

**The Verification of a Global Comprehensive
Test Ban Treaty**

**A Briefing Paper for the Partial Test Ban
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VERIFICATION OF A GLOBAL COMPREHENSIVE TEST BAN

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1. Introduction

A treaty to stop all testing of nuclear weapons by the nuclear weapon states and to prevent other states from testing nuclear weapons in the future, would have a radical effect on military programmes. Consequently, it is paramount that such a treaty should be verified in such a way to make it impossible for states to clandestinely test nuclear weapons.

The issue of verification has been the most controversial in the history of the nuclear test ban debate. Failures of talks have been blamed on verification, technical committees have been formed and reformed to solve the problems of verification, numerous books and papers have been dedicated to the subject and yet still today verification continues to be cited as one of the reasons for failing to negotiate a nuclear test ban.

It is our contention that a Global Comprehensive Test Ban Treaty (CTBT) is verifiable.

This statement is based on the technologies and methods that the world community has at its disposal and from the verification standards set by previous and recent treaties (for example the 1968 Non-Proliferation Treaty, the 1987 Intermediate Nuclear Forces Treaty and the 1990 Conventional Forces in Europe Treaty).

Over the last few years, since the thawing of the Cold War, there has been a tempering of the hardline view that verification should be able to detect the smallest infringement and that on-site inspections should be allowed "any time, anywhere". Instead there is a return to the idea of "reasonable sufficiency" in verification. An effective verification regime is now defined as one which would, in the first place, deter violations and would be able to identify important infringements of a treaty.

The aim of a verification regime of a CTBT is three-fold:

- 1) to establish a verification gauntlet which would mean that the chances of discovering a treaty violation, in enough time to be able to rectify the situation, would be very high
- 2) and consequently, to make a potential violator so unsure of escaping detection that it would not be worth trying.
- 3) to build confidence in the Treaty so that security is enhanced and others are encouraged to join.

2. Evading detection of nuclear tests

It is only by knowing the ways in which a potential violator may try to cheat on a treaty that an efficient verification system can be devised.

The evasion possibilities include:

Hiding in background seismic noise; hiding in an earthquake; decoupling (muffling) the explosion; disguising a test as a large industrial explosion; testing in a remote area possibly belonging to another country; simulating an earthquake; and testing in space - behind the moon or the sun.

Of these, the most serious contender is the potential for decoupling the explosion by detonating the device in a large, underground cavity. If this can be achieved then the explosion would be "fully decoupled" since the low frequency seismic signal would be reduced to a minimum.

There are major engineering problems associated with excavating cavities large enough to have potential for successful decoupling although it might be possible to use existing cavities or cavities created by past nuclear explosions. For this reason it would be necessary to monitor old nuclear test sites closely.

A registration of mines and cavities in the territory of each Party would be a way of monitoring the potential sites for decoupling underground nuclear tests. If this were a pre-requisite of the treaty then any subsequently-discovered activity around an unregistered large cavity would be an indication of possible intent to violate the treaty. At the same time a registration of all cavities and underground mines would be an important confidence-building measure as remote sensing by satellites could monitor activities in their vicinities.

The other possible evasion scenarios are either highly likely to be picked up by seismic monitoring or can be factored into a verification regime by the inclusion of notification of industrial explosions and on-site inspections and other related measures.

3. A Verification Regime for a CTBT

The verification regime proposed by VERTIC consists of:

1. A global network of seismic stations, designed to detect and identify tests of 400 tonnes, fully decoupled.
2. A global network of radioactive debris detectors, designed to detect atmospheric nuclear explosions and any venting from underground explosions.
3. The use of satellite imagery to keep check on key areas and to provide images of regions in which there have been unidentified and unexplained seismic events.
4. The use of aircraft to fly over a region under investigation. Sensors on board the aircraft could be optical and thermal imagers, radiation detectors and human inspectors looking for tell-tale signs of explosions.
5. A regime of random and challenge on-site inspections. Random inspections are included as a confidence-building measure and their execution does not imply suspicion, whereas challenge inspections are carried out specifically to find an explanation for unidentified seismic disturbances or unexplained drilling activity.
6. Extensive notification and data exchange, such as a register of mines and cavities, notification of large industrial explosions etc., all of which would be subject to inspections.

How such a system might operate is illustrated in Figure 1.

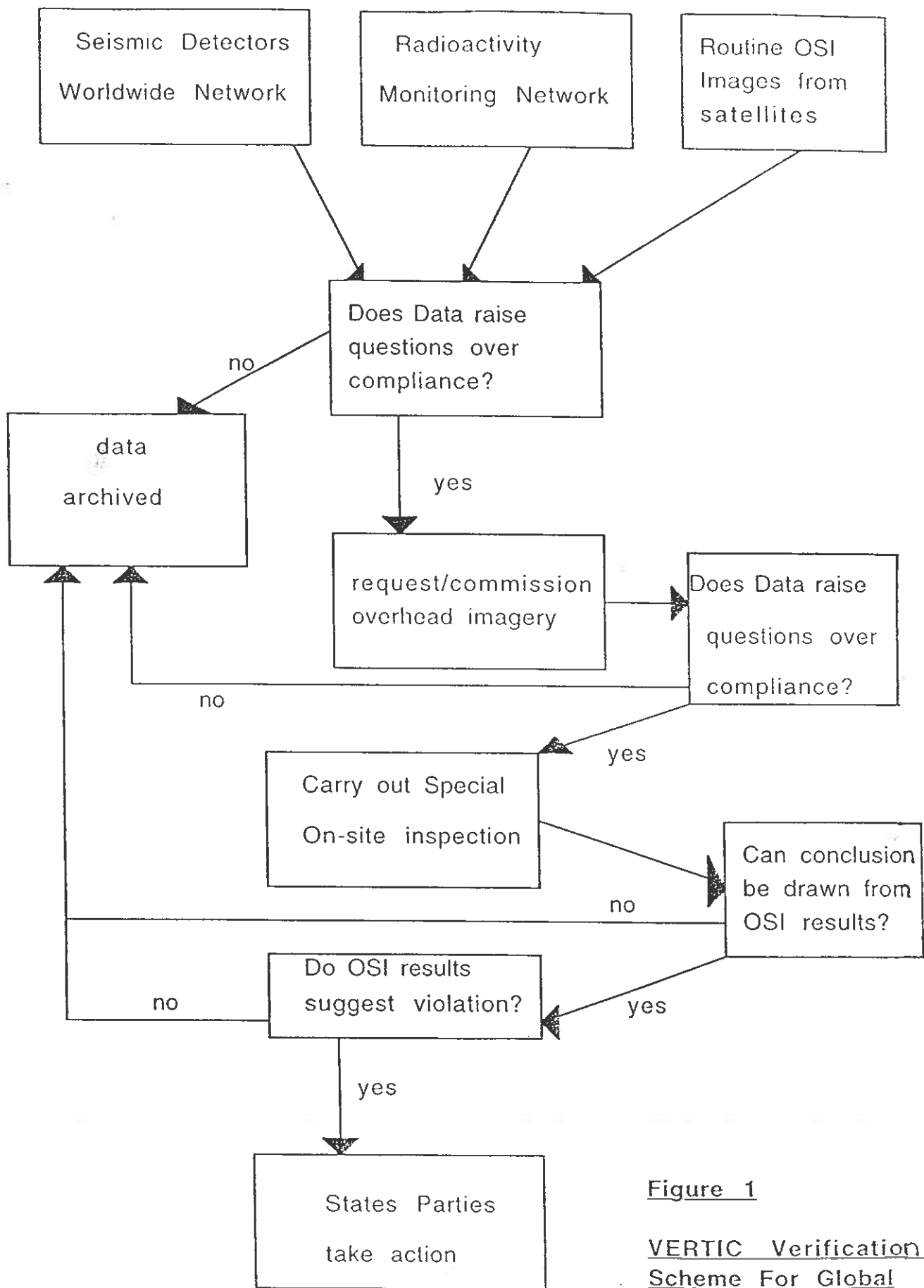


Figure 1

VERTIC Verification Scheme For Global CTBT

4. Seismic monitoring

Seismic waves are vibrations transmitted through the Earth. They can be caused by any disturbance under or on the ground - earthquakes, quarry blasts, industrial machinery, even just traffic on roads and the wind shaking fence-posts and trees. Earthquakes and explosions however, give distinct 'signals'; the rest contribute to the general continuous 'background noise'.

Underground nuclear explosions release only a few percent of their energy as seismic waves, but these can be detected at distances from tens of kilometres up to worldwide, depending on the size of the explosion. For verification purposes, seismology needs to recognise seismic events, discriminate between earthquakes and explosions and, if needed, to estimate the size of the explosions.

There are two types of seismic waves: surface waves, which are like ripples on water and body waves (or P waves), which are sound waves travelling through rock. They are always faster than surface waves and their magnitude is related to the yield of the explosion by a logarithmic scale.

Both types of wave, surface and body, carry a wide range of frequencies in them, but body waves, or P waves, are mainly recorded at about 1 cycle per second, (1 Hz), and surface waves at about 0.05 Hz (i.e.. 1 cycle takes 20 seconds). The waves are recorded by instruments, called seismometers, especially tuned to those frequencies. Modern designs of seismometer record both body and surface waves, and some experimental systems can record P waves at high frequencies of 20-30 cycles/second. There are several thousand observatories around the world equipped with seismometers.

The first stage in seismic verification of a test-ban treaty is to detect that a seismic disturbance has taken place, and to locate where it happened.

Once a seismic disturbance has been detected and located, it must be identified as being either an explosion or an earthquake.

Only those events which are shallow and on land need to be considered as possible explosions. About 90% of the world's earthquakes can be recognised as such simply because they occur far out at sea where drilling operations would be visible to satellites, or they are at depths below which drilling cannot reach.

In order to calculate the number of seismic stations which would be required in a global seismic monitoring network for a CTBT, we have to first stipulate some magnitude or yield level as its basis. In effect, the seismological network has to be designed for a Low-Yield Threshold Test Ban. It cannot take a yield of zero as its design starting point; it could not hope to detect any arbitrarily small explosions in any geographic or geological setting. Nevertheless, a fairly reasonable estimate of what is needed technically can be made once the decision has been made as to what that low yield is to be.

For a number of reasons, which include the practical details of nuclear weapon design and the previous experience of decoupling, we favour a working threshold for designing a seismic network of 0.4kt (400 tonnes). This allows the design performance for the seismic network to be specified.

For the purposes of seismic detection the world can be divided into the following geological types: Shields and cratons; Stable continental platforms; Orogenic belts; Rift zones; Salt domes and bedded salt; Deep-ocean islands; and Ocean floors.

In order to sketch a design for a seismic network, the network pattern and the area required to be covered per station (in terms of the maximum source-station distance) must be specified. At that point the maximum distance at which the required magnitude of seismic event can be detected is estimated and a station density for each of the geological types can be specified. Then, each party to the treaty has its territory classified into the geological categories and the number of seismic stations can then be calculated.

It must be emphasised that a specific design would require extensive and detailed research, involving field studies and computer simulations, reviews of instrumentation, etc. To propose actual locations would need field-based or literature-based noise level surveys. This and several other aspects of the design could be undertaken by some internationally-based and well-funded group of technical experts.

Another key factor is the type of seismic station which is used in the network. There is a range of different qualities of seismic station. We have classified those qualities into three types: "quality 1" - the very new and expensive wide band, 3-phase seismometer which is the current research tool ; "quality 2" - the current off-the-shelf technology which is standard equipment for new seismic stations; "quality 3" - the old style seismic station which is in use in many areas today. We have then calculated the number of seismic stations which would need to be deployed on the territory of each party to the Partial Test Ban Treaty, if we were to monitor down to a yield (fully decoupled) of 400 tonnes.

Selected results are shown in figure 2.

Note: Because of the nature of the installation, calibration and running-in time necessary for the establishment of reliable seismic data from the equipment, a time period of some two to three years for this process should be built into a CTBT.



VERTIC,
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Fig. 2 Seismograph network: quality 1 stations, numbers per signatory state

5. Radioactive debris monitoring

Since the conducting of nuclear weapons tests underground, there have been a number of reported incidents of accidental and non-accidental release of radioactive debris into the atmosphere.

Radioactive debris is detected by radiation detectors. These could be mounted on airplanes when conducting an aerial overflight inspection and they could be installed and collocated with the seismic network.

A number of radiation monitoring networks already exist. For example, the US Environmental Protection Agency operates a radioactive debris detection network which monitors the Nevada Test Site. The UK Meteorological Office has operated a near real-time radiation monitoring network in the UK since 1986. Several countries have their own, similar, national networks for radiation monitoring which are principally concerned with nuclear power station accidents, but could equally well detect radioactive debris from nuclear testing, if it were sufficiently concentrated.

A worldwide network of air and rain sampling stations for monitoring levels of radioactivity in the atmosphere is operated by the Harwell Laboratory, UK. In operation for more than thirty years, the results are published annually in a series of reports. Throughout the network airborne particulate is sampled continuously through highly efficient filters. Rainwater and snow samples are also collected. The programme has been designed primarily to provide a regular inventory of nuclear weapons test debris.

Whilst it may not be appropriate for the verification system of a global CTBT to use data from an existing world-wide network a similar system, with increased numbers of stations could be run in conjunction with the seismic monitoring network. The addition of a radioactive debris monitoring network to seismic monitoring, remote sensing by satellite, on-site inspection and aerial overflights would increase the verification gauntlet, thereby decreasing the chance of successful evasion and increasing confidence in the treaty.

6. Satellite imagery

The monitoring of specific areas by imaging satellites allows a global comprehensive test ban to be verified much more effectively. Knowing that an eye is being kept on the existing, past and potential nuclear testing sites, a potential evader would have far less certainty of escaping detection and would have to go to far greater lengths to try to successfully carry out a clandestine test.

There are two stages in the monitoring of nuclear testing by satellite:

- 1) routine monitoring of potential sites in order to spot any activity which might indicate that a nuclear test is about to take place
- 2) detailed imaging of an area in which an unidentified seismic event has taken place in order to look for evidence of a nuclear test and provide clues for where to pinpoint an on-site inspection.

For routine monitoring, there are seven active or readily reopened nuclear test ranges throughout the world. To that number must be added at least one range within each nuclear threshold country. The number of sites which must be monitored is, therefore, on the order of 20, but could be as much as a factor of two larger, should some nations utilize more than one site or should the NPT regime collapse after 1995.

The frequency with which any site can be observed depends on several factors. The most important of these is the repeat period of the satellite orbit, the time it takes before the ground track of the satellite "exactly" retraces a previous track. Of nearly equal importance is the distance the satellite can look to either side of its ground track because it greatly increases the area on the ground "at risk" of being observed on any one track.

The rate at which observation of any given suspect area must be attempted depends on several parameters:

- o The length of time required for site preparation before a test occurs, including drilling of the emplacement hole and any instrumentation holes and tunnels, as well as the period needed to build the on-site data collection facilities, to emplace the device, and to stem all the holes.
- o The time after construction begins until the purpose of the activity is unambiguous, or at least highly indicative.
- o The weather pattern (at the given season) over the suspect test site, or, alternatively, the availability of weather-independent satellites.
- o The confidence with which probable cause must be established before issuing an alert to the seismic system.
- o The period needed to analyze the imagery and to conclude that probable cause to aim the seismic arrays exists, as well as the additional time needed to tune the seismic system.
- o The gain in monitoring confidence obtained by tuning the seismic arrays.

It must be assumed that any nation which is a party to a comprehensive test ban agreement but which, nevertheless, elects to conduct a nuclear test will do so in utmost secrecy. It is probable that such a nation will take pains to see that its preparations for testing are not readily observable from reconnaissance satellites, or if they can be seen, lack such characteristics as

would positively identify them. Thus, it is improbable that even high resolution satellites would be presented with obvious preparations.

Such clandestine testing could be conducted in a large, deep, and active mine. In a mining operation of such scale the additional earthmoving machinery necessary to excavate horizontal tunnels - or even to bore vertical shafts starting from an existing tunnel - would go unnoticed. The construction spoil from a tunnel, perhaps the most visible signature of such an operation, could even be hidden in played-out regions of the mine. Until the arrival of the nuclear device itself not even an increased level of security need be maintained, although some attempts to conceal the purpose of the special construction from miners employed for the normal work of the facility would have to be made.

Under these circumstances, it is unlikely that any obvious indications would appear before the test which could either alert the seismic network or which could be used to pinpoint the site of the borehole or tunnel. Hence, detection and identification of the nuclear test would have to wait until the test took place. While seismic means alone should provide strong indications of the event and strong evidence that an explosion had occurred, teleseismic arrays cannot be expected to locate the epicenter of the test to better than a few kilometres. Given the clandestine nature of the test, it is improbable that the testing country would opt to test within range of a local seismic array.

Pin-pointing the epicenter must, therefore, be done by observing the site post facto to find surface changes produced by a large explosion at a depth so great that the rock overburden prevents venting and - more importantly - the formation of a collapse crater. Effective on-site inspection requires advance location of the shot and the associated bore hole or tunnel complex to no worse than one or two hundred metres; otherwise, the area to be searched on the surface is too large, and the likelihood of being able to sink an inspection shaft into the cavity produced by the test is very low.

Thus, surface indicators which can be used to identify and localize deep underground explosions must be found. Fortunately several such signatures exist; some have been used already to locate underground tests, while others are in development. All techniques require multispectral information, and a significant advantage to such imaging techniques is that the area surrounding the epicenter appears as an approximate circle at most a few hundred meters in diameter. The centre of this circle can be located with high precision, thus giving an accurate location of the epicenter of the test.

7. Use of aircraft

In addition to satellite imagery, aerial overflights (similar to "Open Skies" overflights) could be initiated. The overflights would be able to photograph a large part of the areas under observation and help ascertain, in the same way as satellite imagery, where, if any, events have taken place. Observers on the

overflights would also be able to survey the areas looking for signs of drilling, unexpected activity, unusual geological features etc.

Images or photographs could help identify surface dislocations, surface disturbances and deformations, signs of recent activity etc. Images using infrared-sensitive detectors or film could help to pick out vegetation changes and cavities. Radiation detectors carried aboard the aircraft could detect any accidentally vented radioactivity from an underground nuclear explosion. In order to hunt for metal objects (as signs of recent activity) electromagnetic and magnetic survey equipment could also be carried aboard aircraft. Magnetometers which measure changes in the magnetic field due to changes in the magnetic fields could also be used.

In addition overflights could be used to help ensure that any pre-inspection restrictions, such as a ban on traffic in the proximity, were adhered to by the party due for an inspection.

8. On-site inspections

In the event of ambiguous data from the global seismic network which cause concern that an illegal test may have occurred, it would help to resolve any discrepancy by sending inspectors to the area in which the ambiguous event originated. The inspectors would be able to carry out a number of scientific measurements which may help to ascertain the cause of the event under consideration.

On-site inspection (OSI) will also be an important confidence-building measure. Regular visits to inactive nuclear test sites and to seismic stations in the global network will help to deter any evasion and will build confidence that equipment is being maintained and unviolated.

An OSI under a CTB verification regime would be carried out for a number of reasons:

1. Under the procedures for notification of large chemical explosions, inspectors would be invited to observe such an explosion as a confidence-building measure.
2. The integrity and operation of in-place detection equipment would need to be checked periodically.
3. For confidence-building purposes, there could be a number of routine visits to old nuclear test sites.
4. If anomalous sets of signals were detected by seismic arrays or if unusual activities were observed by satellites or aerial overflights, then an inspection would be initiated to locate the origin of the event or activities and to ascertain the cause.

Because of the nature of seismic monitoring, it is not easy to pin-point exactly where an event occurred. In some cases the location could only be known to within an area of a few hundred square kilometres whereas in other cases the location could be determined to within a few hundred square metres. The accuracy of location depends heavily on the magnitude of the signals, and on the type of event - the weaker the seismic signals the more difficult it is to locate. For this reason it is vital to be able to include satellite imagery and aerial overflights, as described above, in the verification regime.

There are a number of activities which inspectors can carry out in order to locate the site of a nuclear explosion. These include:

- 1) The measurement of aftershocks - seismic disturbances which follow both explosions and earthquakes, the strength and rate of the after-shocks being dependent on the strength and type of event. In order to detect aftershocks, the inspectors should install an array of seismic detectors over the area of interest as soon as possible after the event. Depending on the strength of the event, the aftershocks could last from 2 weeks to several months.
- 2) Seismic sounding for cavities. Underground nuclear explosions leave cavities and chimneys in the ground, which act as dislocations in the surrounding rock structure. The technique, using the passage and reflection of seismic signals, provides a picture of below-ground features. Large cavities or chimneys would show as discontinuities in the picture.
- 3) Electrical conductivity survey - chimneys and cavities produced by underground explosions can affect the electrical conductivity of the surrounding rocks and soil. A useful procedure for location of a past underground explosion would be a survey of the area's electrical conductivity.
- 4) Detection of radioactivity. A radiation survey of the area could play a significant role in establishing whether a nuclear explosion has taken place. The presence of particular radioactive nucleides would be a unique indication that a nuclear explosion has occurred. Samples of soil, vegetation and water at locations under investigation could be taken away for analysis. Inspectors could carry hand-held radiation monitors to scan the region under investigation.
- 5) Drilling - costly, operationally complicated and time consuming. It could also be a dangerous activity - radioactive gases could be vented into the atmosphere. The application of drilling is therefore limited to locations at which there is a very high degree of certainty of a past nuclear explosion. It is however the one technique which has the potential to provide irrefutable evidence of an illegal underground nuclear test and therefore must be included in permitted OSI techniques.
- 6) Survey for buried and forgotten metal objects. Metal detectors, which are very portable, would be able to scan for equipment left behind or buried following a drilling operation. Although it may be difficult to scan a larger area in this way, evidence of items connected with drilling and nuclear tests (cables engineering tools etc.) could well be found in a location where other evidence was alerting suspicion.

9. Coordinating the verification system

To be effective as a deterrent at a high level of confidence, procedures for data collection need to be fast, efficient, and thorough.

Whilst the science and technology are almost certainly now available for effective verification of a CTBT, the procedures and organisation for data collection should reflect scientific and engineering realities from their inception. Consequently we recommend that there be a central monitoring agency which would be responsible for acquiring and assessing all the data for monitoring a CTBT.

It would be responsible not only for collecting relevant data up to and including initiation of an OSI, but also responsible for analysing it for dissemination to the States Parties. **The Agency would not have responsibility for the final assessment of compliance.** The decisions on compliance would rest with the individual states which are parties to the Treaty. Rather, the Monitoring Agency would act as a service to the States Parties.

This would allow the Agency flexibility and independence. The decision to carry out an on-site inspection, for example, could be made quickly by the Agency and be based solely on technical information. The Agency would however be accountable to the States Parties and would have to report regularly to a Consultative Committee and to the United Nations.

10. Conclusions

The main conclusion of the Verification Technology Information Centre is that **a CTBT can be adequately and effectively verified providing that more than one type of data is used to monitor the Treaty.**

Seismology is crucial to monitoring nuclear test explosions and will remain so for the foreseeable future, but because of the nature of the technology, it will almost invariably leave areas of ambiguity regarding low magnitude signals. Some or all of these ambiguities can be removed if the monitoring process contains other methods of observation apart from seismology.

Other surveillance techniques which must be employed for adequate verification should include on-site inspection spot checks with minimum prior notice, challenge inspections undertaken to investigate ambiguous events, seismic detectors on sites previously used for nuclear test explosions, remote observation by satellite and aircraft and monitoring of airborne radioactivity. Data exchange and notification would form an integral part of the verification regime.

Effective verification would be more readily assured if treaty compliance were monitored by some Central Monitoring Agency. Such an Agency

would not be responsible for any assessment on compliance, those decisions would rest with the States Parties to the treaty.

What is VERTIC?

The Verification Technology Information Centre (VERTIC) is an independent organisation of scientists which conducts research and distributes information on the verification of arms control and disarmament treaties. Funded by charitable trusts and foundations and by contracts for commissioned research, VERTIC operates through office staff in central London, a UK network of leading scientists and arms control experts and an international network of advisors. The network links experts in the fields of: remote sensing, nuclear materials, seismology and nuclear testing, space weapons, conventional forces and arms control. The network of advisors is drawn from many countries including, USA, USSR, Sweden, New Zealand and Switzerland.

VERTIC was established in 1986 in response to the need for reliable information on verification of journalists, policy makers, legislators and the academic community. VERTIC serves all on a non-partisan basis.

As the first organisation in the world dealing exclusively with verification issues, VERTIC has become a major source of information on the subject. The centre maintains an extensive library of books, articles and press clippings pertaining to verification which is open to all and is frequently used by researchers and other arms control organisations.

The Centre's programme includes publications, a monthly bulletin ("Trust and Verify"), an annual book ("Verification Report"), courses on verification, research on verification techniques and methods and public education. VERTIC scientists deliver invited papers at international conferences and are frequently called on by the media to provide expert comment on the topic of verification. In the UK, VERTIC organizes seminars in the Houses of Parliament, in Whitehall and a large number of universities and specialist institutes.

In carrying out its work, VERTIC collaborates with other organisations both in the UK and internationally. For example researchers at VERTIC completed, with the Council for Arms Control, a joint venture contract commissioned by the UK Foreign and Commonwealth Office, on verification of a Conventional Forces in Europe Treaty. VERTIC was also commissioned by Parliamentarians Global Action in New York to study the verification requirements for a Global Nuclear Test Ban Treaty.

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