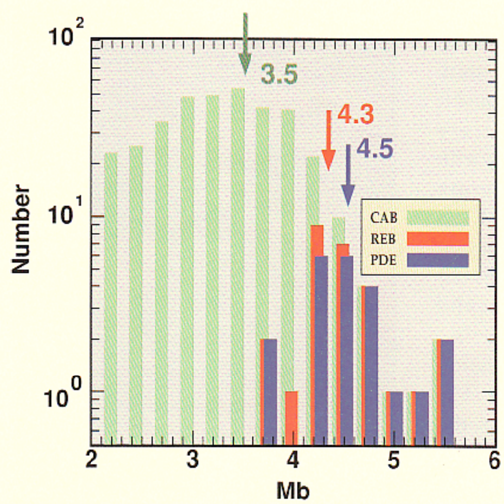


Figure 3. Numbers of events as a function of Mb for the CAB, REB and PDE bulletins. Only crustal depth events within a 10 degree radius of AAK are shown.

actually degrade the location solution by introducing a large number of distant observations that effectively reduces the importance of observations from the closest stations. In order to compute accurate error footprints in the magnitude 3 to 5 range, source location computations need to account for changes in the receiver constellation that will occur in this magnitude range.

We have shown how data collected from IRIS deployments can be used to assess the performance of the prototype IMS. These data can also be used to predict how enhancements to the IMS would effect performance. As the CTBT comes into force and the IMS moves into an operational mode, IRIS facilities will continue to provide the raw material for both operational and evaluational functions in support of the test ban. •

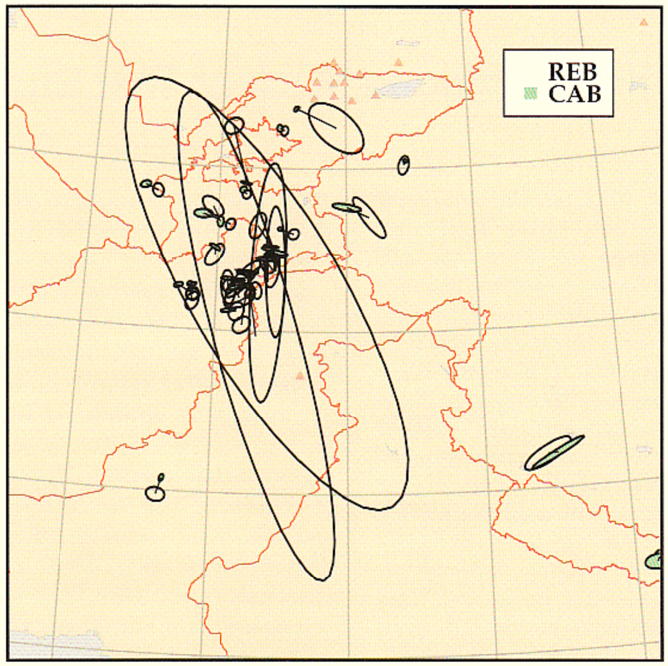


Figure 4. A comparison of location error ellipses for events from the CAB and REB bulletins. The green filled ellipses are those from the CAB bulletin and the unfilled ellipses are those from the REB bulletin.

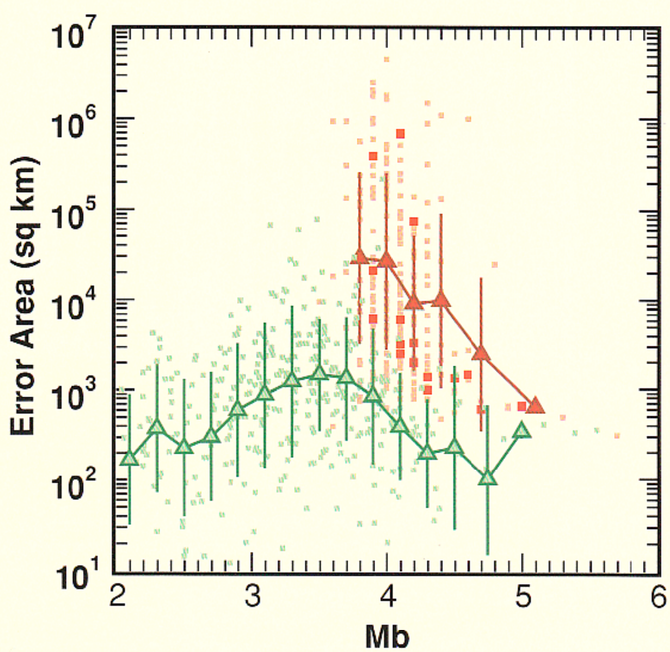
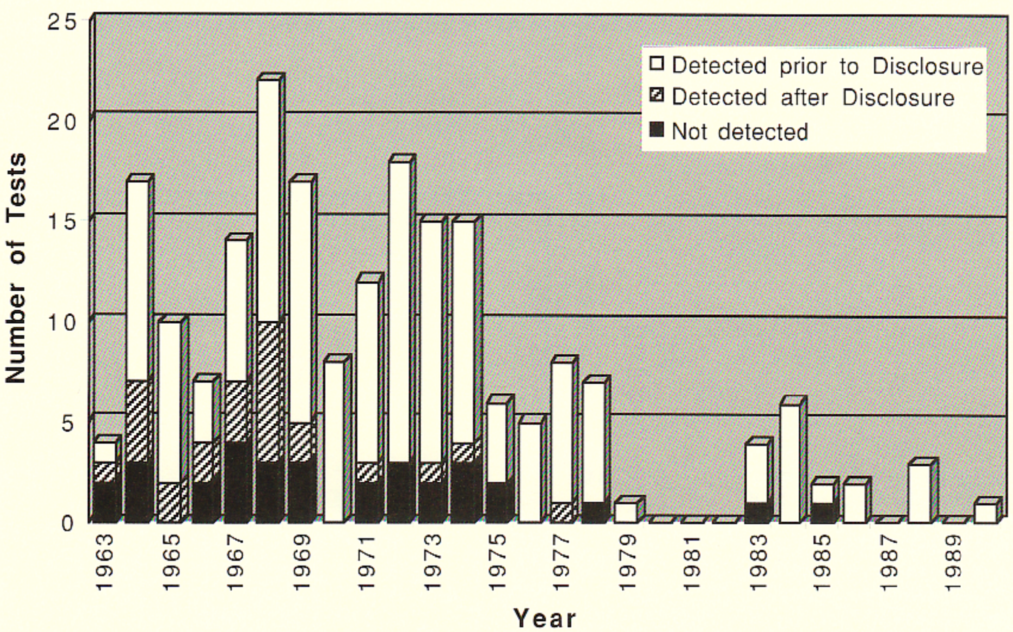


Figure 5. A comparison of location error area for events from the CAB and REB bulletins. Red colors represent REB events and green colors represent CAB events. Mean and standard deviation statistics of the log of the area are shown by the triangles and vertical bars.

IRIS Concludes Nuclear Test Study for US Congress

Since 1993 the Department of Energy has been disclosing information on more that 200 formerly unannounced nuclear tests performed at the Nevada Test Site. After the initial disclosure of information, the US Congress Office of Technology Assessment (OTA) requested IRIS to analyze "which of the formerly unannounced tests had previously been identified... on the basis of publicly available seismic data... ." In the letter to IRIS's Director of Planning, Gregory van der Vink, OTA stated that "This announcement provides a good opportunity to test the power of open-source seismic monitoring to detect unannounced nuclear weapon tests."

Several IRIS member institutions, including: the Lamont-Doherty Earth Observatory, the California Institute of Technology, the University of Nevada, and the Russian Academy of Sciences as well as the USGS were involved in this cooperative effort. Through an assessment of data from five regional and teleseismic networks, the study demonstrated that 85% of all unannounced tests were independently detected and listed in open seismological bulletins. At regional distances, tests with magnitudes as small as 1.4 were detected. At teleseismic distances, stations in the former Soviet Union detected all US unannounced tests with magnitudes of 4 or larger. Since 1983, only two tests were seismically undetected - tests that presumably had less than one ton of TNT equivalent yield. The conclusions of the study were published in the American Geophysical Union's EOS on July 30, 1996.



Prior to the DOE's announcement, 73% (149 of 204) of previously unannounced US nuclear tests were detected and are listed in open seismological bulletins. The detection rate was 89% (16 of 18) for tests conducted since 1983. After the DOE announcement, a review of the regional seismic records increased the number of detections since 1963 to 85% (173 of 204).

The Last Nuclear Weapons Test? A Brief Review of the Chinese Nuclear Weapons Program

Terry C. Wallace and Mark A. Tinker, University of Arizona

Introduction

On 29 July 1996, at 01:49 GMT, the People's Republic of China detonated an underground explosion at their Lop Nor test facility in a remote part of XinJiang autonomous region. Within hours of the test, the Chinese government announced that it had concluded its nuclear testing program and was ready to join a moratorium on the testing of nuclear weapons. The subsequent approval of the Comprehensive Test Ban Treaty (CTBT) by the United Nations in September, which permanently outlaws nuclear weapons testing, makes it quite possible that the 29 July test will be the last nuclear explosion for some time—maybe forever! Figure 1 shows the *P* waves from the explosion at several IRIS stations. The magnitude of the event was $m_b = 5.2$, which translates to an explosive yield of approximately 10 kilotons.

History of the Chinese Test Program

Much less has been written about the Chinese nuclear weapons program than for either the United States or Soviet programs. There is one excellent reference, Lewis and Litai (1988, "China builds the Bomb"), and this article draws heavily from this work. The Chinese quest for nuclear weapons began in 1955 after the "Taiwan Strait Crisis," in which the US made threats of using nuclear weapons to halt Chinese invasions of islands held by the Taiwan government. Previous to this time, Mao Zedong had labeled the atomic bomb "a paper tiger," which only had modest strategic value in the struggle between communism and imperialism. Mao was fond of stating that nuclear attack could kill hundreds of millions of Chinese, but given time the population would breed and grow, eventually overwhelming the enemy.

Unlike the Manhattan project, the Chinese knew *a priori* what it would take to build the atomic bomb. Thus, they were able to develop various aspects of nuclear technology, such as mining uranium, design of the bomb, and production of a nuclear initiator, in parallel. The Chinese plan called for a heavy reliance on Soviet advisors and followed the "Soviet Blue Print" to the bomb. In fact, the Soviets originally agreed to supply the Chinese an actual prototype bomb before 1960. However, almost immediately, Sino-Soviet relations began to deteriorate, and by 1959 the Soviets were seeking to hinder the Chinese program. The Soviets officially suspended their nuclear assistance in a letter dated 20 June 1959. In sarcastic recognition of this event, the Chinese chose the code name "596" for their first atomic bomb

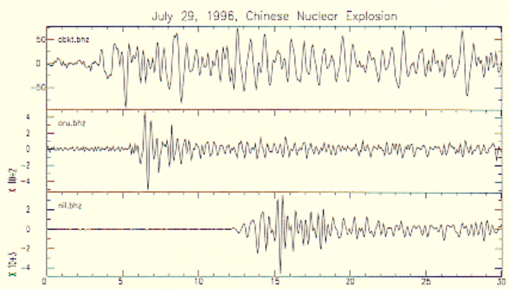


Figure 1: Recording to the P-waves from the "Last Nuclear Test" at several IRIS stations.

The parallel development of the Chinese nuclear program had some unusual consequences. One of the most unusual of these was the decision to use U^{235} as the fissile material in the first weapon. There are two principle fissile materials used in nuclear weapons: U^{235} and Pu^{239}. Plutonium has a relatively short half-life (22,000 years) and is not naturally occurring. On the other hand, U^{235} is found in nature, although is it is much less abundant than U^{238} (the natural ratio is 1:147). There are several methods for separating U^{235} from U^{238}, although the most common is through a process called gaseous diffusion. In this process, uranium hexafloride gas is forced through literally tens of thousands of nickel barriers. The slight mass difference between U^{235} and U^{238} means that the U^{235} gas is preferentially passed through the barrier. It is a tremendously expensive and time consuming process to produce large amounts of U^{235}; for weapons-grade fissile material, U^{235} needs to be "enriched" to the 90% level. On the other hand, only modest enrichment of U^{235} is required to fuel a reactor that can be tuned to produce plutonium. In the early 1960s the Chinese uranium isotope separation facilities were far ahead of their programs for building plutonium production reactors. Economic pressures in 1960 caused the Chinese to halt work on their reactors and concentrate on the uranium enrichment facilities—hence the decision to use U^{235} in the first weapon.

The first Chinese test of a nuclear device took place at the Lop Nor test site on 16 October 1964. The weapon was an implosion-type device suspended from a 120m tall tower. The detonation produced an explosive yield about 15 kt, which is typical for a first-generation weapon test. The news of the explosion was met with wild celebration in Beijing.

The Chinese had an accelerated program to transition their nuclear devices into weapons. The second Chinese test (14 May 1965) was a test of a bomber-delivered weapon based on the 596 design. The fourth test was of a missile warhead. Unlike the US or Soviet programs, the Chinese chose to test their entire missile delivery system in their first test. On October 27, 1966, a missile was launched some 800 km west of Lop Nor; this missile flew over several major cities before detonating in a 20-kt explosion at the test site.

Even before the detonation of 596, the Chinese had begun work on the problem of developing a hydrogen bomb. Again, the Chinese development program benefited from knowledge of the Soviet and American weapons programs. The third and fifth Chinese nuclear explosions were experiments to test the properties of thermonuclear materials, principally lithium-6 deuteride. These tests were "boosted" fission weapons; fusion fuel was placed in the core of an implosion fission weapon. The yields of these weapons were on the order of several hundred kilotons.

It took the Chinese only *six* tests to arrive at a true thermonuclear weapon. On June 17, 1967, a medium-range bomber dropped a bomb over Lop Nor which detonated as a 3-Mt explosion. The rapid development of the Chinese H-bomb is even more remarkable when one considers the political turmoil in China at the time. In 1966, Mao Zedong declared the Great Proletarian Cultural Revolution, and scientists were considered elitist and therefore, suspect in the great battle to empower the proletariat. Nuclear scientists were forced into the countryside; technicians questioned scientific authority, and many of the facilities necessary for the production of nuclear materials were shut down. In one of the more bizarre episodes, one of Mao's nephews led a band of "revolutionaries" to Lop Nor to take over and operate the facility for "the people."

Despite the setbacks of the Cultural Revolution, the Chinese nuclear program survived. In the summer of 1965 Mao wrote a poem called "Two Birds: A Dialogue." In this poem, a giant bird, called a *peng*, is questioned on what is the purpose of being so big and strong. The bird's response is that "because I can land wherever I want" (Salisbury, 1992). Many have interpreted this poem as a commentary on the Chinese challenge to the nuclear programs of the Soviet Union and the US.

The 29 July 1996 explosion marked at least the *44th* Chinese test (P. Richards, unpublished list). Today the Chinese are thought to possess a sophisticated nuclear arsenal, third in size only to the those of the US and Russia.

The Lop Nor Test Site and Underground Explosions

In the summer of 1958, the Chinese began to search for a site to test their future nuclear weapons. The search carried them to the western deserts of XinJiang Province (now an autonomous region). The Soviet advisors to the Chinese recommended a site 150 km from a large city; their rationale was that it was perfect for testing devices with a *maximum* yield of 20 kilotons. The Chinese rejected the Soviet attempts to limit their nuclear program and chose a desert valley which lies on the ancient "silk road." In fact, Marco Polo visited the area in the thirteenth century and stayed at the city of Lop (now called Ruoqiang). Marco Polo wrote that it is a "well known fact that this desert is the abode of many evil spirits, which amuse travelers to their destruction with the most extraordinary illusions." The remoteness of the region was reaffirmed shortly before the first Chinese test. Part of the final test preparations included an aerial inspection, and much to the surprise of the Chinese, the aerial photos revealed an encampment of over 200 inhabitants living close to ground zero! Search parties eventually rounded up the group, which turned out to be a group of Kuomintang (Chinese Nationalists), fugitives that had avoided surrender in 1949.

Lop Nor is located in the northeastern edge of the Tarim basin, an unusual geologic province. The Tarim basin is a rigid block of Precambrian and Paleozoic rocks which have survived relatively undeformed during the ongoing India–Eurasian collision. To the north of the Tarim basin is the Tien Shan; to the south is the Tibetan Plateau and the Hindu Kush. Most of the Tarim basin is covered with a Quaternary sedimentary sequence, although at the Lop Nor test site the sedimentary cover is thin (Matzko, 1994). The basement at the test site consists mainly of metaconglomerates, sandstones, and some Carboniferous-age granite. The basement outcrops as small knobs and ridges.

China's Nuclear Tests at Lop Nor

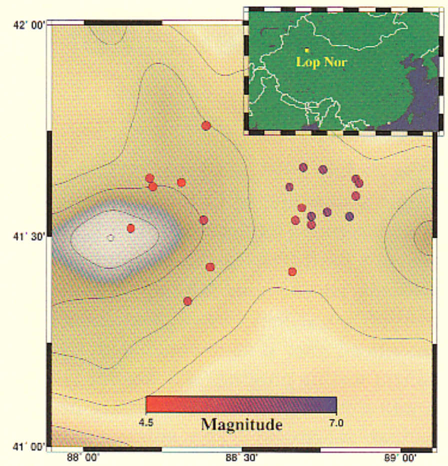


Figure 2: Location of the underground nuclear tests at the Lop Nor test site. The topography is shaded and contoured. The location of the tests are shown with the dots, which are colored coded according to size. The July 29, 1996 event was located in the cluster of tests on the western portion of the test site.

The first underground test at Lop Nor took place on 22 September 1969. The last atmospheric test took place on 16 October 1980, all tests since have been underground. Table 1 lists the known underground tests at Lop Nor and their body wave magnitudes. Figure 2 shows the epicenters determined by ISC or the PDE for the events in Table 1.

The events are clustered in two groups.

The events in the western portion of the test site are thought to have been detonated in horizontal shafts. The events in the basin are vertical emplacements. The use of horizontal and vertical shafts for testing is similar to the US testing program.

The magnitude of the Chinese underground tests range from $m_b = 4.5$ to $m_b = 6.6$. In general, it is assumed that the magnitude–yield relationship for Lop Nor is approximately the same as that observed for the former Soviet test sites in Kazakhstan. Thus, an approximate yield relationship of the form $m_b = 4.45 + 0.75 \log Y$ can be used to assign yields to the Chinese tests. The largest test (21 May 1992) probably had a yield of about 700 kt. Note that most of the presummed horizontal-shaft tests are very small yields.

Most of the Chinese nuclear explosions are accompanied by tectonic release. The 21 May 1992 event produced seismograms with very large tangential motions (Figure 3 shows the waveforms at the IRIS/IDA station ARU). The tectonic release from this event can be modeled as a strike-slip earthquake (Gao et al., 1995) with a moment equivalent to a magnitude M_S 5.1. The tectonic release is strongest for the vertical-shaft events; these are most likely detonated in granite, a material well suited for storing tectonic strain (Toksoz and Kehrer, 1972; Wallace, 1991). As the yield of Lop Nor explosions decreases, the orientation of the tectonic release changes to thrusting-type motion. This is exactly what is observed at the Nevada test site (Patton, 1991).

Conclusions

The 29 July 1996 nuclear explosion at Lop Nor was most likely emplaced in a horizontal shaft in the western side of the test site. The test marked the end of testing program which was in many ways different than the US nuclear weapons program. The Chinese had far fewer tests, yet obviously conducted tests for weapons design as well as to study the effects of nuclear weapons. •

Table 1. Chinese Underground Tests

Date			Lat N	Long E	m_b
22	September	1969	41.35	88.33	5.2
27	October	1975	41.43	88.40	5.0
17	October	1976	41.64	88.21	4.9
14	October	1978	41.42	88.66	4.9
4	May	1983	41.13	88.31	4.5
6	October	1983	41.53	88.72	5.5
3	October	1984	41.54	88.67	5.4
19	December	1984	41.62	88.22	4.7
5	June	1987	41.55	88.72	6.2
29	September	1988	41.52	88.15	4.6
26	May	1990	41.57	88.69	5.4
16	August	1990	41.56	88.77	6.2
21	May	1992	41.55	88.84	6.6
25	September	1992	41.76	88.39	5.0
5	October	1993	41.67	88.70	5.9
10	June	1994	41.64	88.86	5.7
7	October	1994	41.66	88.76	6.0
15	May	1995	41.69	88.87	5.7
17	August	1995	41.60	88.86	5.5
8	June	1996	41.62	88.65	6.0
29	July	1996	41.54	88.38	5.2

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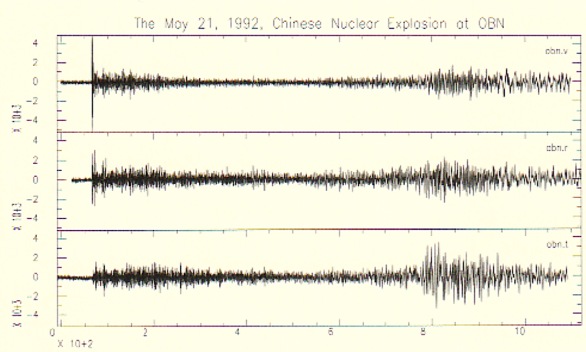


Figure 3a: Seismic records for the May 21, 1992 Lop Nor test. The records are rotated such that the top trace is the vertical component and the bottom is the tangential component. Note the large size of the S and surface waves on the tangential component.

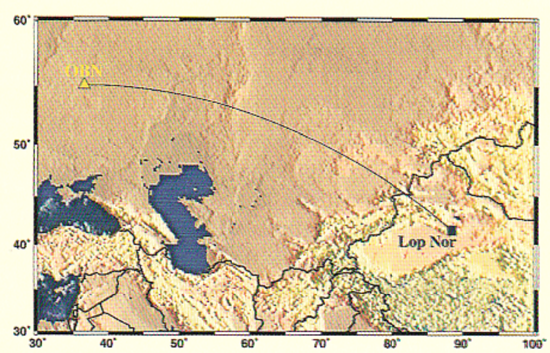
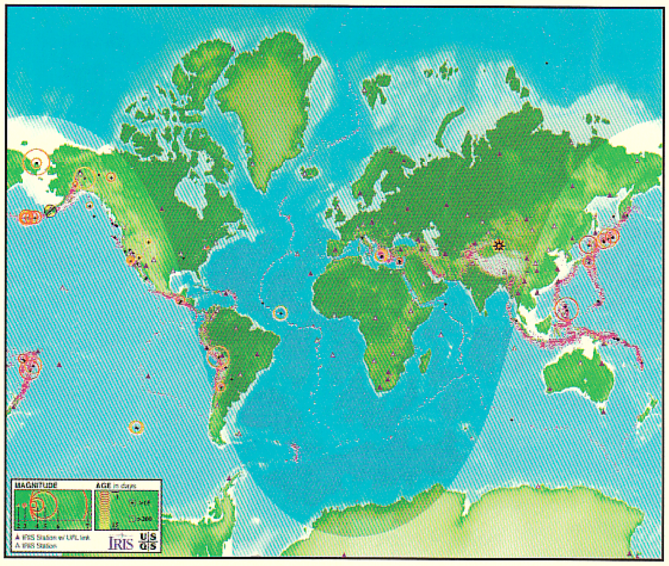


Figure 3b. Travel path for the seismograms shown in 3a. Although the path contains some extremes in topography, the best explanation for the tangential components is tectonic release.

IRIS and the USGS introduce....

The Seismic Monitor

The Seismic Monitor is an interactive educational display of global seismicity that enables users to monitor earthquakes in near real-time, view records of ground motion, and visit seismic stations around the world. A "seismic alert" feature signals users of significant earthquakes (larger than magnitude 5.5) within the United States or of any recorded seismic activity near known nuclear weapon's testing sites.



[located at: http://www.iris.edu (Click on the image to initiate display)]

Monitor Current Earthquakes

Although earthquakes may be associated with destruction in the time frame of human activity; in the evolution of the Earth, they signal the geological forces that build our mountains and create our oceans. In many ways, earthquakes serve as a natural reminder that we are living on the thin outer crust of a planet whose cooling interior is still in motion.

Earthquakes that have occurred within the last 24 hours are shown with red circles. The circles fade through orange to yellow within 15 days. After 30 days, the black dots are replaced by light purple dots that remain on the map for five years.

Click on an earthquake to receive detailed information about the event and to view ground motion recorded at seismic stations around the world.

Visit Seismic Stations

Click on an individual seismic observatory (shown by solid purple triangles) to visit the station. Enlarge the photograph by clicking on the image. Below each picture, you will find detailed information about the seismic observatory such as its exact location, altitude, host institution, equipment, and background noise levels.

View Global Topography and Seismicity

The distribution of seismicity over the past 5 years demonstrates how earthquakes define the boundaries of tectonic plates, and the relationship between topography and seismicity. The Earth's shadow illustrates day/night and seasonal changes.

Be Alerted to Seismic Events

You will be immediately warned of important seismic events through the "seismic alert" function. If a significant earthquake (above magnitude 5.5) occurs within the United States, or if any seismic event is recorded near a known nuclear weapons testing site, an alert symbol will appear on the monitor.

Use the Monitor for Teaching

IRIS is in the process of developing educational exercises derived from the seismic monitor. The exercises are being developed for both the high school and undergraduate level. If you are interested in joining IRIS in this project, please contact Ms. Susan Strain at susan@iris.edu.

[Developed by: The IRIS Consortium, US Geological Survey, University of Colorado, and Reel Illusions Inc. (www.reelillusion.com)] •

IRIS Assists Senate in Investigation of International Terrorist Group

Christel B. Hennet, Gregory van der Vink, IRIS
Danny Harvey, University of Colorado; Christopher Chyba, Princeton University

On March 20, 1995 the Aum Shinrikyo terrorist group staged a sarin gas attack in the Tokyo Subway system that killed 12 and injured 5,000 people. Following the subway attack, the U.S. Senate initiated an investigation into the activities of this previously little known yet powerful religious cult. As part of the investigation, the U.S. Senate's Permanent Subcommittee on Investigations requested IRIS to determine the nature of a seismic event that occurred in 1993 in a remote part of western Australia, where members of the cult had been trying to mine uranium and carrying out tests with chemical weapons. The time and location of the seismic event coincided with eye-witness accounts of a low flying, bright object and a large explosion. IRIS analyzed the event in cooperation with Princeton University, the University of Colorado, and the Australian Geological Survey.

The "Aum" event

On 28 May 1993, the Mundaring Seismic Observatory recorded a seismic event in western Australia with epicenter at 28.47 S, 121.73 E (Figure 1). The event occurred at 11:03 p.m. local time and was registered by regional analogue stations as a magnitude 3.6 event at 1 km depth. That evening, a group of aboriginal prospectors camping in close vicinity to the epicenter reported seeing a star-like object low on the horizon. According to their accounts, the object seemed to travel with the speed of an airplane. The object appeared to emit a bright yellow-blue light and went out of view behind a low ridge. Shortly after the object had disappeared behind the ridge, the group of prospectors reported seeing the sky lit up in a bright flash of white light from the direction in which the flying object had disappeared. The flash of light was followed by a large explosion that lasted several seconds. The explosion was heard by miners, engineers, and others over large distances. The witnesses described the explosion as similar to a large mining blast, only bigger and longer in duration. Truck drivers in the area also observed a bright object traverse to the east; and several people called the Mundaring Observatory to report a whistling fireball-like object low in the sky.

In June 1995, the event raised concern when newspapers reported on the Aum Shinrikyo's attempt to enrich uranium at Banjawarn Station, just north of the estimated epicenter of the seismic event (Figure 1). Suspicion arose that the series of events from 28 May 1993 were related to activities of the Aum Shinrikyo cult.

Possible Explanations

Since the presence of Aum Shinrikyo cult members in western Australia become widely known, many explanations for the seismic event and the eyewitness reports have been suggested, ranging from secret weapons testing to UFO landings. For the Senate Select Committee on Investigation, we analyzed the following two scenarios: a) relying on the seismic evidence alone, is the seismic event more likely caused by an earthquake or an explosion; and b) could a meteorite travel through the atmosphere and impact in western Australia to cause the series of events?

a) Explosion or Earthquake?

The event was recorded by the IRIS GSN station Narrogin (NWAO) at 650 km distance (Figure 1). Our most sensitive Australian GSN station, Tennant Creek (WRAB), was not operational in May of 1993 and the

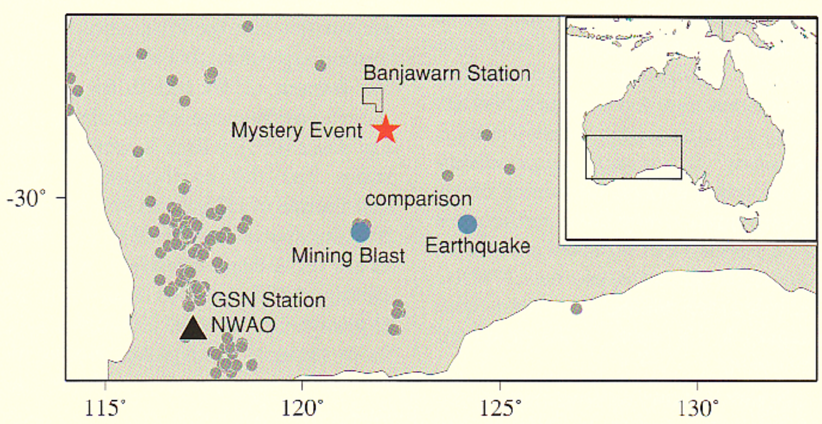


Figure 1. Unusual phenomena, including a seismic event, were observed near Banjawarn Station in western Australia in 1993. Five years worth of PDE listed seismicity indicate that earthquakes are relatively rare in this region. Of those listed in the PDE, only a few events are large enough to be recorded by IRIS GSN station Narrogin (NWAO).

event was too small to be recorded at more distant GSN stations. On the NWAO recordings, the signal appears to have a high frequency content, although we see only a small range of signal frequency from about 2 Hz to 10 Hz, the nyquist frequency of the instrument. At and below 1 Hz, the signal is buried in noise. Above 2 Hz, the event is clear above the noise level with a small P phase and a large and impulsive looking Lg phase (Figure 2).

In many aspects, the event reflects a typical clandestine scenario: a small magnitude event is observed in a region of active mining where earthquakes occur at shallow depths and instrument coverage is poor. While a range of possible sources have to be considered, we can rule out that the event was caused by a legal mining explosion. Mining regulations for western Australia prohibit the use of explosives after sunset and restricts the size of blasts to 30 tons. The largest mining blasts in this region were recorded with magnitudes between 2.0 and 2.8. The seismic event in question occurred at 11:03 p.m. local time and was 170 times larger than the largest mining blast ever recorded in this region.

The high frequency content and the small size of the event make the analysis problematic. We focus here on a comparison study of the event with nearby earthquakes and mining explosions recorded at station NWAO along a similar source-receiver path as the event. To minimize the possibility of including undeclared mining blasts as earthquakes, only those earthquakes were selected that occurred at night. In addition to the earthquake data, NWAO recorded two mining explosions, both magnitude 2.8 events, in the vicinity of the event.

Figure 2 shows a comparison of the event with a nearby earthquake and mining blast. The location of the events are marked in Figure 1. In the frequency band 2-8 Hz, the earthquake and the mystery event show relatively weak P-wave and strong S-wave energy.

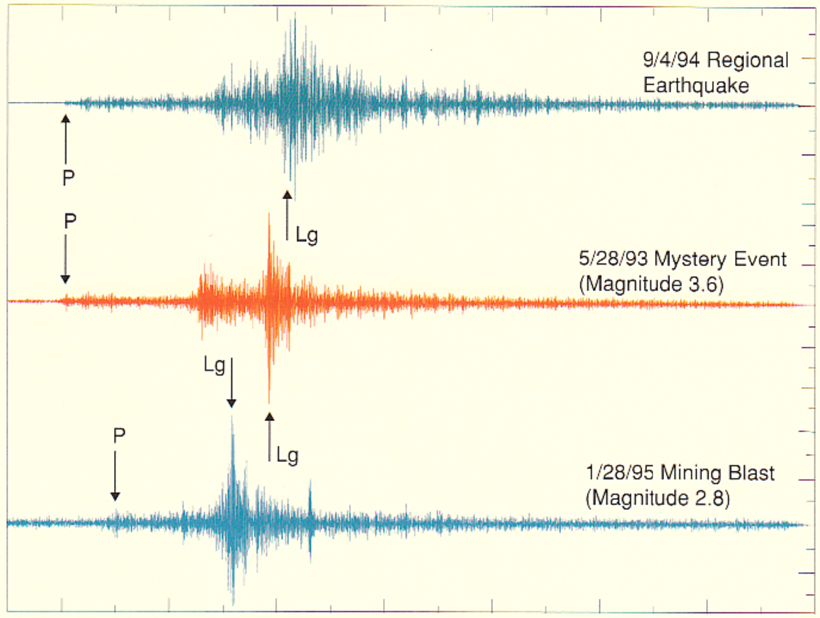


Figure 2. The z-components of NWAO recordings of an earthquake, the May 28 mystery event, and a mining blast, bandpass filtered at 2-8 Hz.

Significantly less S-wave energy is observed on the mining blast record. P/Lg ratios are low for all recordings in the frequency bands 2-4 Hz, 4-6 Hz and 6-8 Hz and show a small separation between earthquakes and mining blasts. Only for the 2-4 Hz frequency band were the S/N ratios high enough for a valid comparison. In this frequency band, the P/Lg ratios for the earthquakes are smaller than the P/Lg ratios for the mining explosions (0.140 and 0.141 for the former; 0.156 and 0.166 for the latter). For the event we calculated a P/Lg ratio 0.111 which is smaller than those for the earthquakes. This distribution of P/Lg ratios may indicate that the source for the May 28, 1993 event is more consistant with an earthquake-like source than with an explosion-like source, although many more regional earthquakes would be needed to appropriately calibrate the data.

b) Meteorite Impact

The seismic energy associated with the magnitude 3.6 event in western Australia is 7.6×10^{15} ergs (using the formula log (E) ergs = 5.8 + 2.8*M (M-magnitude) used by the Mundaring Geophysical Observatory). The seismic energy, however, would constitute only a fraction of the total energy released by a meteorite. For a static explosion on the surface, only about 0.01% of the total energy is converted to seismic energy. For a deeply buried source in hard rock (e.g. a well coupled underground explosion), less than 1% of the total energy may be converted to seismic energy. Assuming these values as the upper and lower bounds, the total energy of the meteorite at the time of explosion would be between 0.02 kT and 2.0 kT.

The estimated maximum energy level has direct implication for the composition of the meteorite. Recent studies on Earth-crossing objects show that asteroids of stony, carbonaceous, or cometary composition with associated kinetic energies below about 2 megatons do not reach the Earth's surface but typically explode at high altitude. Iron meteorites, however, may reach the Earth's surface with energy levels consistent with those derived from the seismic records.

Figure 3 shows the modeling results for an iron meteorite with density 7.9 g/cm3, entering the Earth's atmosphere at oblique incidence angles (20, 45 and 60 degrees). We assumed the median impact velocity for Earth-crossing asteroids of 15 km/s. At the most probable angle of 45 degrees for an incident body, iron meteorites with radii between 0.5 m and 1.6 m, after ablation and deceleration in the atmosphere, would release total energy levels consistent with those derived from the seismic records, between 0.02 kT and 2.0 kT energy. Iron meteorites in this energy range typically impact Earth's surface, whereas stoney and carbonaceous objects explode at altitudes above 10km. A low altitude explosion is therefore unlikely.

The meteorite impact scenario is consistent with the eyewitness observations and with the energy levels derived from seismic records for the event. Unfortunately, because of the lack of signal below 2 Hz, modeling of the NWAO recorded seismic data to further evaluate this scenario is inappropriate. Ultimately, the meteorite scenario could be confirmed if a meteorite was known to have entered the atmosphere over western Australia at the time the events occurred, or if an impact crater could be found in the vicinity of the epicenter. The impact of a meteorite with radius 1.6 meters would generate a crater more than 90 meters in diameter. Despite some preliminary searches, no impact crater has yet been found.

Conclusions

Although the 28 May 1993 event cannot be identified with certainty, a preliminary P/Lg analysis of earthquake and mining explosion data may indicate that the event is inconsistent with an explosion. More regional earthquakes are needed to appropriately calibrate the data. Our analysis suggests the observations ae consistant with a meteorite scenerio - an intriguing by unconfirmed possibility.

Meteorites, however, must be recognized as rare but realistic sources for seismic events. Approximately 5% of all Earth impacting meteorites are of iron composition. Assuming that all Earth impacting iron meteorites with a radius of 1.6 m reach Earth's surface, then about every two years an iron meteorite would hit the Earth's surface with the equivalent explosive yield of 1 kT. Furthermore, about every six years an iron meteor with 1 kT explosive power would be expected to impact on land and generate a seismic event comparable to the May 28 event.

Acknowledgements

We thank Ed Paull from the Australian Geological Survey and Harry Mason for generously providing technical information related to the event from 28 May 1993 as well as bulletin information on local mining blasts. •

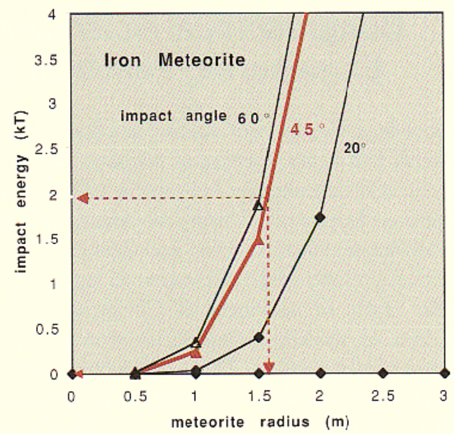
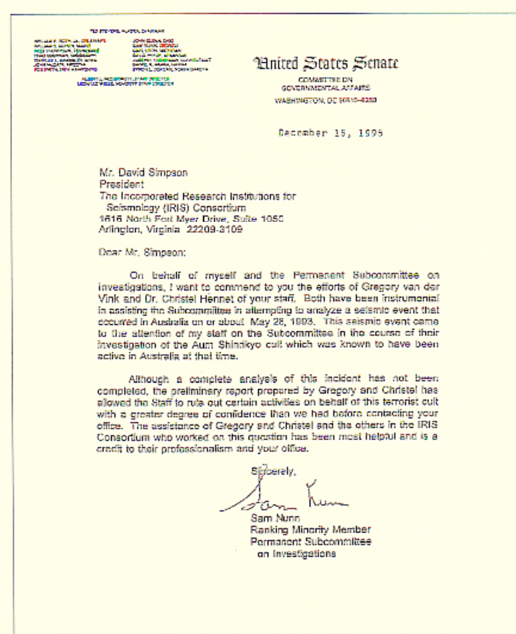


Figure 3: An iron-meteorite less than 3 meters in diameter striking the Earth could generate a seismic event of magnitude 3.6, as observed in western Australia. It is estimated that approximately every 6 years a meteorite will impact on land and generate a seismic signal equivalent to an explosive yield of 1 kT or higher.



United States Senate
COMMITTEE ON
GOVERNMENTAL AFFAIRS
WASHINGTON, DC [illegible]

December 15, 1995

Mr. David Simpson
President
The Incorporated Research Institutions for
Seismology (IRIS) Consortium
1616 North Fort Myer Drive, Suite 1050
Arlington, Virginia 22209-3109

Dear Mr. Simpson:

On behalf of myself and the Permanent Subcommittee on Investigations, I want to commend to you the efforts of Gregory van der Vink and Dr. Christel Hennet of your staff. Both have been instrumental in assisting the Subcommittee in attempting to analyze a seismic event that occurred in Australia on or about May 28, 1993. This seismic event came to the attention of my staff on the Subcommittee in the course of their investigation of the Aum Shinrikyo cult which was known to have been active in Australia at that time.

Although a complete analysis of this incident has not been completed, the preliminary report prepared by Gregory and Christel has allowed the Staff to rule out certain activities on behalf of this terrorist cult with a greater degree of confidence than we had before contacting your office. The assistance of Gregory and Christel and the others in the IRIS Consortium who worked on this question has been most helpful and is a credit to their professionalism and your office.

Sincerely,

Sam Nunn
Ranking Minority Member
Permanent Subcommittee
on Investigations

Congressional Science and Engineering Fellowships

More than twenty professional scientific and engineering societies will be sponsoring or cosponsoring Congressional Science and Engineering Fellows in 1997-98, including the American Geophysical Union, the American Association for the Advancement of Science, and the Geological Society of America. Fellows spend one year working as special assistants on the staffs of members of Congress or Congressional Committees, working in legislative areas requiring scientific and technical expertise. The program includes an orientation on Congressional and Executive branch operations and a year-long seminar program on issues involving science and public policy. For further information contact:

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PASSCAL Education Initiatives

Opportunities for Undergraduate Students - Many PASSCAL experiments, particularly active source experiments need volunteers to help with field work. If you are conducting a field program and need help, or are willing to have undergraduate students participate, send a brief summary of your experiment and any requirements you might have for participants to Susan Strain (susan@iris.edu). Susan will forward your information by email to all IRIS member institutions and post it on the IRIS web page. Make sure to include contact information (email address and phone number) so interested students can contact you directly.

Internships for Graduate Students - PASSCAL is considering a new program to support an annual graduate student internship at PASSCAL Instrument Centers. This internship is intended for graduate students with a particular interest in instrumentation or hardware/software development. The internship would include a 12 month support package. Students would spend a year working in the PASSCAL instrument centers and possibly on field projects. We would appreciate comments or suggestions from interested students or faculty advisors. Watch for a more detailed announcement in the next few months. Applications will be accepted from both Earth science and engineering students.

(asm3@lehigh.edu) *Anne Meltzer, Lehigh University.*

the IRIS CONSORTIUM

The IRIS Newsletter is published quarterly by The IRIS Consortium. Please address your letters or inquires to:

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The Incorporated Research Institutions for Seismology (IRIS) is a consortium of over 80 research institutions with major commitments to research in seismology and related fields. IRIS operates a facilities program in observational seismology and data management sponsored by the National Science Foundation. Major funding for IRIS programs is provided by the National Science Foundation through its Division of Earth Sciences and the Air Force Office of Scientific Research.

The IRIS Newsletter welcomes contributed articles. Articles should be less than 1000 words and four figures. Please send articles or requests for submission of articles to the address listed above.

Executive Editor: David Simpson (simpson@iris.edu)
Special Issue Guest Editor: Gregory E. van der Vink (gvdv@iris.edu)
Production Editor: Anne DeLaBarre Miller (anne@iris.edu)

GSN Update

Two new GSN sites have been installed since the last Newsletter. An IRIS/USGS team (Albuquerque Seismological Laboratory) has completed a new vault site at SSE, Sheshan, China. The SSE site is a cooperative joint station with the New Chinese Digital Seismographic Network (NCDSN). An IRIS and USGS team from the Lamont-Doherty Earth Observatory of Columbia University and the Albuquerque Seismological Laboratory completed a new vault installation at MAKZ, Makanchi, Kazakstan.

GSN in Geneva

by Rhett Butler

As an official observer on the US Delegation from the Arms Control and Disarmament Agency, I have had the honor of serving the GSN and the IRIS community in the technical discussions in Geneva surrounding the Comprehensive Test Ban Treaty (CTBT), and representing the IRIS Global Seismographic Network in its participation in the International Monitoring System (IMS) for the CTBT. Starting in November 1995, I attended four meetings of the United Nations Conference on Disarmament's Ad Hoc Group of Scientific Experts (GSE) and one meeting of the Group of Experts of the Working Group for Verification of the Ad Hoc Committee for the Nuclear Test Ban.

My first trip to Geneva began last November, 1995, when ACDA invited IRIS to send a representative to the GSE meeting for selecting stations for the Auxiliary Seismic Network of the IMS. The Primary Network of fifty sites (mostly arrays for detecting events globally in near-real time) had been already selected, and the task ahead was selecting Auxiliary Network stations for improving locations and characterizing the events as earthquakes or possible nuclear explosions. In 1995, the GSN included 75 stations (over 90 now), with the highest technical standards and near-real time communications links. Stations of the GSN were natural for IMS participation.

The Palais des Nations, which originally housed the League of Nations, is situated on vast grounds overlooking Lake Geneva and the Alps. The Palais is a vast labyrinth of a building, where the third floor is the only level which links the various parts together. In the hall where the meetings were held there are three parallel, long rows of tables arranged with alphabetical name cards for each country represented. Most countries have one or two members in their delegation, the US has 5 members plus observers. The sessions are very formal. The Chair recognizes a county's delegation by name, as opposed to individual people. The sessions are simultaneously translated into the official UN languages, and everyone wears an ear piece.

Walking into the meeting for the first time, I was heartily welcomed both personally and as a representative of the GSN. In various international meetings and associations over the years, I had come to meet or know about half of the people in the room. Many delegations came up and asked what IRIS was doing here. My answer—to help with the Auxiliary Network—was greatly appreciated, as most in the international community recognized the difficulty of the task at hand. With stations of the GSN available for use in the International Monitoring System, first-class seismic facilities established for science could greatly expand the global coverage with dual-use in treaty monitoring. In presentations by many delegations in the sessions, there were frequent, positive reference to "IRIS stations."

In selecting the Auxiliary Network, there were diverse initial positions among the delegations. Some delegations proposed up to 150 stations, whereas another saw scientific need for no more than 30. China, a country larger than the United States, felt that no more than two Auxiliary stations should be selected within her borders. Israel, a country smaller than Connecticut, desired four stations. The science of seismology formed the basis for the discussions during the sessions. However, the delegations represent countries, and countries have national objectives. During the sessions a number of the scientific arguments being made had a distinctly political edge. Nearly all of the delegations desired between 100 and 150 stations for the Auxiliary Network. Within this group there was some "horse trading" on which site among several contenders might be selected. Naturally, those countries represented at the session are well represented in the Auxiliary Network, though there are some notable exceptions. The GSN played a key role in a compromise at the end of the session concerning the number of Auxiliary stations in Asia, by agreeing to establish a new station at Makanchi, Kazakstan.

Later sessions concerned the other IMS technologies, the International Data Center, and the transition from GSETT-3 (Group of Scientific Experts Technical Test-3) to the planned IMS. It was my honor to speak on behalf of the US delegation in answering questions about the participation of GSN stations. At the later sessions, there was a palpable excitement regarding the outcome of the treaty negotiations—as of my last meeting in August, India was still blocking consensus in the Conference on Disarmament for accepting the Treaty, ironically against the backdrop of Greenpeace blocking the entrances to the Palais on Hiroshima Day. The eventual outcome, where the Treaty was taken directly to the UN, was one of several scenarios being actively discussed.

The formality of the sessions is balanced by the informal meetings during the breaks, where friendly diplomacy over coffee or hot chocolate leads to arrangements which are quickly gaveled later in the formal session. The

to be continued on page 19

Comments to the Seismological Community

The Honorable John D. Holum
Director, U.S. Arms Control and Disarmament Agency

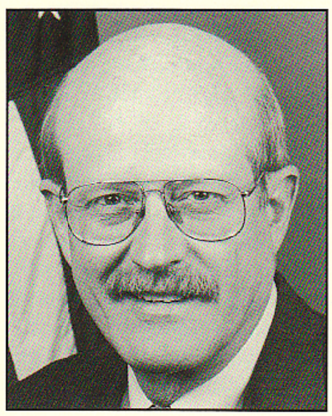
As an arms control official, I am probably not the consumer you typically envision. But in a larger sense arms control has been the direct beneficiary of a series of remarkable advances in your field in the decades since Gutenberg published his papers on the Trinity and Baker tests in the 1940s, and the Berkner Panel released its report in 1959. From the time of the Limited Test Ban Treaty in 1963, seismology has cemented its primary role.

Since then, supported by the U.S. Government, you and your predecessors have made great progress in event detection, location, and identification — giving us truly sensitive seismic arrays and forensic seismology techniques of extraordinary utility. And we are gaining access to new realms of information from regional distances and even to data from close-in seismometer networks.

Your strides in pushing the seismic state of the art have already made substantial contributions to arms control and our national security. They provided a significant part of the basis for President Clinton's 1993 decisions to continue the testing moratorium and pursue a test ban treaty. They helped give us the requisite confidence to embrace a true zero-yield treaty last year.

Historically, verification has been a major stumbling block for the CTBT, and during the past 2 years in Geneva, it was the most time-consuming issue to resolve. As you know, the CTBT text presented in New York will set in place a new global information-gathering and -processing regime. Its International Monitoring System will include four distinct systems of sensors: seismic, radionuclide, hydroacoustic, and infrasound. Their data will be fed to the International Data Center, to be compiled, analyzed, combined with other data, and shared.

The CTBT will provide for a far-flung global network of fifty primary seismic stations — either highly-capable arrays, or in some cases capable three-component single seismometers — distributed so that the basic event detection capability will be significantly below a seismic magnitude of four, or roughly one kiloton fully-coupled in hard rock. For many places on the globe, the event detection threshold for the prototype system is routinely about seismic magnitude three — roughly equivalent to an explosion of some 50-100 tons fully-coupled in hard rock.



John D. Holum, Director, U.S. Arms Control and Disarmament Agency

To help localize seismic events, the IMS will also provide for a network of 120 auxiliary stations. Many of these are multiple-use stations designed for general geophysics purposes. Together, the primary and auxiliary seismic networks will seek to localize seismic events to 1,000 square kilometers or less — an area sufficiently small to permit an on-site inspection with some reasonable prospects for success.

In addition, a network of eighty radionuclide sensors will provide further information — and deterrence — against atmospheric or underground testing attempts. Because many natural seismic events occur under the oceans, a hydroacoustic network is also being established to assist in discriminating such events from nuclear explosions. And the network of infrasound (or very low-frequency acoustic) sensors will detect and deter atmospheric explosions, particularly in the remotest regions.

We intend to process all the data collected centrally by the IMS. Identifying an event as a nuclear explosion is a task left to the Treaty parties themselves. Of course, we are not limited to the IMS. The Treaty text permits States Parties to provide supplementary data to the IDC from national monitoring stations outside the IMS — which could be used either to raise or answer questions about a specific event. The Treaty also supports the international exchange of data for scientific purposes, and promotes cooperation among States Parties to strengthen Treaty implementation. And it provides for confidence-building measures, including information-sharing about large chemical explosions.

Most importantly, the Treaty spells out the right of States Parties to make use of national technical means — provisions the United States made clear were indispensable, despite the opposition of several countries. Thus we will be able to draw on assets not specified in the IMS, including seismic, hydroacoustic, and satellite means of detecting nuclear explosions.

We intend to integrate our national data along with that collected centrally by the IMS, in our own ongoing monitoring against any potential evader of the CTBT. When we do this, we expect the whole to exceed the sum of its parts. Our aim is a national capability that will meet our own standards for event detection in all environments.

All of this brings us to the bottom line question: as my Agency performs its statutory responsibility to report to the Congress on the verifiability of arms control treaties, what will we say about the CTBT? We are still working on a final assessment. But we've been engaged for more than two years in a rolling assessment as the text evolved. I expect a conclusion that this Treaty will meet our baseline standards for detecting and deterring violations.

So as the Treaty prevails and its history is written, your contributions will earn a lengthy chapter and an honored place.

Obviously we should not count on detecting events all the way down to zero explosive yield by remote sensing alone. But even down to very low yields, a potential evader runs the risk of detection — and at any yield he runs the risk of being exposed by other means, and being subject to an on-site inspection.

Taken together, the IMS and its International Data Center, the other geophysical sensors spread around the world, the United States' own sensor systems, other national means, plus the prospect of prompt on-site inspections, will create a risk of detection that a potential violator will not be able to calculate with any precision. That, and the prospect of global sanctions upon being found out, will create a powerful deterrent against violations.

You deserve America's gratitude for this — and more. You deserve the most stable funding and rational supervision of your efforts that our country can provide. Now that we have signed a CTBT, it is no time to dissipate or take for granted the unparalleled expertise we have cultivated in your field. For your work is not done. In announcing the zero-yield decision of August 1995, the President said: "I recognize that our present monitoring systems will not detect with high confidence very low-yield tests. Therefore, I am committed to pursuing a comprehensive research and development program to improve our treaty monitoring capabilities and operations."

Your efforts are vital to this program. So I am heartened to see how much of your work is addressing practical monitoring needs, such as: work on the crustal geology of regions such as South Asia, the Middle East, the Korean Peninsula, and China; efforts to calibrate specific areas; the development of enhanced algorithms and calculational methods to help us understand data collected at regional distances; valuable empirical work on characterizing mining blasts; investigations of effective discriminants such as the Lg phase; refinements in epicenter determination; and a variety of efforts to understand and build forensic synergies between our dedicated national assets and other seismic stations — and most broadly, between seismic and other detection techniques.

Such work is already enhancing our considerable abilities to monitor nuclear testing worldwide. I know you will not rest until the President's call for high confidence even at very low yields is answered. So as the Treaty prevails and its history is written, your contributions will earn a lengthy chapter and an honored place. I thank you for that, and for all your work here to help advance a leading priority of President Clinton, and a profoundly important global mission.

[These comments were modified from remarks by the Honorable John D. Holum at the 18th Annual Seismic Research Symposium on "Monitoring a Comprehensive Test Ban Treaty,", sponsored by Phillips Lab, AFOSR, AFTAC and DOE and held at Lowes Annapolis Hotel, Annapolis, Maryland, September 6, 1996.] •

GSN in Geneva

continued from page 17

informal and friendly get-togethers over lunch and dinner lead to in-depth discussions of issues. The friendships forged are remembered beyond Geneva.

Sitting in the Council Chambers watching the Ambassadors do the business of nations is fascinating. Surrounded by frescoes of workers toiling and human conflict of the ages, and in the best diplomatic attire, the nations sit and politely offer their national views. Here too, the work is behind the scenes. Three hundred people may meet for only ten minutes—a couple of routine announcements—when behind the scenes discussions have not reached a consensus. The pace seems glacial, yet patience abounds and the end is reached.

Several delegates told me that I came to the most interesting and exciting GSE sessions in the history of the group. During the 1970's, entire meetings were said to be taken up with deciding when next to meet. Nearing the completion of the CTBT, there were things to be decided and decisions were made. The stations of the GSN now have a fundamental contribution for the International Seismological Monitoring System for the Treaty, in addition to their value for Earth science.•

The Political Sensitivity of Earthquake Locations

Gregory E. van der Vink , IRIS Consortium and Terry C. Wallace, University of Arizona

Despite the often complex nature of the task, most seismologists regard locating earthquakes as a relatively routine exercise; not a task that might begin a chain of events leading to a crisis in international diplomacy or the outbreak of nuclear war. In the context of monitoring underground nuclear weapons testing, however, a mistake in the location of a seismic event can have severe political consequences.

In 1996 and 1991, earthquakes occurred in particularly sensitive locations during particularly sensitive times: one at a Russian test site during the international negotiations of a Comprehensive Test Ban Treaty (CTBT), and the other near the Indian nuclear test site during a period of heightened military readiness between India and Pakistan. If the location errors had not been recognized and quickly corrected, both of these seismic events could have undermined sensitive diplomatic negotiations.

Although there are strong arguments for keeping the overall capability of a monitoring system secret, these two events clearly demonstrate the importance of open and readily accessible data. It is through the open and independent assessment of the data that the concerns were resolved. In addition, debate exists over the relative negative impact of missing a violation versus falsely accusing a nation. For nuclear monitoring, either mistake can be dangerous.

Possible Derailment of the CTBT Negotiations

In the Spring of 1996, a potential derailment to the nuclear test ban treaty talks occurred when reports surfaced that Russia might have violated international agreements by secretly conducting a nuclear test. On March 7, *The Washington Times* revealed that "U.S. intelligence agencies suspect Russia secretly set off an underground nuclear test."[1] An anonymous source in the article was quoted as saying "It was a low-yield test in mid-January" and the location was referenced as being at the Russian arctic test site of Novaya Zemlya. The next day, further support for the allegation was provided in a follow-up article under the title "Perry cites evidence of Russian nuke test" in which the Secretary of Defense was quoted as saying "there is some evidence on the subject, but there's also some ambiguity in the evidence".[2]

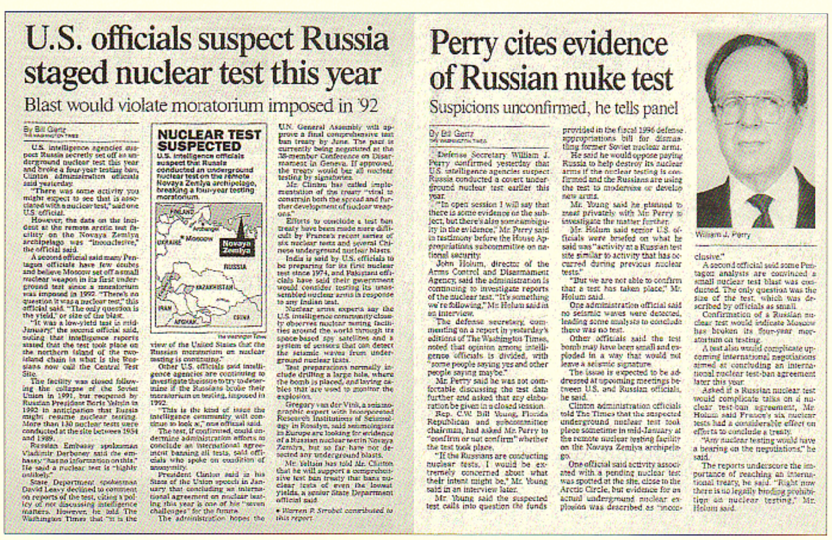


Figure 1: Newspaper articles in *The Washington Times* revealing reports of a suspected nuclear weapons test at the Russian test site in Novaya Zemlya during January 1996.

The two articles (Figure 1) inferred that the intelligence community had based their suspicions on observed activities at the Arctic test site, and that the activities they saw were similar to what is seen during a nuclear weapons test. The ambiguity is most likely because such activities are not unique to underground nuclear tests. For example, subcritical nuclear experiments are conducted underground at test sites in a manner similar to nuclear weapons tests. The experiments involve tens to hundreds of pounds of high-explosive charge and result in the dispersal of nuclear materials such as plutonium-239. Because the explosions do not produce neutrons, gamma rays, or a nuclear yield, however, they are not considered nuclear test explosions, and therefore are not restricted by international agreements. The United States, in fact, had plans to conduct a series of six subcritical experiments (two in 1996 and four in 1997) underground at the Nevada Test Site.[3]

While testing-related activity may not necessarily imply a nuclear test, a corresponding seismic event would be conclusive. According to the articles in *The Washington Times*, the lack of such a seismic signal lead some intelligence analysts to conclude that there was no test. Others, however, apparently argued that the test was either too small to generate a seismic signal, or else the test was conducted in such a manner that the seismic signal was muffled or masked.

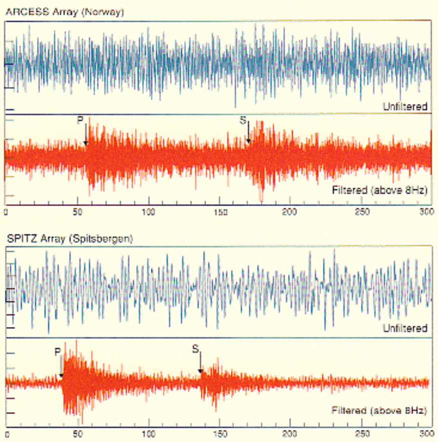


Figure 2: Seismic recordings of the January 13 event from the ARCESS array in Norway and the SPITZ array in Spitsbergen. The blue data is unfiltered, the red data is filtered above 8 Hz. P and S wave arrivals are identified on the data.

The Search for a Seismic Smoking Gun

Despite its remote Arctic location, several seismic observatories have been installed around Novaya Zemlya to monitor the nuclear weapons testing program of the Soviet Union. As a result, the detection threshold for the area is significantly lower than the global average of around magnitude 4.0 to 4.5.[4] In fact, the seismic arrays in Norway (called ARCESS) and in Spitsbergen (called SPITZ) are capable of clearly recording seismic events on Novaya Zemlya over 1000 times smaller — as small as magnitude 2.5 and perhaps even smaller.[5] These observatories, however, did not list a seismic event corresponding to the activity on Novaya Zemlya…at least initially.

A few days after *The Washington Times* articles appeared, however, the seismological equivalent of a smoking gun was thought to have been found. A re-examination of the seismic records revealed that a magnitude 2.5 event occurred at 1717Z on January 13, 1996. As illustrated in Figure 2, it is easy to understand why no event was recognized initially. The signal is barely discernable above the noise level, even when the data are high pass filtered above 8Hz.

A magnitude 2.5 seismic event is relatively small. On a global scale, over 200 magnitude 2.5 earthquakes occur each day. However, while magnitude 2.5 may be small for an earthquake, it represents a significant explosion. The relationship between seismic magnitude and explosive yield is variable, particularly at low yields. Factors that relate to how well the force of the explosion is coupled to the surrounding rock, and the extent to which the seismic waves are attenuated as they pass through the Earth, create variability in the relationship.

While an exact explosive yield can not be precisely determined, the magnitude of 2.5 does allow some bounds to be placed on the range of possible yields. For a stable tectonic setting such as Novaya Zemlya, the relationship between explosive yield and magnitude is approximately:

$mb = 4.45 + 0.75 \log Y$. [6]

A magnitude 2.5 seismic signal would therefore correspond to a well-coupled explosion of a few tons of TNT. The yield determination becomes further complicated, however, if one assumes that the explosion could have been detonated in a large underground cavity in an attempt to "muffle" or reduce the seismic signature. Based on experiments conducted in salt deposits in both the former Soviet Union and the United States, such decoupling could in principle reduce the seismic signal by a factor of 70.[7] Making the worst-case assumption that the event was caused by an explosion successfully decoupled at the maximum reduction of a factor of 70, the explosion may have been as large as 700 tons.

If the event was caused by a nuclear explosion, the yield would have been between a few tons and 700 tons. An explosion in this range would exceed the limits for subcritical experiments, and would be construed as a meaningful nuclear test. The test would indicate the end of Russia's declared moratorium on nuclear testing. Furthermore, because Russia did not announce the test in advance to the United States, the test would also be a violation of the notification agreements associated with the 1974 Threshold Test Ban Treaty. Such violations, in turn, would seriously undermine international efforts to attain agreement on the Comprehensive Test Ban Treaty.

The Seismic Event Re-analyzed

The standard procedure for locating events with seismic arrays uses the difference in arrival times of the various seismic phases at each of the array elements. These differences can be used to determine the direction (azimuth) of the arriving wavefront and its apparent velocity. The velocity of the wavefront,

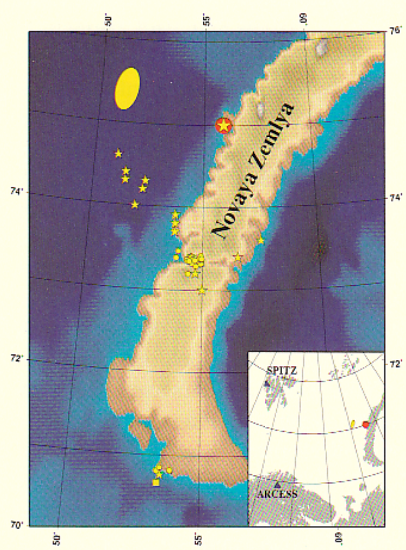


Figure 3. The preliminary location of the January 13 event on Novaya Zemlya (red circle with yellow star) lead to incorrect newspaper statements that a seismic record supported the allegation of a Russian nuclear test. The revised epicenter is marked with a yellow ellipse and indicates that the event could not have been caused by an underground nuclear test. The small yellow stars indicate the location of atmospheric tests. The small yellow circles mark the sites of previous underground tests.

in turn, is dependent on the distance between the earthquake and array locations. For the ARCESS and SPITZ arrays, we obtained results shown in Table 1.

The difference in azimuth determinations between the Pn and Sn phases at both stations is due to the relative low signal to noise ratio of the recorded signal and the fact that the different phases traveled along multiple-paths to the array. The Sn phases are used for distance but not for azimuth determination. Using the apparent azimuths from the Pn phases and the picks for the Pn and Sn phases, we determine the location of the event at 51.27N 75.40W, seventy kilometers west of the preliminary location of 75.3N, 55.3E. The error ellipse for the epicenter determination covers 560 square kilometers, and represents the 90% confidence level. Although factors such as station and path corrections create uncertainty in the location, we can determine with high confidence that the event did not occur on the island of Novaya Zemlya. The location therefore precludes the event from being an underground nuclear explosion. If the seismic recordings were produced by an underwater explosion, the explosion would have produced a "bubble pulse" reverberating between the surface and the ocean floor. Such reverberations would be visible in the seismic signature of the event; and none are observed in the waveforms.

At regional distances, the seismic recordings of earthquakes and explosions have some subtle differences. The differences in the seismic recordings arise from the fundamental differences in the source of the signal. Explosions exert a primarily compressive motion over a relatively small volume of rock. Earthquakes, on the other hand, have a shearing motion along extended fault surfaces. One of the best methods for discriminating earthquakes from explosions is therefore the ratio of the high frequency S (shear waves) to the high frequency P (compressional waves). In general, the S/P ratio is much smaller for explosions than earthquakes. The regional S/P ratio discriminant must be calibrated for individual regions and paths because both compressional and shear waves are affected by the structure and physical properties of the regional geology.[8]

Table 1

Array	Seismic Phase	Frequency	Azimuth	Appar. Vel. (km/sec)
ARCESS	Pn	6-9 Hz	59	9.3
ARCESS	Sn	6-9 Hz	63	5.0
SPITZ	Pn	6-9 Hz	99	6.8
SPITZ	Sn	6-9 Hz	89	4.6

The pathway between the ARCESS array and Novaya Zemlya is well calibrated, and ratios of greater than one are known to be characteristics of earthquakes.[9] As can be seen in Figure 2, the ARCESS recording shows that the amplitude of the S waves is greater than that of the P waves for the frequency band of 1 to 8 Hz, thus indicating a ratio of greater than one and providing further indication that the event was an earthquake.

Mistaken Identity

A seismic signal emanating from the Russian activities on Novaya Zemlya would have been strong evidence of major violations of international agreements. Taken together, the location, magnitude, and character of the January 13 seismic records, however, strongly indicate that they were created not by an explosion on Novaya Zemlya, but rather by a small earthquake in the Barents Sea. Although the absence of a seismic signal can not be construed as proof of innocence, it does shift the burden of proof. Quite possibly, the Russians were conducting a subcritical experiment. Such activities are permissible under current test ban agreements, and therefore do not violate international agreements. The lack of a seismic signal makes such an alternative explanations credible. Paradoxically, the signing of a CTBT would allow for on-site inspections, thus creating a mechanism for resolving such ambiguous activities in the future. Thus the very agreement that was threatened by the ambiguous nature of the activity, will provide a mechanism to resolve such ambiguity in the future.

Although the relocation of the seismic event was able to reduce suspicion that the Russians may have conducted a test, it is frustrating to note that this reassuring information never made it to the attention of the press that publicly raised the concern in the first place. In fact, just the opposite seems to have occurred. Three months after the first report, an article in *The Washington Times* about Russia's efforts to modernize their nuclear forces also cited the event. By this time, the seismic evidence had been completely, and erroneously, turned around. In a self-perpetuating fashion, the presence of a seismic signal, which had been cause for doubt in the earlier stories, had now become the basis for the allegation, and was touted as follows as evidence of Russian duplicity:

> *In January, as this paper revealed and Defense Secretary William Perry confirmed, the Pentagon detected seismic activity consistent with a low-yield nuclear blast at the underground arctic nuclear test site in Novaya Zemlya, even though Moscow had pledged in 1992 to stop such detonations.*[10]

Not the first time

Unfortunately, the Novaya Zemlya event is not the only example of where a mis-located seismic event had the potential to create international conflict. On April 30, 1991 the Government of Pakistan notified the U.S. Ambassador that Pakistan had detected a seismic disturbance in India's Rajasthan Desert, the location of India's 1974 nuclear test (Figure 4). Because the seismic event appeared to have no aftershocks, the Pakistanis were suspicious that the event was not an earthquake, but rather by inference, that India had conducted an underground nuclear test.

Since the end of British colonial rule in 1947, territorial battles between India and Pakistan have fueled an arms race that according to testimony by the Director of the Central Intelligence Agency:

> *poses perhaps the most probable prospect for future use of weapons of mass destruction, including nuclear weapons.* [11]

Both India and Pakistan are thought to possess nuclear weapons, or at least to be capable of assembling nuclear weapons rapidly.

The Pakistanis asked the U.S. Ambassador for an assessment of the April 28, 1991 seismic event. The United States was able to respond to Pakistan, and assure them that the seismic event that they had recorded was an earthquake and not an Indian underground nuclear weapons test. The U.S. response was based primarily on the location of the event. The event was listed in the U.S Geological Survey's global seismic catalog. It had been recorded by several dozen stations around the world. The location for the event was not near the Indian test site, but rather in the center of Pakistan and at a depth of 26 kilometers (Figure 5).[12] The Pakistanis had mislocated at the Indian test site an earthquake that had occurred within their own country.

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UNCLAS ISLAMABAD 05889
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TAGS: SENV, MNUC, PREL, PK, IN
SUBJECT: PAKISTANIS DETECT SEISMIC DISTURBANCE IN
INDIA'S RAJASTHAN DESERT
1. SENIOR GOP OFFICIAL TOLD AMBASSADOR OAKLEY LATE
APRIL 30 THAT THE GOP HAD DETECTED A SEISMIC
DISTURBANCE AT 9:00 PM ON APRIL 28 IN THE RAJASTHAN
DESERT THAT REGISTERED 5.6 ON THE RICHTER SCALE.
THEY DETECTED NO AFTERSHOCKS AND ARE THEREFORE
SUSPICIOUS THAT THE EVENT WAS NOT AN EARTHQUAKE. THE
GOP HAS CONSULTED WITH THE NORWEGIANS WHO ALSO
MEASURED THE SEISMIC DISTURBANCE AND NO AFTERSHOCKS.
2. THE GOP ASKED FOR ANY INFORMATION U.S. AGENCIES
MAY HAVE RECORDED ON THIS EVENT. EMBASSY WOULD
APPRECIATE KNOWING WHETHER GOLDEN RECORDED ANY
SEISMIC ACTIVITY DURING THE PERIOD MENTIONED TO US BY
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Figure 4: Telex from the United States Embassy in Islamabad Pakistan requesting information for Pakistan about a seismic event with no aftershocks that was thought to have occurred near the Indian test site on April 28, 1991.

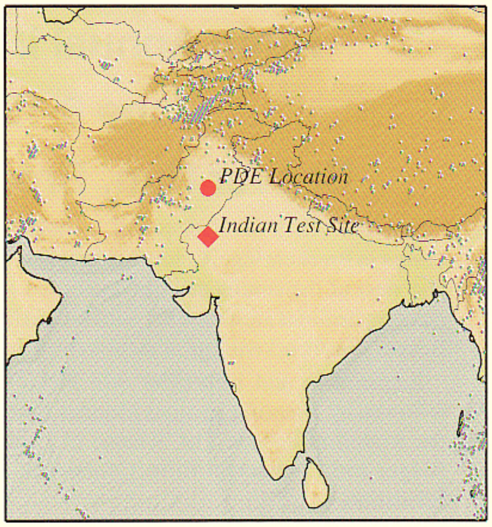

Figure 5: Actual location of the April 28 seismic event as determined from several dozen seismic stations and listed within the U.S. Geological Survey's Preliminary Determination of Epicenters global catalog.

Acknowledgments:

We would like to thank Doug Baumgardt for helpful discussions and preliminary analysis of the array data, and Mark Tinker for technical assistance. •

Endnotes

1 "U.S. officials suspect Russia staged nuclear test this year" by Bill Gertz, *The Washington Times*, March 7, 1996, p.A3.

2 "Perry cites evidence of Russian nuke test" by Bill Gertz, *The Washington Times*, March 8, 1996, p.A8

3 "Subcritical Experiments at the Nevada Test Site," U.S. Department of Energy Fact Sheet, October 1995.

4 Catalogs of global seismology, such as the "Preliminary Determination of Epicenters" (PDE) produced by the U.S. Geological Survey and the "Reviewed Event Bulletin" (REB) produced by the International Monitoring System are generally thought to be complete on a global scale down to magnitude 4.5 - 4.0.

5 See for example: "The Novaya Zemlya Event of 31 December 1992 and Seismic Identification Issues" 15th Annual Seismic Research Symposium, 8-10 September 1993, Vail Colorado, Proceedings published by the Department of Defense Advanced Research projects Agency (ARPA).

6 "Seismic Yield Determination of Soviet Underground Nuclear Explosions at the Shagan River Test Site" by F. Ringdal, P.D. Marshall, and R.W. Alwine, *Geophysical Journal International*, vol. 109, p. 65-77, 1992

7 "Dealing with Decoupled Nuclear Explosions Under a Comprehensive Test Ban Treaty" by Lynn R. Sykes, in *Monitoring a Comprehensive Test Ban Treaty*, 247-293, edited by Eystein S. Husebye and Anton M. Dainty, Kluwer Academic Publishers, 1996. 836pp.

8 See for example, "Regional Seismic Event Discrimination" by Robert R, Blandford, in *Monitoring a Comprehensive Test Ban Treaty*, 689-719, edited by Eystein S. Husebye and Anton M. Dainty, Kluwer Academic Publishers, 1996. 836pp.

9 "Resolving Regional Discrimination Problems: Some Case Histories" by Alan S. Ryall, Douglas R. Baumgardt, Mark D. Fisk, and Flourence Riviere-Barbier, in *Monitoring a Comprehensive Test Ban Treaty*, 721-741, edited by Eystein S. Husebye and Anton M. Dainty, Kluwer Academic Publishers, 1996. 836pp.

10 "Out with the old nukes, in with the new" by J Michael Waller, *The Washington Times*, June 10, 1996, p.A3. The statement was echoed a month later in an editorial that stated "In January this year, the Pentagon detected seismic activity consistent with an underground blast at the arctic nuclear test center of Novaya Zemlya.", "The ever elusive test ban treaty", *The Washington Times*, July 30, 1996, p.A16.

11 According to the February 24, 1993 Senate testimony of CIA Director James Woolsey as reported in "India and Pakistan's nuclear arms race: Out of the closet but not in the street" by David Albright, *Arms Control Today*, June 1993, page 12-16.

12 The listing also indicates that 51 P arrivals were used in the location, that the depth was determined from two or more compatible pP phases, and that the 90% confidence intervals for location and depth are 8 km.

Calendar

1996

Dec. 15-19 American Geophysical Union, Moscone Center San Francisco, CA

Dec. 16 IRIS Board of Directors Meeting Yank Sing Restaurant, San Francisco, CA

1997

Feb. 13-18 AMSIE - AAAS Annual Meeting and Science Innovation Foundation Seattle, WA

April 3-6 NSTA 1997 National Convention, New Orleans, Louisiana

May 27-30 American Geophysical Union Spring Meeting Baltimore, MD

June 8-12 IRIS Annual Workshop Beaver Run, CO

June 17-21 Chapman Conference Marconi Center, Marshall, CA

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IRIS welcomes as a new foreign affiliate member: Universidade de Sao Paolo, Dr. Marcelo Sousa de Assumpo, Representative. •

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June 8-12, 1997

Beaver Run, Breckenridge, CO

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Registration and icebreaker will kickoff the Workshop on Sunday evening, followed by scientific sessions Monday thru Wednesday. The themes emerging for the workshop include The Science of Earthquakes, The Structure of Mid-ocean Ridges and Continental Rifts, Continental Roots and Origins, IRIS and Science Education.

Participation in the workshop is not limited to IRIS members and all those interested are welcome to attend, subject to availability of accommodations. More information will be mailed early next year! •

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