Scientific and Technical Aspects of the Verification of a Comprehensive Test Ban Treaty

A Study

by

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Chapter 1

GENERAL CONSIDERATIONS

Verification has been the most controversial issue in the history of the nuclear test ban debate. Failures to negotiate agreement of a long-standing commitment to a nuclear test ban have been blamed on inadequate verification. Technical committees have been formed and reformed to discuss the problems of verification, numerous books and papers have been dedicated to the subject and yet today verification still continues to be cited as a reason for failing to negotiate a nuclear test ban.

It is our intention to provide a working model for the verification of a Global Comprehensive Test Ban (CTB). We have done this by taking into account all the scientific, technical and operational methods which are at our disposal and by integrating these methods into a structure for verification of a CTB with the following criteria.

1.1 Criteria for the Verification of CTB

It is important to be clear what is required from verification of a CTB treaty.

<u>First we require that the verification regime be effective</u>:
Effectiveness of the verification regime is the assurance of compliance within treaty limits. There can never be 100% assurance, but there can be *sufficient* assurance that there is no *military significant* violation. The terms "sufficient" and "significant" are difficult terms to define.

It is clear that the greater the extent of violation, the more certain we need to be of our capability of detecting it rapidly.

<u>Second, a verification regime also needs to deter violation</u>. This can be achieved by imposing a high cost (political, military and economic) on cheating. The harder it is to evade detection, the more a treaty evader would have to resort to more and more intricate and expensive ways of carrying out clandestine activity. For example, if all previous nuclear test sites were to be closely monitored, an evader would have to find an entirely new nuclear test site elsewhere, and, if there were a risk of that site being seen by satellite or plane, then the evader would have to build all of it underground. The evader would therefore, incur large financial costs and there would be a large operational cost in the total amount of effort in keeping the facility concealed and in getting the equipment from production to clandestine deployment without detection. Of course, if the political costs and operational costs of being caught were low, then the evader would not go to that much trouble. Political and operational costs would depend on the extent of cheating, but for them to be effective as a deterrent, violations must be detected in enough time for a response to be meaningful. Therefore in keeping the verification

gauntlet long and difficult and the costs of being caught cheating high, there can be high confidence in the verification regime.

Third, we require that the verification of a CTB be efficient and cost-effective. By this we mean that the verification procedures are commensurate with the task. We need to establish a programme which will be effective and provide us with the information we need without becoming a huge drain on resources.

Fourth, we require that verification not be over-intrusive. The methods used for verification should not enable any party to gain sensitive information which is not necessary for verifying a CTB treaty.

Fifth, verification procedures must be reciprocal. This does not mean that factors such as geography cannot be taken into account, but that the principle of equal treatment of signatories to a treaty holds.

Finally, verification must be legal. Verification procedures must not contravene national laws. It may of course be possible to change national law, but it should not be assumed that such laws would be amended to facilitate verification of a proposed CTBT.

We also need to consider what provisions in a treaty could be monitored and what risks the non-compliance of one side could pose to the other and how to deal with a violation to deny any benefit from it to the violator.

Thus, parties to a CTB would have three major requirements from a verification regime. First, it should dissuade all parties from contravening the Treaty. Second, it should give timely warning of any violations that do occur so that action can be taken. Third it should build confidence in the Treaty so that security of the participating nations is enhanced and other states are encouraged to sign. The type of regime that we need depends to an important degree on the extent to which parties are prepared to rely on a deterrence to cheating. This depends in turn on an assessment of what types of contravention are most likely to occur, and for what reasons.

1.2 Robustness and Redundancy

No verification system can be perfect, but it can be structured to have a high capability of detecting violations. There are several ways to monitor compliance of a CTB agreement, these are outlined in the following report. In a different world it may be that seismic detection would be all that would be required for a high level of confidence. In reality, to rely wholly on the results of one measurement method is foolhardy. It may be that the chosen method of measurement is not suitable for the task, it may be that the method has large, unknown errors which bias the results. Only through other independent measurements using different techniques do we gain confidence in our results. The more ways at the disposal of the measurer to determine an unknown the closer the measurer will be to the true value.

For example, say a satellite detects drilling activity in a remote area, a subsequent challenge on-site inspection could then reveal whether or not the drilling activity could be useful for underground nuclear testing. Disagreement might be resolved by subsequent inspections at later dates. Other approaches such as an overflight or seismic detectors on-site could resolve any discrepancies between the satellite data and the on-site inspection data. Agreement between all methods (within the errors of measurement) would lend confidence to the treaty and establish which methods are the most accurate.

In addition different methods of measuring reveal different types of information. For example, random on-site inspections give detailed information about a small number of sites, satellite imaging gives general information on many sites. These types of data can be combined so that they enhance each other.

To rely on one or two methods could jeopardize the treaty in future years. We would argue that as many verification methods as possible should be negotiated, in that way the options for the future are established. Not all of the options need be exercised, but that they exist would allow their employment if necessary.

In this way, a seeming redundancy of verification techniques would make the regime more robust. If one method fails, then others could still continue to establish compliance with the treaty. In addition improvements could be made in the verification regime at a later date. The success of the verification regime, and hence the success of the treaty, would not then be dependent on the success of one approach to verification. This is particularly important if deliberate attempts to deceive are employed by one or more countries. Certain verification procedures may be more susceptible to deception than others. On site inspection (OSI) for verification is a new situation for arms control and using OSI may contain unforeseen pitfalls.

1.3 The Issues in Verifying a CTBT

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 some military programmes. It is paramount that such a treaty should be effectively verified, so that it would not be possible for states to evade detection if they clandestinely tested nuclear weapons. For this reason a vast amount of work in a number of countries has gone into developing scientific and technical methods for verifying a CTBT.

There are a number of ways in which, theoretically speaking, it may be possible to violate a CTBT and evade detection. These include cavity decoupling; hiding a test in an earthquake, testing in outer space, arranging a series of tests to mimic an earthquake etc. The evasion scenarios are discussed in Chapter 2.

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, were 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 the security of all parties is enhanced and other states are encouraged to join.

CHAPTER 2

ELEMENTS OF VERIFICATION

There are three main functions of verification:

1. To detect significant cheating

2. To deter cheating

3. To build confidence in the treaty

Each of these is important and is related to the others.

In order to establish a working structure for verification of a CTBT, we shall look at the technical means available, consider each of them in turn and then consider how they may work together so that each enhances the other. We shall set up a "verification gauntlet" that a potential evader would have to run - each of the hurdles on the way would have a high probability of discovering non-compliance. In this way parties considering violating the treaty would be dissuaded from doing so if it were important to them not to be discovered.

2.1 Seismic Signal Detection

Since the 1963 Limited Test ban Treaty, most nuclear testing has taken place below ground. Underground and surface explosions and earthquakes emit seismic waves which propagate through the ground and can be detected by seismic detectors or seismometers. There are a number of types of seismic waves and they each have different characteristics, these include compressional and shear (P and S) body waves and also surface (Love and Rayleigh) waves.

The magnitudes of seismic vibrations are proportional to the size or yield of the underground explosion. The P-waves propagate to long distances and so the P-wave magnitude (m_b) is used to measure the strength of the explosion - its yield. Surface-waves and other wave types are also used.

The ability of seismic detectors and seismic networks to detect seismic events depends on many factors, which include: the distance from the event location to the detectors, the quality and sensitivity of the seismic equipment, the level of background noise, the type of geology between the event and the detectors, knowledge of the seismic conditions locally, the numbers of detectors in a network etc.

Because most of the scientific research has, until recently been focussed on National Technical Means (NTM), most attention has been paid to teleseismic monitoring, which means monitoring seismic activity at distances of over (approximately) 2,000 km away. Recent political change, particularly in arms control, has meant that more attention can be paid to in-country monitoring. This development changes the potential capabilities of the seismic detection networks and encourages research into regional-range and high frequency detection and identification, which have the potential of becoming very powerful seismic tools.

This study investigates the type of seismic detection network that would be necessary to verify a global CTBT with current capabilities. In the near future those capabilities may well improve, thereby adding increased confidence to the detection capabilities of the seismic network.

2.2 Radioactivity Detection

In addition to the seismic network a radiation and radioactive-debris monitoring network would lend increased confidence to the verification system. Because there is always a possibility of accidental release of radioactivity into the atmosphere, as has happened in the past, a potential violator of the treaty may be further deterred from carrying out an underground nuclear test, if it is probable that the radioactive release would be detected. Since the 1950s radioactivity detection networks have been in place and have been used to monitor the 1963 Partial Test Ban Treaty.

2.3 Overhead imagery

Images of terrain and activities, in particular images that monitor temporal change, can be taken by imaging equipment mounted on satellites and aircraft. Although satellites and aircraft will not be able to monitor continuously, spot checks would act as a deterrent to cheating. Targeted monitoring, for example following an unidentified seismic event, or unusual, unreported activity would provide information that could help to decide whether or not to initiate an on-site inspection.

2.4 Notification

Large industrial explosions could be misinterpreted as small, perhaps decoupled nuclear tests. In order to increase confidence in the treaty, large industrial explosions could be notified in advance and routine inspections could be made to verify their non-nuclear character.

2.5 On-Site Inspections

On-site inspection will have an important role to play in verifying a CTBT. They will be used in a routine and ad hoc manner to check equipment in the seismic and radiation monitoring network, to check that notified chemical explosions are just chemical explosions and to check that previous nuclear test sites are no longer in use.

In addition to routine and ad hoc inspections, on-site inspections will be used to establish the cause of unusual, unidentified or anomalous events detected by the seismic or radiation monitoring networks or detected by overhead imaging. These will be special inspections, only used if there are grounds for concern.

During a special inspection, inspectors will need to make measurements of seismic activity and of electrical conductivity and they will need to survey the region by aeroplane. The full range of techniques required are discussed in this report.

2.6 Evasion Scenarios

There have been a number of scenarios suggested for detonating nuclear devices and escaping detection. It is important to take evasion possibilities into account when designing a verification system. 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 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.

Decoupling

One proposed way to decrease the signal from an underground nuclear explosion is to detonate the device in a large, underground cavity. The cavity would have to be large enough to stop the walls fracturing or becoming plastic from the shock of the explosion. If this can be achieved then the explosion would be "fully decoupled" since the low frequency seismic signal is reduced to a minimum.

Although there is very little evidence available, theoretical predictions of the decoupling factor have not been borne out in practice (Rodean 1971, Leggett 1988). In the one reported experiment with a nuclear detonation (SALMON-STERLING experiment in 1966), the decoupling factor was much less than predictions (Fetter 1988). This was probably due to cavity walls having been weakened by an earlier explosion (to create the cavity) and a very large initial pressure pulse which may fracture cavity walls.

The volume of the cavity needed for full decoupling is proportional to the yield of the explosion and inversely proportional to the pressure that the cavity walls can withstand and is given:

$$V = 3 \times 10^5 W/p$$

Where W is the yield in kilotons and p is the maximum permissible pressure in kilobars exerted on the cavity walls. For example to fully decouple a 5 Kt explosion in salt, a spherical cavity with a radius of at least 43 metres would be required, for 1 Kt a minimum radius of 25 metres. In the SALMOM-STRELING event in Mississippi in 1966, the cavity created by the SALMON test in 1964 (5 Kt shot) was roughly 34 m in diameter at a depth of 820 m. The cavity proved to be too small to try to decouple a 5 Kt blast and the STERLING shot detonated for the experiment was a 0.38 kt explosion.

Clearly there are major engineering problems associated with excavating cavities large enough to have potential for successful decoupling. It might be possible, however, 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.

Hiding a nuclear test in background seismic noise

In addition to decreasing the seismic signal of a nuclear test by decoupling it would be possible to increase the noise levels in the areas around the nuclear test site and around detector stations likely to detect the signals. Activities which produce such noise around seismic stations could be viewed as interference in verification and taken to a consultative committee set up to resolve difficulties in monitoring the treaty. In the meantime the stations could be moved to quieter regions.

Hiding a nuclear test in an earthquake

If a potential treaty violator tried to hide a nuclear test in the tail of a large earthquake (Leggett 1988), the operational difficulties would be substantial. The evader would have to be in a constant state of readiness for a long period (potentially up to several years) to await a suitable earthquake. In addition the relatively high frequency signals generated by the explosion may be impossible to hide from an internal network of seismic detectors; furthermore, the explosion signal may well precede the earthquake signal at one or more stations. Any drilling or mining activity near the site of a major earthquake could initiate a request for an on-site inspection (Fetter 1988).

Disguising a nuclear test as a large industrial explosion

It may well be possible to detonate a small (probably decoupled) nuclear explosion at the same time as a large industrial explosion. The evader could then show, on request that a large industrial explosion had taken place (the explosion may have also been notified) and, because of uncertainties in seismic detection a low magnitudes, it may not be possible to distinguish seismically between two nearby explosions.

However a comprehensive on-site inspection after such an event could reveal the detonation of a nuclear device. In addition, notification of large industrial explosions, of say above a few tonnes, allowing routine inspections to take place at the time of the notified explosion, would add confidence.

Testing in a remote area belonging to another country

It is possible to imagine a violator carrying out a test in another country's territory (the country being known not to possess nuclear weapons) with or without the knowledge of that country. This could occur once in the hope that the nuclear test, although detected, was not identified as such because of the territory in which it was detonated. In particular, if the country which owns the surrogate nuclear test site is not a signatory to the treaty, then there would be no inspection rights to further establish the cause of unidentified seismic events. This is a particularly difficult evasion scenario to deal with satisfactorily. The evader, as a signatory to the CTBT would be acting illegally. The State acting as surrogate, and not as a signatory of the treaty, would not necessarily be acting illegally (depending on what other treaties it was party to) and also would not be legally obliged to accept any on-site inspections. The activity could be further checked by satellite observation and a request for an on-site inspection may be welcomed to clear up any misunderstanding.

Simulating an earthquake

It has been suggested that, theoretically, a multiple underground nuclear explosion might be made to look like an earthquake. This could be achieved by detonation in a region of high seismic activity, with the intention of producing the prolonged P-waves and large-amplitude surface waves that are characteristic of earthquakes (Kolar and Pruvost 1975). Whilst this strategy may complicate the signals, and hence make identification more difficult, it would be difficult to predict in advance that such mixing and confusion would occur. Even so the variation with azimuth of earthquake signals would be extremely difficult to simulate (Clark and Pearce 1988) - multiple explosions are given little credence as evasion ploys.

Testing in space

While many regard this scenario as so fanciful to be barely worth discussing, it has had some attention paid to it in recent years. It may just be possible to detonate a nuclear device behind the sun and escape detection although receiving the results could prove to be the largest deterring factor in this scenario. Detonation behind the moon risks detection by radiation monitors on satellites. One preventative measure that has been suggested, is to inspect space payloads before launching (Fetter 1988).

2.7 The Strategy for Verification

In order to satisfactorily verify a multilateral Comprehensive Test Ban Treaty, including taking into account possible evasion scenarios, several monitoring techniques and notification measures must work together. It is important that all types of data are analysed in a coherent manner.

The collection of data in a CTBT verification regime is analogous to the collection of data in a scientific experiment. Each set of data revealing information has to be correlated with the other sets of data. These data may be obtained in a variety of ways. they may have come from seismic detection, from satellite observations, from on-site inspections and so on. Is it possible to make sense of all the information? What if the pieces of information are in conflict? Does it make any sense to try to put some "degrees of confidence" on the numbers? For example if only one seismic station records an event, then confidence in the recording is not high, whereas if 3 or more record the event, not only is confidence relatively higher but a fix can be put on other parameters such as location.

The answers to these question are crucial to determining compliance - the end point of the verification process.

It is possible to assign weights to the data. These weights reflect the degree of confidence in the data and are directly obtained from the method by which the data are obtained and hence the errors associated with each data set.

There will be occasions when data from different measuring techniques are apparently in conflict with each other (for example, the radioactivity monitoring network detects a release of radioactivity whereas none of the seismic detectors, even those close to the region of high radioactivity, detected anything unusual). When such a situation arises, it is important to consider the possible explanations for discrepancy and to initiate ways to resolve it, for example by carrying out an on-site inspection.

It would be very difficult to analyse the data coherently without some form of centralised mechanism for analysis. Whilst each State may have access to the seismic data and radioactivity data, not every Party will have access to or be able to commission overhead images or the results from on-site inspections.

In which case, analysis would be carried out without the full data set by most countries party to the treaty. Consequently there could be large discrepancies between the national decisions on compliance.

In order to assess this difficulty, this study looks at the verification regime from two standpoints:

(i) One is a centralised mode of operation, which employs a central monitoring agency to carry out the collection of data from seismic stations, on-site inspections, overhead imagery etc. The final compliance decision would however rest with the States party to the Treaty.

(ii) The other is a decentralised mode of operation (based on the 1983 Draft CTBT presented to the Conference on Disarmament in Geneva by Sweden) in which the parties to the treaty are responsible for seismic stations in their territories and responsibility for on-site inspections rests with committees.

In both models the verification scheme shown in Figure 2.1 outlines the steps and decision tree which would be necessary for effective verification of a CTBT.

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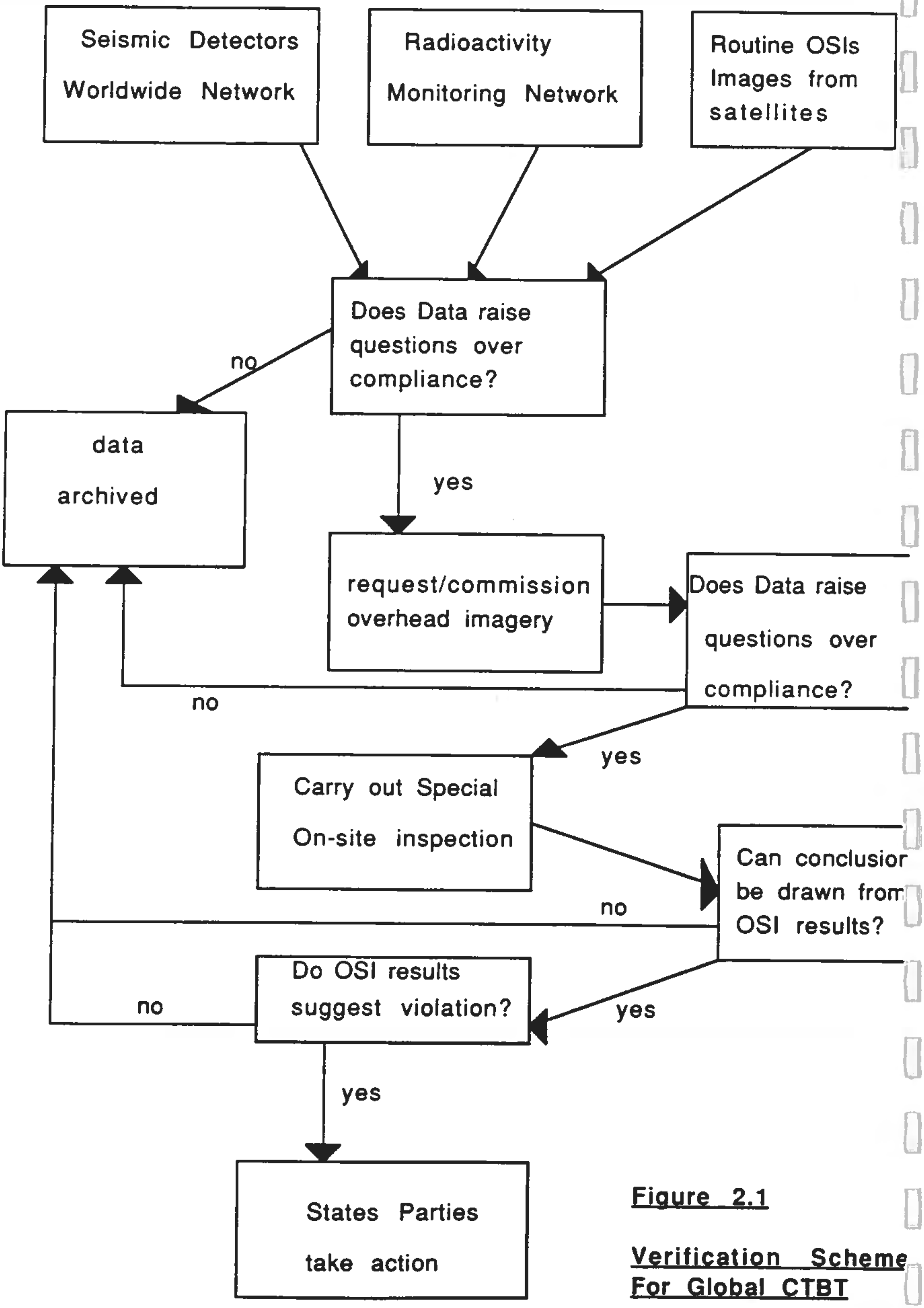


Figure 2.1

Verification Scheme For Global CTBT

Chapter 3

SCIENTIFIC AND TECHNICAL PAPERS

1. SEISMIC MONITORING.

1.1 Introduction

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. Because of this, seismology offers the most important means of carrying out the 3 stages of verification needed in treaties: "Detection- Identification - Yield estimation" (i.e.. recognising seismic events; discriminating between earthquakes and explosions; and, if needed, deciding how large the explosions were).

The most important types of seismic waves are shown in figure 3.1.

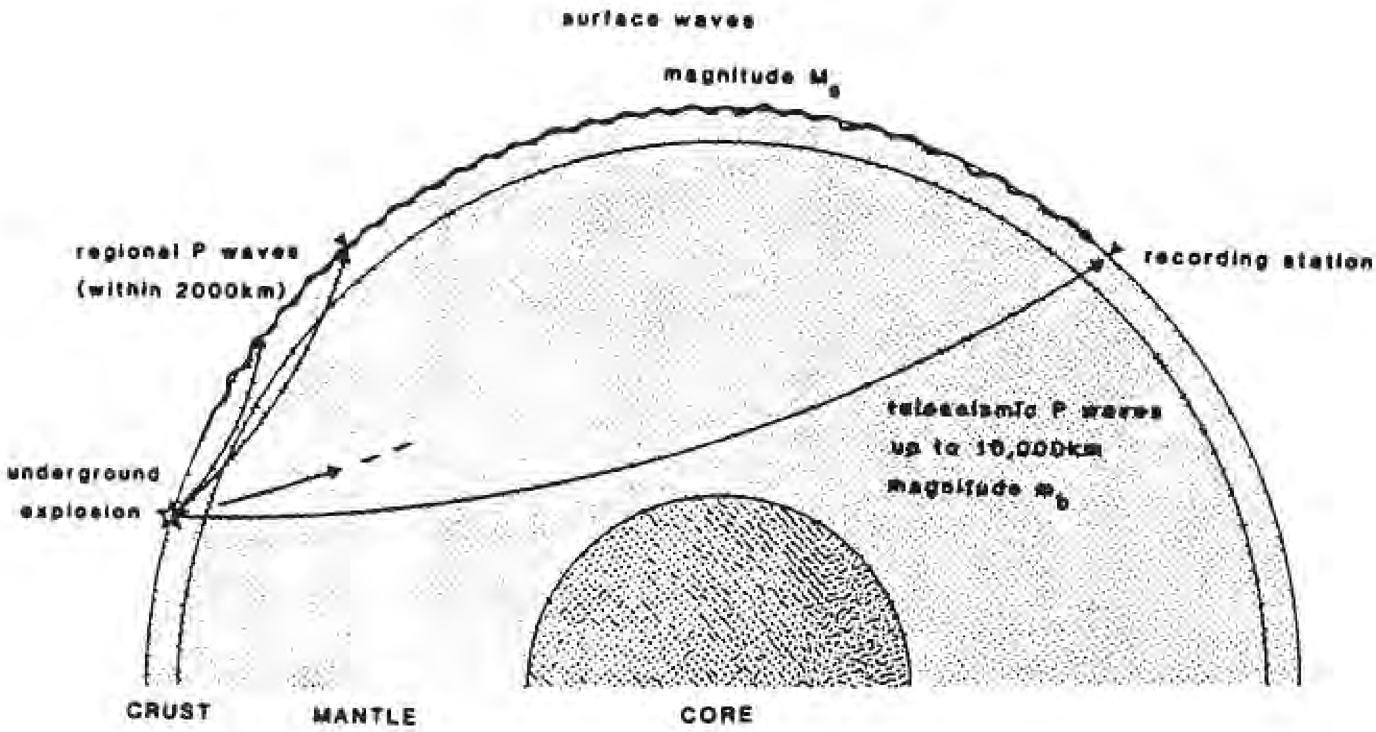


Figure 3.1

Surface waves, whose size or "magnitude" is termed M_s, are like ripples on water.
Body waves, or P waves, are sound waves travelling through rock. They are always faster than surface waves and their magnitude, m_b, is related to the yield of the explosion by a logarithmic scale. This means that if a 1 kT explosion gives an m_b of 4, then a 10 kT explosion gives an m_b of 5, a 100 kT explosion gives an m_b of 6 and so on.

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 surfaces waves at about 0.0.05 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.

1.2 Detection

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.

The existing network of seismic stations outside the USSR can detect events within the USSR down to about m_b 4 or less. This is equivalent to detecting an explosion of yield between 200 tonnes and 8,000 tonnes (8 kt), depending on the type of rock in which it was set off. To be sure of detecting a 1 kt explosion in any setting, we need to detect events as small as m_b 2.0-2.5 Only a very few of the most sophisticated and well-situated stations (such as the Norwegian NORSAR-NORESS) are currently this sensitive. To achieve low level detection routinely, more existing stations need to be upgraded, and a network of 10-30 stations installed within the USSR would further increase likelihood of detection. A recently published report by the US Congress Office of Technology Assessment (1988), summarising the results of lengthy hearings involving dozens of the USA's leading seismologists, comments that "in principle, almost any desired signal detection level could be achieved within the Soviet Union if a sufficient number of internal stations were deployed."

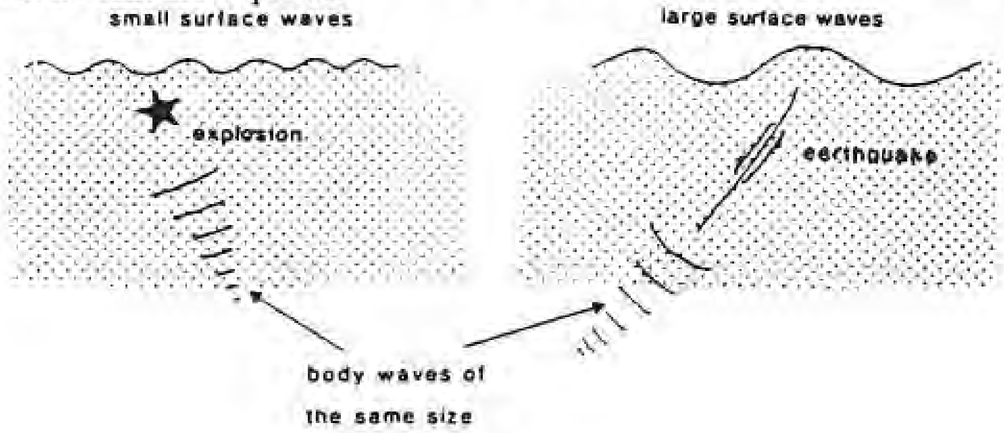
The number of earthquakes that would have to be analysed regularly is shown by statistical studies, which indicate that in the USSR there are about 50-55 earthquakes per day of m_b 2.5 or greater. These are mostly concentrated along the southern borders of the Soviet Union and along the Kamchatka-Kuriles area. About 30% of these are above m_b 3.5. On average about 2 per day are bigger than m_b 4, while worldwide there are over 20 per day of such magnitudes. The lower the yield limit of a treaty, the more earthquakes which need processing. In addition, at the low magnitudes many industrial chemical explosions would also require examination or pre-notification.

1.3 Identification

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. About 50% of the earthquakes within the USSR are deep enough to be readily identified this way.

Most other identification and discrimination criteria exploit the fact that underground nuclear explosions exert extremely sudden outward compression onto the surrounding rock, whereas earthquakes are rock masses sliding past each other relatively slowly. This leads to differences in some characteristics of their seismic waves; the direction of the first P-wave pulse, for example. The most effective criterion is that explosions are very inefficient at creating surface waves, but shallow earthquakes are just the opposite. Hence comparing m_b (body wave magnitudes) and M_s (surface wave magnitudes) enables us to distinguish between explosions and earthquakes (Figure 2). Other discriminants, successful to varying degrees, include analysing the frequencies of P waves: explosions show more high frequencies than earthquakes.



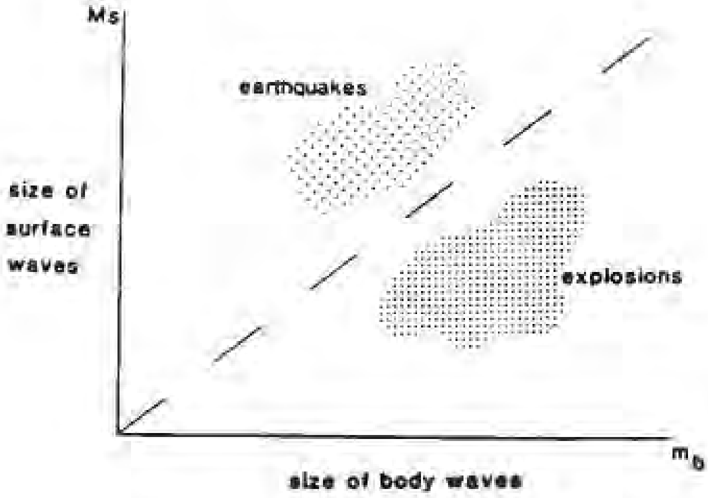


Figure 3.2

These simple criteria don't always work, however. The direction of the first pulse can be obscured by background noise; some earthquakes produce ambiguous m_b:M_s ratios, occasional earthquakes have occurred naturally in or very close to known Test Sites; explosions can set off small simultaneous earthquakes. All these make discrimination difficult, and some 'problem events' have required lengthy and detailed study before being positively identified as earthquakes.

Discrimination between nuclear and chemical explosions can be much more problematic, as they are often detonated in similar geological environments and have fewer differences in their seismic wave types. These problems could be largely overcome if mining explosions had to be detonated as a "ripple fired" pattern of charges rather then a single simultaneous salvo.

1.4 Yield estimation

Calculating the explosive yield of an underground nuclear test using seismic data is, in principle, quite straightforward. The more powerful the explosion the bigger the amplitude of the seismic waves it creates, i.e. the larger the values of m_b (see section 1.1). So, for those explosions where the yield has been announced, a graph of m_b against yield shows a simple straight-line relationship that can then be used to estimate yields of other explosions from seismic measurements (see Figure 3).

In practice, a difficulty arises because factors other than just random measurement errors affect m_b:

(1) Explosions set off in relatively soft rocks (like shales and alluvium) expend more of their energy in compressing the rock than if they were in a 'hard' rock such as granite; so the body wave magnitude, m_b, depends on the geology local to the test site.

(2) The Earth's upper mantle, between some 25km and 150km depth, absorbs seismic waves slightly. Because it is hotter in some areas than others, the amount of absorbtion varies, and so m_b depends on the general geological setting of the test site. This factor, referred to as "regional bias", is very important: the Earth absorbs less seismic energy below the Soviet test site at Semipalatinsk than it does below the US test site in Nevada; accordingly, a Soviet bomb let off at Semipalatinsk with the same explosive power as an American bomb let off in Nevada generates seismic waves of higher magnitude. This 'regional bias' means that explosions at the USSR's test sites give m_b values at least 0.2-0.4 larger than they would at the Nevada Test Site in the US . Until this was properly appreciated, the large seismic waves from Soviet explosions were thought to mean that all their tests had relatively high yields. Changing m_b by 0.2- 0.4 is equivalent to changing yield estimates by factors of 0.5 to 2.5, which at high yield is very significant.

3) Detonating such large explosions below ground sometimes causes some of the stresses already in the Earth's crust to be released in the form of a small earthquake simultaneously with the explosion, releasing seismic waves of its

own, which complicate those from the explosion. Thus m_b depends on how large an earthquake (if any) was triggered by the test.

All of these effects conspire to make seismic yield estimates from P waves accurate only to about a factor of about 2, for most areas.
However, as the 1988 Office of Technology Assessment (OTA) report made clear, the accuracy of seismic yield estimates can improve, to between 30 and 50%. All the processes above can be carried out using surface waves and other wave types also, and using them all simultaneously reduces uncertainties. If the Threshold and Peaceful Nuclear Explosion Treaties are ratified, then an exchange of geological data is required, which would make all the effects above much easier to assess.

1.5 Evasion ploys

There are several schemes that have been suggested whereby tests of significant size (several kilotons and larger) might be detonated without being recognised by seismic methods:

1. Multiple explosions. It is possible to design a sequence of several explosions such that all their surface waves sum up and appear as a single large surface wave, but their combined P wave is spread out and its maximum size is no greater than the largest individual P wave. Thus it might initially appear to be an earthquake. However, there are more complex analyses that would clearly identify it as a multiple explosion, and this is not considered a realistic evasion scheme. If all the explosions are simultaneous and very close (even in the same bore hole), it could be very difficult to distinguish that more than one explosion had occurred. This problem might make a quota treaty difficult to enforce, without on-site inspections.

2. Hide-in-earthquake. A clandestine test could, in theory, be set up in an area where earthquakes happen naturally and detonated as soon as one occurs. The earthquake signals could mask those of a small explosion. However, with an in-country network of seismic stations, it is possible to separate the two different signals. One of the promising aspects of recording high-frequency P waves is that explosions create much larger high frequency waves than earthquakes ever can, and so should stand out even more clearly form earthquake recordings. For this reason, the 1988 OTA report concludes that this evasion ploy is not a credible one. Nuclear explosions might be more difficult to detect by seismic means if camouflaged by a coincident chemical explosion, however.

3. Cavity decoupling. If an explosion is set off inside a large cavity, possibly many tens of metres in diameter, then its seismic signals are greatly reduced in size; experiments have found factors of up to 70 times (a reduction in mb of 1.8-2.0). This means that a decoupled explosion could appear like one much smaller in yield, or perhaps go entirely undetected. A decoupled 1 kT explosion gives an mb of about 2, much like a 'normal' 10-ton explosion. A network of seismic stations within the USSR is required to detect down to this level. Though theoretical predictions suggest high-frequency P waves should be much less 'muffled' by the cavity, decoupling remains the most serious evasion threat for small (i.e., less than 5kt) tests. For yields larger

than 10 kt, the 1988 OTA report concludes that the cavities would be too difficult to construct.

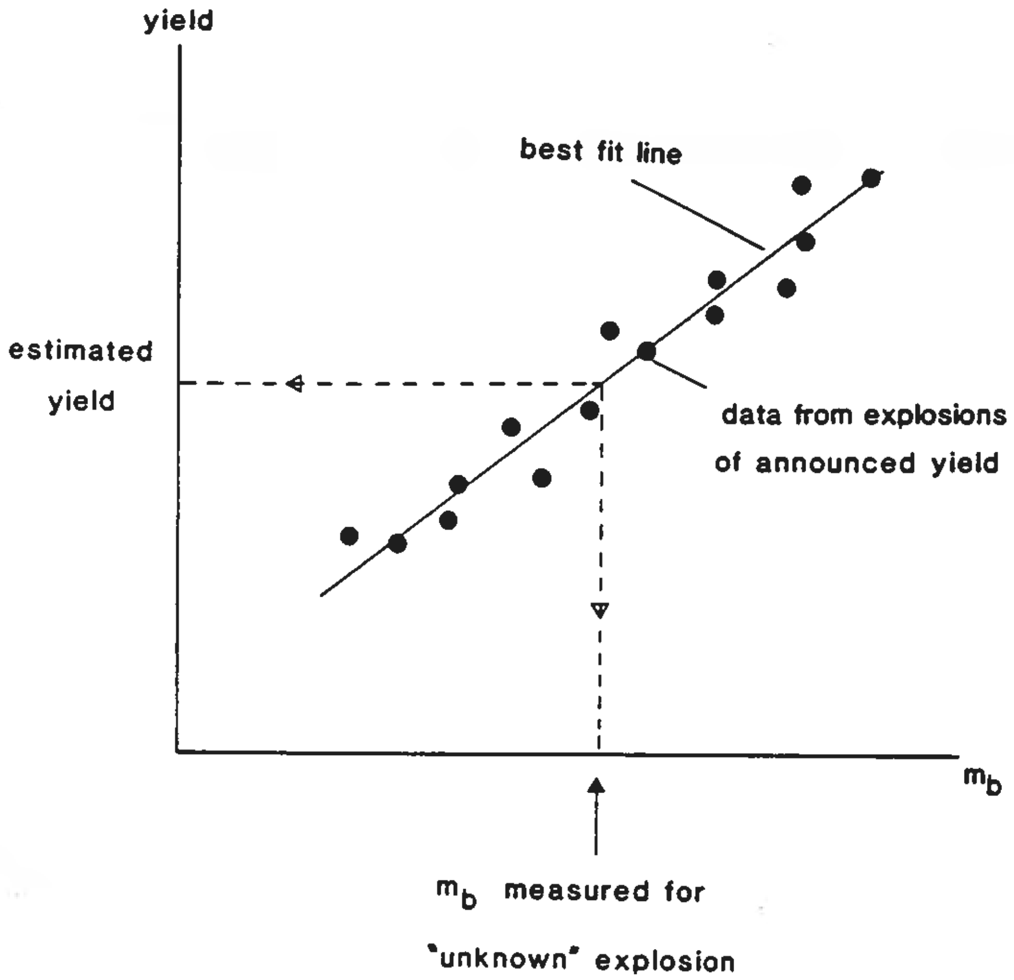


Figure 3.3

II THE SEISMIC NETWORK

OUTLINE DESIGN OF A SEISMOLOGICAL MONITORING NETWORK

Part I. Background to network design.

The seismological monitoring network has to have some magnitude or yield level as its basis - it has to be, in effect, 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 political decision has been made as to what that low yield is to be. That yield can be arbitrarily low - 1kt, 0.1kt, 0.001kt or whatever - and the seismic station density will increase accordingly; detection and location is not, in principle, a problem (although it may become a logistically implausible exercise to install enough stations and to manage and analyse their output).

As an example of this latter difficulty, consider the smallest announced nuclear explosion yield, which was just 0.0006kt (0.6 tonnes) or a P-wave magnitude of 0.5-0.6 if the explosion was fully coupled in hard rock. The 100+ seismic stations in Great Britain in 1985 only achieved a detection threshold of magnitude 0.5 under average noise conditions in regions where the stations are closely concentrated (see Figure 1); for example, within the 5-station Leeds University network. At such a station density (about 1 per 200 square km), over 110,000 stations would be needed in the USSR alone. Given that a 0.6 tonne explosion could have been fully contained at a depth of only a few tens of metres, a lower magnitude (appropriate to softer unconsolidated rocks) is quite probable. If fully decoupled a 0.6 tonne explosion would have a P-wave magnitude of only -1.3. The consequences for the scale of seismic network if such very low detection levels are required can easily be envisaged with reference to Figure 3.4.

In practice, firm data on detection thresholds etc. are difficult to obtain. Note also that most public-domain research (e.g. Marshall et al 1979) into earthquake-explosion discrimination involves yields in excess of 1kt (no US explosions after the early 1970s, before most high-quality/digital seismic data was routinely acquired, have had their yields announced); therefore the identification methods at our disposal extend beyond routine and 'proven' capability into 'research results' and extrapolations. So too do yield estimation methods, though that is not of relevance here.

For this study we make no judgements about logistic or financial feasibility. We attempt to design to entire system around proven technology and science. We feel it would expose the study to dispute if we were to rely on anything not accepted by the academic and government seismological community as established. On the question of the "hidden low-yield threshold", we feel that our choice should be clear. We choose 0.4kt (400 tonnes), because it has been claimed (von Hippel et al (1987)) to be the smallest possible fission device that will trigger a fusion explosion. This allows the design performance for the seismic network to be specified, in terms of the lowest magnitude seismic source it will have to detect and allow to be analysed. P-wave magnitudes for a 0.4kt shot fired in various geological settings are given in Table 1.

Table 1. Expected P-wave magnitudes (m_b) and surface (Rayleigh) wave magnitude M_s, for 0.4kt in various emplacement media, and no.of earthquakes/year worldwide at or above that m_b. The M_s values are very approximate, and are based on regional-range m_b:M_s data from Nevada Test Site (Taylor et al 1986); for $m_b < 3.8$ are extrapolated

	m_b	M_s	annual number
water-saturated rock	4.3	2.5	(47,500)
hard rock	3.4	1.6	(60,000)
dry unconsolidated rock	2.5	0.8	(480,000)
fully decoupled	1.7	-0.1	(1,500,000)

Note that in Table 1, the yearly number of events is for earthquakes only. For the smaller magnitudes, an unknown number - probably some hundreds of thousands - of industrial chemical explosions also take place, with increasing numbers as magnitude decreases. Some characteristics of a 0.4kt explosion are given in Table 2. These should be borne in mind when the feasibility of clandestine emplacement & detonation are examined.

Table 2. Some approximate source parameters of a 400 tonne explosion

elastic radius in granite	160m
containment depth (NTS)	90m
equivalent TNT explosion to fully coupled shot	<0.20-0.21kt
equivalent TNT explosion to fully decoupled shot	<0.003kt (3 tonnes)

Note that the containment depth actually used at NTS is set at a minimum of about 120m even where the explosion yield indicates shallower burial would still prevent venting. A clandestine explosion would need to be buried deeper still to avoid any surface expression such as a collapse crater.

Very little has been published on detection capability and other aspects of nuclear explosion seismology at such low magnitudes. Indeed, for m_b less than some 4.0-4.5, the physical basis of the discriminant commonly applied to teleseismic data, the m_b:M_s criterion, has been called into question both empirically and theoretically (e.g. Stevens & Day 1985). The means of identification (as an explosion or an earthquake) are still tentative, and is not clear what level of signal relative to background noise is required for effective analysis. Taking for the present the simplistic assumption (reasonable for teleseismic data) that the identification threshold should be 0.3 magnitude units greater than the detection/location threshold, the required detection threshold for decoupled explosions becomes a P-wave magnitude of 1.4, or >2.2 for fully coupled explosions. The implied data processing load for these two magnitudes is shown in Table 3; these data, and the earthquake statistics quoted in Table 1, are based on Lilwall & Douglas (1985) and Evernden & Archambeau (1986).

Table 3. Seismicity estimates at P-wave magnitude 1.4 - 2.2

P-wave magnitude 1.4:-	
no.of earthquakes/year at m_b 1.4 or larger	3,000,000
no.of candidate explosions from the earthquake population on location criterion only:-	
	=470,000/year
	=1,250/day
P-wave magnitude 2.2:	
no.of earthquakes/year at m_b 2.2 or larger	740,000
no.of candidate explosions from the earthquake population on location criteria only:-	110,000/year
	=300/day
no.of mining explosions/year	??100,000??

In areas with a high risk of decoupling (i.e. salt domes), the network design must anticipate decoupling, i.e. it must have a detection threshold of P-wave magnitude 1.4. In addition, orogenic (mountain-building) belts, where there is much natural seismic activity, merit closer attention in case of clandestine 'hide-in-earthquake' tests; so these too are assigned a detection threshold of m_b 1.4. Elsewhere on land we assume that clandestine decoupling is not practical, hence the lowest m_b will be the 'dry unconsolidated' case, i.e. a threshold of m_b 2.2. Ocean-floor explosions will be in water-saturated rock, so a sea-floor seismic network needs an easier threshold of m_b 4.3.

A further complication is that the decay in amplitude of seismic signals with distance depends on the geological characteristics of the Earth's crust and upper mantle that the signals are traversing. Hence the spatial density of stations needed to detect a given magnitude varies in the same way. Many geophysical studies over the last 20-30 years have established that the Earth's uppermost 700km or so can be classified seismologically into a small number of types. Those used here are summarised in Table 4, together with the design specification of the CTB verification network and the approach taken to determine its details.

Table 4.

(a) Design specification of the seismic network

geological province	required detection threshold (P-wave mag)
1. Shields and cratons	2.2
2. Stable continental platforms	2.2
3. Orogenic belts	1.4
4. Rift zones	2.2
5. Salt domes and bedded salt	1.4
6. Deep-ocean islands	2.2
7. Ocean floors	4.3

(b) steps required to compute network station density

1. Specify network pattern, and area covered per station in terms of the maximum source-station distance

2. For each geological province, estimate maximum distance at which required magnitude of event can be detected - hence specify station density in that type of geological province.

3. For each State Party, determine its surface area and break it down into the geological categories. Find the numbers of stations needed in each category and hence number for that country, rounding up where necessary and with a minimum number of 1 per nation.

There are a few useful benchmarks directly and indirectly applicable to this 0.4kt level. One is the SALMON-STERLING decoupling experiment (the only known actual decoupling experiment with nuclear explosives). The maximum range at which the decoupled 0.38kt shot was detected was about 110km, by every individual element of a 6-station 2.5km-aperture array (Springer et al 1968) with all local noise sources minimised. A further useful standard is the proposed US National Network (USNN; Masse et al 1989) which specifies 150 stations for detection (by 5 or more stations) of a P-wave magnitude 2.5 event anywhere throughout the 48 states. Also of value is the performance analysis by Herrin (1985) of the state-of-the-art borehole seismometers at Lajitas, Texas; this system detected a 5-tonne explosion at a range of over 725km, and Herrin concluded that "...a fully-decoupled nuclear explosion of 0.2kt yield could be detected at a range of 750-1000km...processing should be expected to further increase this range..".

Other information comes from publications not directly related to nuclear-explosion seismology. Worthy of specific mention among these is evidence that ocean-floor seismometers have been shown capable of recording the "P_o" and "S_o" phases (P and S waves trapped by the ocean crust acting as a waveguide) at ranges of up to 3750km or more, and the T-phase (an intra-water wave) still further away - supporting the widespread feeling that monitoring of deep-ocean regions does not require high station densities.

Finally, we must emphasise that the tenor of the whole design is to be considered an outline only. A specific design would require extensive and detailed research, involving field studies and computer simulations, reviews of instrumentation, etc.; one aspect of a more full study is described below. Thus, for example, our design suggestions tabulate only numbers of stations per State Party to the 1963 PTBT (by way of example); to propose actual locations would need field- or literature-based noise level surveys. This and several other aspects of the design could only realistically be undertaken by some internationally-based and well-funded Working Group or Committee.

Part II. Seismic station design.

Considerable advances are currently being made in both seismometer design and seismograph systems as a whole; for example, seismometers with stable mechanical and electronic designs which generate minimal background noise themselves, 16- and 32- bit direct digital recording to allow a wide dynamic range (ratio of smallest to largest signal registered), high-volume mass digital storage devices, etc. Many of these are really only at the experimental stage, especially the signal-processing techniques needed to extract the smallest possible signals from e.g. borehole- and/or 3-component seismometer arrays. Thus the choice of station specification for the CTB network is not clear. We offer instead 3 alternative designs, and then derive station numbers etc for each. What the designs represent is summarised in Table 5. The options 1-3 represent a range from 'research' to 'established', and get progressively poorer in detection ability. In practice the price of stations and numbers required trade off against each other. The stations in the example from the UK quoted earlier fall into category 3. The proposed USNN is of quality 2.

Table 5. Outline station specifications.

Quality 1. State-of-the-art research tool. 3-component broad-band borehole seismometer supplemented by 4, single-element, outstations and a 3-component surface seismometer at the borehole top. All emplaced in a site with optimum (lowest) possible noise environment. $1.25million US

Quality 2. Off-the-shelf current high-technology station. 9-element array of broad-band, 3-component low-noise seismometers. Individual elements are typical of a modern station - feedback broadband seismometer, direct digital recording, etc. $0.2million US

Quality 3. Typical existing 'good' station. Single-site 3-component SP and LP seismometers. Could be partly drawn from current stations (some 7000 registered although not all active and very uneven in quality and distribution). $50,000 US

A note on costs; these are necessarily approximate and are for purchase and installation of the seismological, time code radio, and microbarograph equipment, and digital recording equipment, only. Quality 1 costs are based loosely on the NRDC stations installed in Kazakhstan, USSR. A quality 2 station is based on current or proposed prices for Guralp Systems CMG-3 seismometers, OmegaRec timing radios, and Mass Data Systems Helical-Scan digital recorders. For a quality 3 network, costs would probably be reduced by making use of existing stations. No economy of scale has been accounted for.

Part III. Details of design calculations.

What has been the methodology for deriving the station densities in this study? We need to specify (see Table 4b):

1. Station layout pattern

2. i. Minimum detectable signal (nanometres)
   ii. Distance-decay rate of P-wave

3. Geological character of regions to be covered

1. Station layout.

We must specify the relation of a network/station distribution pattern and its spacing etc to the predicted maximum distance (Dmax) at which a signal is detectable. We follow others in using a regular equilateral-triangular distribution of seismic stations where the sides of the triangle are Dmax. This allows an event anywhere in the network to be detected by 3 or more stations. For this triangular network, the area covered per station can be shown by simple trigonometry to be $0.43Dmax^2$ (the area of an equilateral triangle of side Dmax). The value 0.43 is here termed the 'network geometry factor' (as for any network whose dimensions are governed by a maximum range Dmax, the area covered per station will be proportional to $Dmax^2$).

2. Minimum detectable signals and decay rates

This is by no means a clear-cut problem, because for teleseismic range, the distance-decay of P waves is reasonably well known and is invariant worldwide. For regional-range recording, though, the distance-decay factor (known as "B(delta)") varies with tectonic province; but there are not well-defined B(delta) terms for all parts of the world. Additionally, the B(delta) functions are traditionally given for "1Hz P-waves" when at close range, the dominant frequencies will probably be higher; for example, the P-wave from a 0.4kT explosion (presumed fully coupled) at the USSR Semipalatinsk site gave a 5 nanometre peak-to-peak P-wave signal of 2-3Hz at a broad-band seismometer at Garm, Tajikistan SSR (Davies, 1989). So what is the frequency dependence of attenuation, and how therefore does B(delta) change with frequency? Whatever method is used to estimate station density, the B(delta) terms are pivotal, thus a few lines are given to explaining them.

For orogenic belts (seismically active and with thickened crust) we use the B(delta) derived by Marshall, Bingham & Young (1986) for the USSR. Though the USSR is almost all shield, the earthquakes which have supplied the near range (<3deg) data are all along the southern border as are most of the stations. For rift areas, we use the Western US as a reference i.e. the classic Gutenburg & Richter (1956) curve. Again, although it is applied 'worldwide' the near-range data all originate in the Western US. The Booth Marshall & Young (1974) curve is similar. None of the other published B(delta) data apply to other tectonic provinces. Other tectonic provinces are not so readily addressed, in the case of shield areas because they have very few earthquakes and in others because they are not so extensive, and so less direct means are needed to study them.

The approach taken to combine signal decay rates and minimum signal amplitude is outlined in Table 6. It is based around the expression:-

magnitude = signal amplitude + distance-decay correction

which is Richter's original definition of seismic magnitude.

Table 6. Procedure for estimating maximum detectable source-receiver range for event of a given magnitude.

Estimate minimum detectable amplitude directly (knowledge of instruments, actual data, etc)

Take event of known or inferred magnitude (Lajitas study, 5 tonnes = m_b 1.8 or SALMON-STERLING m_b 1.4) and known distance at which it is 'just' detected

Find B(delta) for that distance hence the amplitude/period of seismic signal

Adjust if necessary by some signal enhancement factor that would be gained by array recording/processing

Given that signal amplitude and required magnitude (1.4 or 2.2) find distance at which signal amplitude + distance correction term exactly match magnitude.

3. The surface areas of each State Party have been taken from the 1988 edition of the Times World Atlas. The division into different geological types is based on the world tectonic map of Condie (1982) and, for bedded/domed salt specifically, Lefond (1969). These areas are also tabulated below.

Thus the combination of maximum ranges, network pattern, and geological character allow the general features of the network to be estimated (Table 4b). However, to illustrate the extent to which the analysis given here is an outline design only, we illustrate below a more rigorous procedure, that is followed in computer simulations of seismic network performances, such as that of Harjes (1985):-

* specify criterion for declaring a detection (e.g. better than 95% chance of 4 stations with signal > noise by factor of 2)

⇓

* specify station locations.

⇓

* specify station background noise (amplitudes and temporal character)

⇓

* specify a latitude and longitude grid spacing, say 1 degree: for EVERY lat/long position;

↓←←←←←←←←←←←←←←←←←←←←←

* determine raypaths from a hypothetical epicentre to all stations and signal decay factors along them ↑

↓←←←←←←←←←←←←←←←←←←←←←

* specify hypothetical event's magnitude as some extremely low value; predict signal amplitudes at all stations: compute probability of each station detecting and hence whether the hypothetical event is detected. ↑ ↑

↓

* Gradually increase magnitude until the event is declared detected; hence the detection threshold for a source at that point is determined. ↓ →→→→→→→→→→→→→→→→→→→ ↑

↓→→→→→→→→→→→→→→→→→→→→→→ ↑

* Contour up the grid of detection thresholds. Examine for any thresholds above design specification. Revise numbers and locations of stations as necessary.

This is an extensive project. Such a programme would need many person-months and considerable computer resources to complete, and as noted earlier some parameters such as noise levels and signal decay rates need to be obtained first.

A more detailed technical and scientific consideration of equipment is given in Annex A to this discussion. Annex B describes the database requirements prior to and after the network is established.

Part IV. Results

The results of our analysis are presented in Tables 7-11. That the various approximations and estimates are at least reasonable can be seen by comparison of some predicted station numbers to other studies. For example, Quality 2 requires 130 stations for the USA. The USNN design, using single stations not arrays, needs 150 for a m_b 2.5 threshold. Nevertheless, some figures might merit revision. Each country has been considered only on the basis of its geology and area. Where small countries assigned only 1 station have no other State Party adjacent to them, then a minimum number of 3 stations should be installed. In other cases where signatories are neighbours, some reductions could be accepted. Table 7 gives the detection ranges by geological province and a breakdown of the geological characteristics of each State Party. Tables 8-10 give a detailed summary of the assignment of stations by nation and by geology; Table 11 gives a review by nation and by cost for each station quality.

The costs given in Tables 8-11 are just for the seismic stations. For all quality networks, an additional cost of $0.05-1.00million per station would be needed to survey geophysically the site's structure where not already known - say 50% of them. A minimum requirement is that the seismic data would need to be copied, archived, and processed at International Data Centres; at least 3-6 of these would be needed but this figure is probably sensitive to political issues also. If the structure of the CTB monitoring is to included centralised analysis, then the costs of these Data Centres would be considerably higher, both in capital and recurrent costs. Similarly the means of data transmission (almost certainly satellite-based) will depend on whether any Verification Agency had exclusive access to satellite channels, so are not included here.

Our results can thus be summarised as:

* Quality 1 network (state-of-the-art station in optimum low-noise environment); 520 stations, cost about $650 million US. In the USA, 27 stations, in the USSR 58.

or:-

* Quality 2 network (off-the-shelf high-technology seismometers in small arrays); 1350 stations, cost about $340 million US. In the USA, 130 stations, in the USSR 273.

or:-

* Quality 3 network (existing 'routine' stations); 3100 stations, cost about $150 million US. In the USA, 302 stations, in the USSR 668.

* Site survey costs: $20-1000 million US

* Date archiving/copying centres: setup costs $20 million US each excluding recurrent costs and data transmission.

Exact values can be found in Table 11.

Of these, our recommended option for *immediate* application is Quality 2. All necessary instrumentation is available at once, and some national networks aspire to this standard anyway. Such stations may be able to be upgraded directly to Quality 1 with the addition of a borehole site, if they are in a suitably 'quiet' environment.

Table 7. Basic data for outline design of seismic network.

(a) Seismic station characteristics:

type 1: Cratons & shields
maximum range for P-wave detection, m_b threshold 2.2 -
station quality 1, 2000. km
station quality 2, 800. km
station quality 3, 500. km

type 2: Stable platforms
maximum range for P-wave detection, m_b threshold 2.2 -
station quality 1, 1000. km
station quality 2, 750. km
station quality 3, 400. km

type 3: Rift zones
maximum range for P-wave detection, m_b threshold 2.2 -
station quality 1, 750. km
station quality 2, 350. km
station quality 3, 180. km

type 4: Orogenic belts
maximum range for P-wave detection, m_b threshold 1.4 -
station quality 1, 1000. km
station quality 2, 500. km
station quality 3, 350. km

type 5: Deep-ocean isls.
maximum range for P-wave detection, m_b threshold 2.2 -
station quality 1, 1000. km
station quality 2, 750. km
station quality 3, 400. km

type 6: Salt domes/beds
maximum range for P-wave detection, m_b threshold 1.4 -
station quality 1, 750. km
station quality 2, 220. km
station quality 3, 150. km

type 7: Ocean floors
maximum range for P-wave detection, m_b threshold 4.3 -
station quality 1, 3750. km
station quality 2, 3750. km
station quality 3, 3750. km

(b) Seismic network characteristics

network geometry factor = 0.400
(i.e. area per station is FACTOR x $RANGE^2$)

geology type Cratons & shields	
station quality 1 , area/station =	1600000 sq.km
station quality 2 , area/station =	256000 sq.km
station quality 3 , area/station =	100000 sq.km
geology type Stable platforms	
station quality 1 , area/station =	400000 sq.km
station quality 2 , area/station =	225000 sq.km
station quality 3 , area/station =	64000 sq.km
geology type Rift zones	
station quality 1 , area/station =	225000 sq.km
station quality 2 , area/station =	49000 sq.km
station quality 3 , area/station =	12960 sq.km
geology type Orogenic belts	
station quality 1 , area/station =	400000 sq.km
station quality 2 , area/station =	100000 sq.km
station quality 3 , area/station =	49000 sq.km
geology type Deep-ocean isls.	
station quality 1 , area/station =	400000 sq.km
station quality 2 , area/station =	225000 sq.km
station quality 3 , area/station =	64000 sq.km
geology type Salt domes/beds	
station quality 1 , area/station =	225000 sq.km
station quality 2 , area/station =	19360 sq.km
station quality 3 , area/station =	9000 sq.km
geology type Ocean floors	
station quality 1 , area/station =	5625000 sq.km
station quality 2 , area/station =	5625000 sq.km
station quality 3 , area/station =	5625000 sq.km

(c) total areas and areas by geology for each party to the 1963 PTBT

country	area (km^2)	percentages of total area by geology types 1-7						
		1	2	3	4	5	6	7
Afghanistan	647500	0	25.	0	70	0	5	0
Algeria	2381745.	15	69.	0	6	0	10	0
Antigua & Barbuda	445	0	0.	0	0	100	0	0
Argentina	2766889	0	76	0	22	0	2	0
Australia	7667080	27	55	2	12	0	4	0
Austria	83849	0	5	0	70	0	25	0
Bahamas	13865	0	100	0	0	0	0	0
Bangladesh	144000	0	55	0	45	0	0	0
Belguim	30508	0	85	0	0	0	15	0
Benin	116314	88	12	0	0	0	0	0
Bhutan	46620	0	0	0	100	0	0	0
Bolivia	1098580	41	50	0	6	0	3	0
Botswana	575000	20	80	0	0	0	0	0
Brazil	8511965	47	35	3	0	0	15	0
Bulgaria	110842	0	28	0	70	0	2	0
Burkino Faso	274123	79	21	0	0	0	0	0
Burma	678033	0	48	0	52	0	0	0
Burundi	27835	80	0	20	0	0	0	0
Cameroon	475000	69	7	24	0	0	0	0
Canada	9922385	50	27	0	15	0	8	0
Cape Verde Islands	4033	0	0	0	0	70	30	0
Central Africa Republic	624975	77	23	0	0	0	0	0
Chad	1284640	11	83	4	0	0	2	0
Chile	756946	0	0	0	80	0	20	0
Colombia	1138618	47	13	0	27	0	13	0
Costa Rica	51010	0	0	0	100	0	0	0
Cote D'Ivoire	322463	99	1	0	0	0	0	0
Cyprus	9251	0	0	0	75	0	25	0
Czechoslovakia	127827	0	65	0	31	0	4	0
Denmark	43017	0	60	0	0	0	40	0
Dominican Republic	48735	0	0	0	70	0	30	0
Ecuador	461475	0	50	0	40	0	10	0
Egypt	1000253	9	83	2	0	0	6	0
El Salvador	21200	0	0	0	100	0	0	0
Ethiopia	906500	10	24	56	0	0	10	0
Fiji	18345	0	0	0	0	100	0	0
Finland	337008	70	30	0	0	0	0	0
Gabon	266770	74	18	0	0	0	8	0
Gambia	10368	0	100	0	0	0	0	0
FRG (West Germany)	245861	0	48	4	8	0	40	0

GDR (East Germany)	107860	0	75	0	0	0	25	0
Ghana	237873	67	33	0	0	0	0	0
Greece	132561	0	0	0	92	0	8	0
Guatemala	109000	0	56	42	0	0	2	0
Guinea Bissau	36125	0	100	0	0	0	0	0
Haiti	27750	0	0	0	100	0	0	0
Honduras	112088	0	0	0	100	0	0	0
Hungary	93012	0	0	0	100	0	0	0
Iceland	102999	0	0	100	0	0	0	0
India	3166830	75	12	0	9	0	4	0
Indonesia	1919445	0	10	0	85	5	0	0
Iran	1648000	0	5	0	80	0	15	0
Iraq	444441	0	94	0	2	0	4	0
Ireland	68894	0	100	0	0	0	0	0
Israel	20894	0	68	12	0	0	20	0
Italy	301191	0	0	0	90	0	10	0
Jamaica	10960	0	0	0	90	0	10	0
Japan	369813	0	0	0	100	0	0	0
Jordan	96514	0	88	8	0	0	4	0
Kenya	582646	29	24	47	0	0	0	0
Republic of Korea	98445	50	0	0	50	0	0	0
Kuwait	24280	0	95	0	0	0	5	0
Lao Democratic Republic	236726	0	5	0	93	0	2	0
Lebanon	10171	0	100	0	0	0	0	0
Liberia	111370	100	0	0	0	0	0	0
Libya	1759587	1	94	0	0	0	5	0
Luxembourg	2585	0	100	0	0	0	0	0
Madagascar	589836	71	29	0	0	0	0	0
Malawi	94080	64	0	36	0	0	0	0
Malaysia	332965	0	40	0	60	0	0	0
Mali	1240140	15	78	2	0	0	5	0
Malta	316	0	100	0	0	0	0	0
Mauritania	1085806	26	72	0	0	0	2	0
Mauritius	1865	0	0	0	0	100	0	0
Mexico	1969369	0	20	0	40	0	40	0
Mongolia	1565000	2		0	8	0	5	0
Morocco	710850	6	58	0	24	0	12	0
Nepal	141415	0	0	0	100	0	0	0
Netherlands	41160	0	80	0	0	0	20	0
New Zealand	268687	0	0	0	100	0	0	0
Nicaragua	148000	0	20	0	80	0	0	0
Niger	1188794	2	[illegible]	5	0	0	12	0
Nigeria	923850	45	46	8	0	0	1	0
Norway	323918	0	96	4	0	0	0	0
Pakistan	803940	0	30	0	60	0	10	0
Panama	82860	0	0	0	100	0	0	0

Papua New Guinea	474650	0	22	0	78	0	0	0
Paraguay	406752	30	70	0	0	0	0	0
Peru	1285215	37	0	0	48	0	15	0
Philippines	299681	0	0	0	98	0	2	0
Poland	311730	0	77	0	3	0	20	0
Portugal	91823	0	90	0	0	0	10	0
Romania	237428	0	5	0	55	0	40	0
Ruwanda	54172	95	0	5	0	0	0	0
Western Samoa	2927	0	0	0	0	100	0	0
San Marino	61	0	0	0	100	0	0	0
Senegal	197161	72	8	0	0	0	20	0
Seychelles	404	0	0	0	0	100	0	0
Sierra Leone	72326	92	8	0	0	0	0	0
Singapore	616	0	0	0	100	0	0	0
Somalia	630000	4	96	0	0	0	0	0
South Africa	1224378	33	58	9	0	0	0	0
Spain	503545	0	72	0	18	0	10	0
Sri Lanka	65610	100	0	0	0	0	0	0
Sudan	2505825	43	52	0	0	0	5	0
Swaziland	17366	20	80	0	0	0	0	0
Sweden	449679	55	45	0	0	0	0	0
Switzerland	41287	0	0	5	85	0	10	0
Syria	184920	0	90	5	0	0	5	0
Taiwan	35975	0	0	0	100	0	0	0
Tanzania	939760	47	20	21	0	0	12	0
Thailand	513519	0	12	0	73	0	15	0
Togo	54999	72	28	0	0	0	0	0
Tonga	645	0	0	0	0	100	0	0
Trinidad & Tobago	5128	0	100	0	0	0	0	0
Tunisia	125177	0	20	0	32	0	48	0
Turkey	779450	0	4	0	91	0	5	0
Uganda	243411	81	0	19	0	0	0	0
United Kingdom	244739	5	73	0	0	0	22	0
Uruguay	186926	32	68	0	0	0	0	0
USA	9363130	4	41	1	39	0	15	0
USSR	22400000	10	57	1	18	0	14	0
Venezuela	912050	46	46	0	6	0	2	0
Yemen Arab Republic	189850	0	90	0	0	0	10	0
Yemen Peoples rep.	287680	0	90	0	0	0	10	0
Yugoslavia	255281	0	0	0	95	0	5	0
Zaire	2343932	36	56	8	0	0	0	0
Zambia	752615	64	25	11	0	0	0	0
Ocean Floor/ Continental shelf	361300000	0	0	0	0	0	0	100

Table 8.
Details of required numbers of 'quality 1' stations, tabulated by country and by geology

country	types 1-7 as above							
	1	2	3	4	5	6	7	total
Afghanistan	0	1	0	1	0	1	0	3
Algeria	1	4	0	1	0	1	0	7
Antigua & Barbuda	0	0	0	0	1	0	0	1
Argentina	0	5	0	2	0	1	0	8
Australia	1	11	1	2	0	1	0	16
Austria	0	1	0	1	0	1	0	3
Bahamas	0	1	0	0	0	0	0	1
Bangladesh	0	1	0	1	0	0	0	2
Belguim	0	1	0	0	0	1	0	2
Benin	1	1	0	0	0	0	0	2
Bhutan	0	0	0	1	0	0	0	1
Bolivia	1	1	0	1	0	1	0	4
Botswana	1	1	0	0	0	0	0	2
Brazil	3	7	1	0	0	6	0	17
Bulgaria	0	1	0	1	0	1	0	3
Burkino Faso	1	1	0	0	0	0	0	2
Burma	0	1	0	1	0	0	0	2
Burundi	1	0	1	0	0	0	0	2
Cameroon	1	1	1	0	0	0	0	3
Canada	3	7	0	4	0	4	0	18
Cape Verde Islands	0	0	0	0	1	1	0	2
Central Africa Republic	1	1	0	0	0	0	0	2
Chad	1	3	1	0	0	1	0	6
Chile	0	0	0	2	0	1	0	3
Colombia	1	1	0	1	0	1	0	4
Costa Rica	0	0	0	1	0	0	0	1
Cote D'Ivoire	1	1	0	0	0	0	0	2
Cyprus	0	0	0	1	0	1	0	2
Czechoslovakia	0	1	0	1	0	1	0	3
Denmark	0	1	0	0	0	1	0	2
Dominican Republic	0	0	0	1	0	1	0	2
Ecuador	0	1	0	1	0	1	0	3
Egypt	1	2	1	0	0	1	0	5
El Salvador	0	0	0	1	0	0	0	1
Ethiopia	1	1	2	0	0	1	0	5
Fiji	0	0	0	0	1	0	0	1
Finland	1	1	0	0	0	0	0	2
Gabon	1	1	0	0	0	1	0	3

Gambia	0	1	0	0	0	0	0	1
FRG (West Germany)	0	1	1	1	0	1	0	4
GDR (East Germany)	0	1	0	0	0	1	0	2
Ghana	1	1	0	0	0	0	0	2
Greece	0	0	0	1	0	1	0	2
Guatemala	0	1	1	0	0	1	0	3
Guinea Bissau	0	1	0	0	0	0	0	1
Haiti	0	0	0	1	0	0	0	1
Honduras	0	0	0	1	0	0	0	1
Hungary	0	0	0	1	0	0	0	1
Iceland	0	0	1	0	0	0	0	1
India	1	1	0	1	0	1	0	4
Indonesia	0	1	0	4	1	0	0	6
Iran	0	1	0	3	0	1	0	5
Iraq	0	1	0	1	0	1	0	3
Ireland	0	1	0	0	0	0	0	1
Israel	0	1	1	0	0	1	0	3
Italy	0	0	0	1	0	1	0	2
Jamaica	0	0	0	1	0	1	0	2
Japan	0	0	0	1	0	0	0	1
Jordan	0	1	1	0	0	1	0	3
Kenya	1	1	1	0	0	0	0	3
Republic of Korea	1	0	0	1	0	0	0	2
Kuwait	0	1	0	0	0	1	0	2
Lao Democratic Republic	0	1	0	1	0	1	0	3
Lebanon	0	1	0	0	0	0	0	1
Liberia	1	0	0	0	0	0	0	1
Libya	1	4	0	0	0	1	0	6
Luxembourg	0	1	0	0	0	0	0	1
Madagascar	1	1	0	0	0	0	0	2
Malawi	1	0	1	0	0	0	0	2
Malaysia	0	1	0	1	0	0	0	2
Mali	1	2	1	0	0	1	0	5
Malta	0	1	0	0	0	0	0	1
Mauritania	1	2	0	0	0	1	0	4
Mauritius	0	0	0	0	1	0	0	1
Mexico	0	1	0	2	0	4	0	7
Mongolia	1	3	0	1	0	1	0	6
Morocco	1	1	0	1	0	1	0	4
Nepal	0	0	0	1	0	0	0	1
Netherlands	0	1	0	0	0	1	0	2
New Zealand	0	0	0	1	0	0	0	1
Nicaragua	0	1	0	1	0	0	0	2
Niger	1	2	1	0	0	1	0	5
Nigeria	1	1	1	0	0	1	0	4
Norway	0	1	1	0	0	0	0	2

Pakistan	0	1	0	1	0	1	0	3
Panama	0	0	0	1	0	0	0	1
Papua New Guinea	0	1	0	1	0	0	0	2
Paraguay	1	1	0	0	0	0	0	2
Peru	1	0	0	2	0	1	0	4
Philippines	0	0	0	1	0	1	0	2
Poland	0	1	0	1	0	1	0	3
Portugal	0	1	0	0	0	1	0	2
Romania	0	1	0	1	0	1	0	3
Ruwanda	1	0	1	0	0	0	0	2
Western Samoa	0	0	0	0	1	0	0	1
San Marino	0	0	0	1	0	0	0	1
Senegal	1	1	0	0	0	1	0	3
Seychelles	0	0	0	0	1	0	0	1
Sierra Leone	1	1	0	0	0	0	0	2
Singapore	0	0	0	1	0	0	0	1
Somalia	1	2	0	0	0	0	0	3
South Africa	1	2	1	0	0	0	0	4
Spain	0	1	0	1	0	1	0	3
Sri Lanka	1	0	0	0	0	0	0	1
Sudan	1	3	0	0	0	1	0	5
Swaziland	1	1	0	0	0	0	0	2
Sweden	1	1	0	0	0	0	0	2
Switzerland	0	0	1	1	0	1	0	3
Syria	0	1	1	0	0	1	0	3
Taiwan	0	0	0	1	0	0	0	1
Tanzania	1	1	1	0	0	1	0	4
Thailand	0	1	0	1	0	1	0	3
Togo	1	1	0	0	0	0	0	2
Tonga	0	0	0	0	1	0	0	1
Trinidad & Tobago	0	1	0	0	0	0	0	1
Tunisia	0	1	0	1	0	1	0	3
Turkey	0	1	0	2	0	1	0	4
Uganda	1	0	1	0	0	0	0	2
United Kingdom	1	1	0	0	0	1	0	3
Uruguay	1	1	0	0	0	0	0	2
USA	1	10	1	9	0	6	0	27
USSR	1	32	1	10	0	14	0	58
Venezuela	1	1	0	1	0	1	0	4
Yemen Arab Republic	0	1	0	0	0	1	0	2
Yemen Peoples rep.	0	1	0	0	0	1	0	2
Yugoslavia	0	0	0	1	0	1	0	2
Zaire	1	3	1	0	0	0	0	5
Zambia	1	1	1	0	0	0	0	3
Ocean floor/cont shelf	0	0	0	0	0	0	64	64

totals by geology for "quality 1" stations :

Cratons & shields	total 57 for	26847625. km^2
Stable platforms	total 176 for	51631488. km^2
Rift zones	total 29 for	2710704. km^2
Orogenic belts	total 90 for	23133651. km^2
Deep-ocean isls.	total 8 for	123426. km^2
Salt domes/beds	total 95 for	10841713. km^2
Ocean floors	total 64 for	361300000. km^2

**** TOTALS FOR "QUALITY 1" STATIONS ****

no.of stations	520 (approx)
total area covered	476588600 km^2
mean station density	918300 km^2/station.
total cost	648.750 million US$

Table 9.
Details of required numbers of 'quality 2' stations, tabulated by country and by geology.

country	types 1-7							
	1	2	3	4	5	6	7	total
Afghanistan	0	1	0	5	0	2	0	8
Algeria	1	7	0	1	0	12	0	21
Antigua & Barbuda	0	0	0	0	1	0	0	1
Argentina	0	9	0	6	0	3	0	18
Australia	8	19	3	9	0	16	0	55
Austria	0	1	0	1	0	1	0	3
Bahamas	0	1	0	0	0	0	0	1
Bangladesh	0	1	0	1	0	0	0	2
Belguim	0	1	0	0	0	1	0	2
Benin	1	1	0	0	0	0	0	2
Bhutan	0	0	0	1	0	0	0	1
Bolivia	2	2	0	1	0	2	0	7
Botswana	1	2	0	0	0	0	0	3
Brazil	16	13	5	0	0	66	0	100
Bulgaria	0	1	0	1	0	1	0	3
Burkino Faso	1	1	0	0	0	0	0	2
Burma	0	1	0	4	0	0	0	5
Burundi	1	0	1	0	0	0	0	2
Cameroon	1	1	2	0	0	0	0	4
Canada	19	12	0	15	0	41	0	87
Cape Verde Islands	0	0	0	0	1	1	0	2
Central Africa Republic	2	1	0	0	0	0	0	3
Chad	1	5	1	0	0	1	0	8
Chile	0	0	0	6	0	8	0	14
Colombia	2	1	0	3	0	8	0	14
Costa Rica	0	0	0	1	0	0	0	1
Cote D'Ivoire	1	1	0	0	0	0	0	2
Cyprus	0	0	0	1	0	1	0	2
Czechoslovakia	0	1	0	1	0	1	0	3
Denmark	0	1	0	0	0	1	0	2
Dominican Republic	0	0	0	1	0	1	0	2
Ecuador	0	1	0	2	0	2	0	5
Egypt	1	4	1	0	0	3	0	9
El Salvador	0	0	0	1	0	0	0	1
Ethiopia	1	1	10	0	0	5	0	17
Fiji	0	0	0	0	1	0	0	1
Finland	1	1	0	0	0	0	0	2
Gabon	1	1	0	0	0	1	0	3
Gambia	0	1	0	0	0	0	0	1
FRG (West Germany)	0	1	1	1	0	5	0	8

GDR (East Germany)	0	1	0	0	0	1	0	2
Ghana	1	1	0	0	0	0	0	2
Greece	0	0	0	1	0	1	0	2
Guatemala	0	1	1	0	0	1	0	3
Guinea Bissau	0	1	0	0	0	0	0	1
Haiti	0	0	0	1	0	0	0	1
Honduras	0	0	0	1	0	0	0	1
Hungary	0	0	0	1	0	0	0	1
Iceland	0	0	2	0	0	0	0	2
India	9	2	0	3	0	7	0	21
Indonesia	0	1	0	16	1	0	0	18
Iran	0	1	0	13	0	13	0	27
Iraq	0	2	0	1	0	1	0	4
Ireland	0	1	0	0	0	0	0	1
Israel	0	1	1	0	0	1	0	3
Italy	0	0	0	3	0	2	0	5
Jamaica	0	0	0	1	0	1	0	2
Japan	0	0	0	4	0	0	0	4
Jordan	0	1	1	0	0	1	0	3
Kenya	1	1	6	0	0	0	0	8
Republic of Korea	1	0	0	1	0	0	0	2
Kuwait	0	1	0	0	0	1	0	2
Lao Democratic Republic	0	1	0	2	0	1	0	4
Lebanon	0	1	0	0	0	0	0	1
Liberia	1	0	0	0	0	0	0	1
Libya	1	7	0	0	0	5	0	13
Luxembourg	0	1	0	0	0	0	0	1
Madagascar	2	1	0	0	0	0	0	3
Malawi	1	0	1	0	0	0	0	2
Malaysia	0	1	0	2	0	0	0	3
Mali	1	4	1	0	0	3	0	9
Malta	0	1	0	0	0	0	0	1
Mauritania	1	3	0	0	0	1	0	5
Mauritius	0	0	0	0	1	0	0	1
Mexico	0	2	0	8	0	41	0	51
Mongolia	1	6	0	1	0	4	0	12
Morocco	1	2	0	2	0	4	0	9
Nepal	0	0	0	1	0	0	0	1
Netherlands	0	1	0	0	0	1	0	2
New Zealand	0	0	0	3	0	0	0	3
Nicaragua	0	1	0	1	0	0	0	2
Niger	1	4	1	0	0	7	0	13
Nigeria	2	2	2	0	0	1	0	7
Norway	0	1	1	0	0	0	0	2
Pakistan	0	1	0	5	0	4	0	10
Panama	0	0	0	1	0	0	0	1

Papua New Guinea	0	1	0	4	0	0	0	5
Paraguay	1	1	0	0	0	0	0	2
Peru	2	0	0	6	0	10	0	18
Philippines	0	0	0	3	0	1	0	4
Poland	0	1	0	1	0	3	0	5
Portugal	0	1	0	0	0	1	0	2
Romania	0	1	0	1	0	5	0	7
Ruwanda	1	0	1	0	0	0	0	2
Western Samoa	0	0	0	0	1	0	0	1
San Marino	0	0	0	1	0	0	0	1
Senegal	1	1	0	0	0	2	0	4
Seychelles	0	0	0	0	1	0	0	1
Sierra Leone	1	1	0	0	0	0	0	2
Singapore	0	0	0	1	0	0	0	1
Somalia	1	3	0	0	0	0	0	4
South Africa	2	3	2	0	0	0	0	7
Spain	0	2	0	1	0	3	0	6
Sri Lanka	1	0	0	0	0	0	0	1
Sudan	4	6	0	0	0	6	0	16
Swaziland	1	1	0	0	0	0	0	2
Sweden	1	1	0	0	0	0	0	2
Switzerland	0	0	1	1	0	1	0	3
Syria	0	1	1	0	0	1	0	3
Taiwan	0	0	0	1	0	0	0	1
Tanzania	2	1	4	0	0	6	0	13
Thailand	0	1	0	4	0	4	0	9
Togo	1	1	0	0	0	0	0	2
Tonga	0	0	0	0	1	0	0	1
Trinidad & Tobago	0	1	0	0	0	0	0	1
Tunisia	0	1	0	1	0	3	0	5
Turkey	0	1	0	7	0	2	0	10
Uganda	1	0	1	0	0	0	0	2
United Kingdom	1	1	0	0	0	3	0	5
Uruguay	1	1	0	0	0	0	0	2
USA	1	17	2	37	0	73	0	130
USSR	9	57	5	40	0	162	0	273
Venezuela	2	2	0	1	0	1	0	6
Yemen Arab Republic	0	1	0	0	0	1	0	2
Yemen Peoples rep.	0	1	0	0	0	1	0	2
Yugoslavia	0	0	0	2	0	1	0	3
Zaire	3	6	4	0	0	0	0	13
Zambia	2	1	2	0	0	0	0	5
Ocean floor/cont shelf	0	0	0	0	0	0	64	64

totals by geology for "quality 2" stations:

Cratons & shields	total	124 for	26847625. km^2
Stable platforms	total	266 for	51631488. km^2
Rift zones	total	64 for	2710704. km^2
Orogenic belts	total	246 for	23133651. km^2
Deep-ocean isls.	total	8 for	123426. km^2
Salt domes/beds	total	575 for	10841713. km^2
Ocean floors	total	64 for	361300000. km^2

**** TOTALS FOR "QUALITY 2" STATIONS ****

no.of stations	1350 (approx)
total area covered	476588600 km^2
mean station density	353800 km^2/station.
total cost	336.750million US$

Table 10.
Details of required numbers of 'quality 3' stations, tabulated by country and by geology.

country	type 1-7: 1	2	3	4	5	6	7	total
Afghanistan	0	3	0	9	0	4	0	16
Algeria	4	26	0	3	0	26	0	59
Antigua & Barbuda	0	0	0	0	1	0	0	1
Argentina	0	33	0	12	0	6	0	51
Australia	21	66	12	19	0	34	0	152
Austria	0	1	0	1	0	2	0	4
Bahamas	0	1	0	0	0	0	0	1
Bangladesh	0	1	0	1	0	0	0	2
Belguim	0	1	0	0	0	1	0	2
Benin	1	1	0	0	0	0	0	2
Bhutan	0	0	0	1	0	0	0	1
Bolivia	5	9	0	1	0	4	0	19
Botswana	1	7	0	0	0	0	0	8
Brazil	40	47	20	0	0	142	0	249
Bulgaria	0	1	0	2	0	1	0	4
Burkino Faso	2	1	0	0	0	0	0	3
Burma	0	5	0	7	0	0	0	12
Burundi	1	0	1	0	0	0	0	2
Cameroon	3	1	9	0	0	0	0	13
Canada	50	42	0	30	0	88	0	210
Cape Verde Islands	0	0	0	0	1	1	0	2
Central Africa Republic	5	2	0	0	0	0	0	7
Chad	1	17	4	0	0	3	0	25
Chile	0	0	0	12	0	17	0	29
Colombia	5	2	0	6	0	16	0	29
Costa Rica	0	0	0	1	0	0	0	1
Cote D'Ivoire	3	1	0	0	0	0	0	4
Cyprus	0	0	0	1	0	1	0	2
Czechoslovakia	0	1	0	1	0	1	0	3
Denmark	0	1	0	0	0	2	0	3
Dominican Republic	0	0	0	1	0	2	0	3
Ecuador	0	4	0	4	0	5	0	13
Egypt	1	13	2	0	0	7	0	23
El Salvador	0	0	0	1	0	0	0	1
Ethiopia	1	3	39	0	0	10	0	53
Fiji	0	0	0	0	1	0	0	1
Finland	2	2	0	0	0	0	0	4
Gabon	2	1	0	0	0	2	0	5
Gambia	0	1	0	0	0	0	0	1

FRG(West Germany)	0	2	1	1	0	11	0	15
GDR (East Germany)	0	1	0	0	0	3	0	4
Ghana	2	1	0	0	0	0	0	3
Greece	0	0	0	2	0	1	0	3
Guatemala	0	1	4	0	0	1	0	6
Guinea Bissau	0	1	0	0	0	0	0	1
Haiti	0	0	0	1	0	0	0	1
Honduras	0	0	0	2	0	0	0	2
Hungary	0	0	0	2	0	0	0	2
Iceland	0	0	8	0	0	0	0	8
India	24	6	0	6	0	14	0	50
Indonesia	0	3	0	33	1	0	0	37
Iran	0	1	0	27	0	27	0	55
Iraq	0	7	0	1	0	2	0	10
Ireland	0	1	0	0	0	0	0	1
Israel	0	1	1	0	0	1	0	3
Italy	0	0	0	6	0	3	0	9
Jamaica	0	0	0	1	0	1	0	2
Japan	0	0	0	8	0	0	0	8
Jordan	0	1	1	0	0	1	0	3
Kenya	2	2	21	0	0	0	0	25
Republic of Korea	1	0	0	1	0	0	0	2
Kuwait	0	1	0	0	0	1	0	2
Lao Democratic Republic	0	1	0	4	0	1	0	6
Lebanon	0	1	0	0	0	0	0	1
Liberia	1	0	0	0	0	0	0	1
Libya	1	26	0	0	0	10	0	37
Luxembourg	0	1	0	0	0	0	0	1
Madagascar	4	3	0	0	0	0	0	7
Malawi	1	0	3	0	0	0	0	4
Malaysia	0	2	0	4	0	0	0	6
Mali	2	15	2	0	0	7	0	26
Malta	0	1	0	0	0	0	0	1
Mauritania	3	12	0	0	0	2	0	17
Mauritius	0	0	0	0	1	0	0	1
Mexico	0	6	0	16	0	88	0	110
Mongolia	1	21	0	3	0	9	0	34
Morocco	1	6	0	3	0	9	0	19
Nepal	0	0	0	3	0	0	0	3
Netherlands	0	1	0	0	0	1	0	2
New Zealand	0	0	0	5	0	0	0	5
Nicaragua	0	1	0	2	0	0	0	3
Niger	1	15	5	0	0	16	0	37
Nigeria	4	7	6	0	0	1	0	18
Norway	0	5	1	0	0	0	0	6
Pakistan	0	4	0	10	0	9	0	23

Panama	0	0	0	2	0	0	0	2
Papua New Guinea	0	2	0	8	0	0	0	10
Paraguay	1	4	0	0	0	0	0	5
Peru	5	0	0	13	0	21	0	39
Philippines	0	0	0	6	0	1	0	7
Poland	0	4	0	1	0	7	0	12
Portugal	0	1	0	0	0	1	0	2
Romania	0	1	0	3	01	1	0	15
Ruwanda	1	0	1	0	0	0	0	2
Western Samoa	0	0	0	0	1	0	0	1
San Marino	0	0	0	1	0	0	0	1
Senegal	1	1	0	0	0	4	0	6
Seychelles	0	0	0	0	1	0	0	1
Sierra Leone	1	1	0	0	0	0	0	2
Singapore	0	0	0	1	0	0	0	1
Somalia	1	9	0	0	0	0	0	10
South Africa	4	11	9	0	0	0	0	24
Spain	0	6	0	2	0	6	0	14
Sri Lanka	1	0	0	0	0	0	0	1
Sudan	11	20	0	0	0	14	0	45
Swaziland	1	1	0	0	0	0	0	2
Sweden	2	3	0	0	0	0	0	5
Switzerland	0	0	1	1	0	1	0	3
Syria	0	3	1	0	0	1	0	5
Taiwan	0	0	0	1	0	0	0	1
Tanzania	4	3	15	0	0	13	0	35
Thailand	0	1	0	8	0	9	0	18
Togo	1	1	0	0	0	0	0	2
Tonga	0	0	0	0	1	0	0	1
Trinidad & Tobago	0	1	0	0	0	0	0	1
Tunisia	0	1	0	1	0	7	0	9
Turkey	0	1	0	14	0	4	0	19
Uganda	2	0	4	0	0	0	0	6
United Kingdom	1	3	0	0	0	6	0	10
Uruguay	1	2	0	0	0	0	0	3
USA	4	60	7	75	0	156	0	302
USSR	22	199	17	82	0	348	0	668
Venezuela	4	7	0	1	0	2	0	14
Yemen Arab Republic	0	3	0	0	0	2	0	5
Yemen Peoples Rep.	0	4	0	0	0	3	0	7
Yugoslavia	0	0	0	5	0	1	0	6
Zaire	8	21	14	0	0	0	0	43
Zambia	5	3	6	0	0	0	0	14
Ocean floor/cont shelf	0	0	0	0	0	0	64	64

totals by geology for "Quality 3" Stations :

Cratons & shields	total	277 for	26847625. km^2
Stable platforms	total	828 for	51631488. km^2
Rift zones	total	215 for	2710704. km^2
Orogenic belts	total	479 for	23133651. km^2
Deep-ocean isls.	total	8 for	123426. km^2
Salt domes/beds	total	1212 for	10841713. km^2
Ocean floors	total	64 for	361300000. km^2

**** TOTALS "FOR QUALITY 3" STATIONS****

no.of stations	3100 (approx)
total area covered	476588600 km^2
mean station density	154590 km^2/station.
total cost	154.150million US$

Table 11.

Summary by nation of the numbers of stations (and their purchase & installation costs) to each of the options Quality 1 to 3.

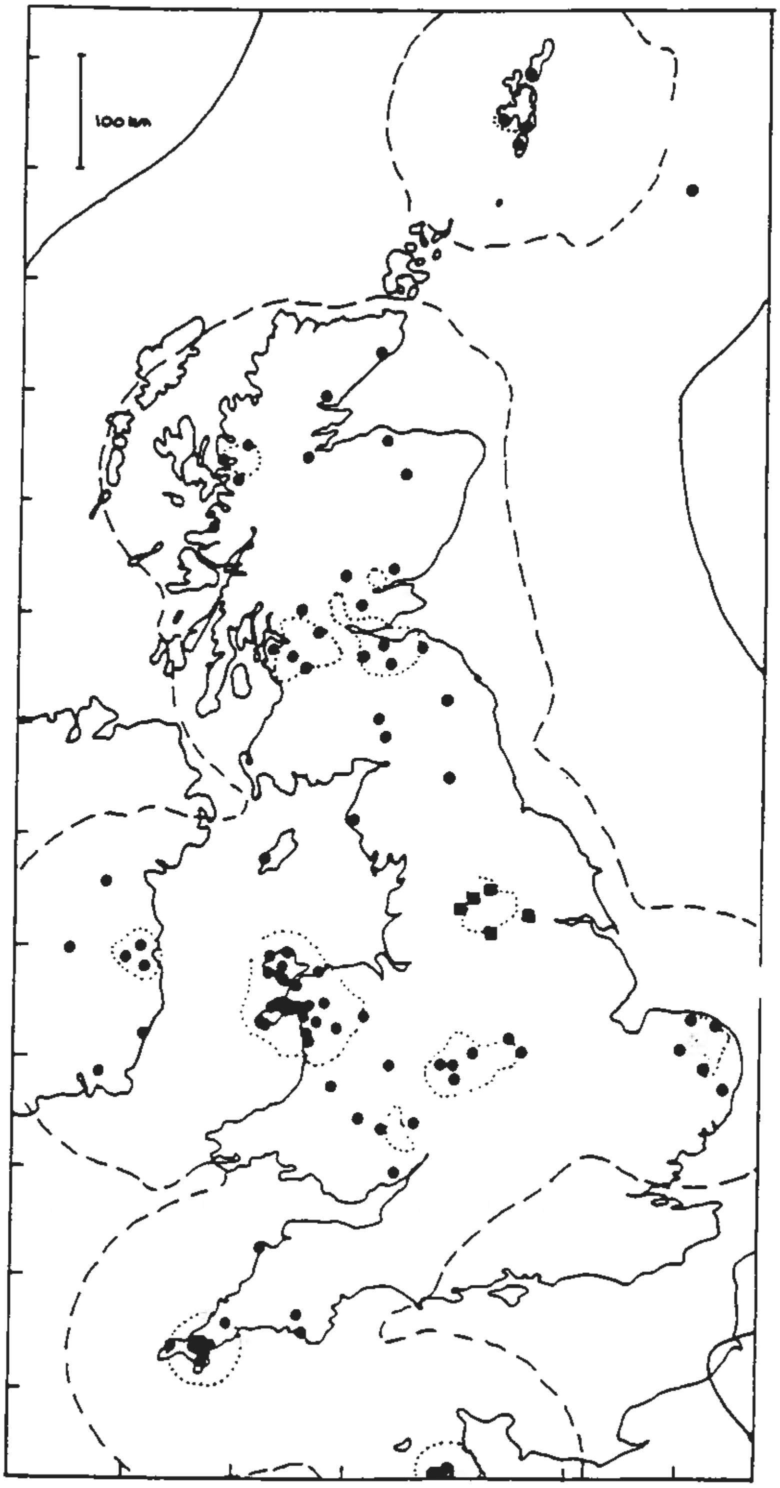
signatory	no.of stations / cost (millions US$) quality 1	quality 2	quality 3
Afghanistan	3 / 3.75	8 / 1.60	16 / 0.80
Algeria	7 / 8.75	21 / 4.20	59 / 2.95
Antigua & Barbuda	1 / 1.25	1 / 0.20	1 / 0.05
Argentina	8 /10.00	18 / 3.60	51 / 2.55
Australia	16 /20.00	55 /11.00	152 / 7.60
Austria	3 / 3.75	3 / 0.60	4 / 0.20
Bahamas	1 / 1.25	1 / 0.20	1 / 0.05
Bangladesh	2 / 2.50	2 / 0.40	2 / 0.10
Belguim	2 / 2.50	2 / 0.40	2 / 0.10
Benin	2 / 2.50	2 / 0.40	2 / 0.10
Bhutan	1 / 1.25	1 / 0.20	1 / 0.05
Bolivia	4 / 5.00	7 / 1.40	19 / 0.95
Botswana	2 / 2.50	3 / 0.60	8 / 0.40
Brazil	17 /21.25	100/20.00	249 /12.45
Bulgaria	3 / 3.75	3 / 0.60	4 / 0.20
Burkino Faso	2 / 2.50	2 / 0.40	3 / 0.15
Burma	2 / 2.50	5 / 1.00	12 / 0.60
Burundi	2 / 2.50	2 / 0.40	2 / 0.10
Cameroon	3 / 3.75	4 / 0.80	13 / 0.65
Canada	18 /22.50	87 /17.40	210/10.50
Cape Verde Islands	2 / 2.50	2 / 0.40	2 / 0.10
Central Africa Republic	2 / 2.50	3 / 0.60	7 / 0.35
Chad	6 / 7.50	8 / 1.60	25 / 1.25
Chile	3 / 3.75	14 / 2.80	29 / 1.45
Colombia	4 / 5.00	14 / 2.80	29 / 1.45
Costa Rica	1 / 1.25	1 / 0.20	1 / 0.05
Cote D'Ivoire	2 / 2.50	2 / 0.40	4 / 0.20
Cyprus	2 / 2.50	2 / 0.40	2 / 0.10
Czechoslovakia	3 / 3.75	3 / 0.60	3 / 0.15
Denmark	2 / 2.50	2 / 0.40	3 / 0.15
Dominican Republic	2 / 2.50	2 / 0.40	3 / 0.15
Ecuador	3 / 3.75	5 / 1.00	13 / 0.65
Egypt	5 / 6.25	9 / 1.80	23 / 1.15
El Salvador	1 / 1.25	1 / 0.20	1 / 0.05
Ethiopia	5 / 6.25	17 / 3.40	53 / 2.65
Fiji	1 / 1.25	1 / 0.20	1 / 0.05
Finland	2 / 2.50	2 / 0.40	4 / 0.20

Gabon	3 / 3.75	3 / 0.60	5 / 0.25
Gambia	1 / 1.25	1 / 0.20	1 / 0.05
FRG (West Germany)	4 / 5.00	8 / 1.60	15 / 0.75
GDR (East Germany)	2 / 2.50	2 / 0.40	4 / 0.20
Ghana	2 / 2.50	2 / 0.40	3 / 0.15
Greece	2 / 2.50	2 / 0.40	3 / 0.15
Guatemala	3 / 3.75	3 / 0.60	6 / 0.30
Guinea Bissau	1 / 1.25	1 / 0.20	1 / 0.05
Haiti	1 / 1.25	1 / 0.20	1 / 0.05
Honduras	1 / 1.25	1 / 0.20	2 / 0.10
Hungary	1 / 1.25	1 / 0.20	2 / 0.10
Iceland	1 / 1.25	2 / 0.40	8 / 0.40
India	4 / 5.00	21 / 4.20	50/ 2.50
Indonesia	6 / 7.50	18 / 3.60	37 / 1.85
Iran	5 / 6.25	27 / 5.40	55 / 2.75
Iraq	3 / 3.75	4 / 0.80	10/ 0.50
Ireland	1 / 1.25	1 / 0.20	1 / 0.05
Israel	3 / 3.75	3 / 0.60	3 / 0.15
Italy	2 / 2.50	5 / 1.00	9 / 0.45
Jamaica	2 / 2.50	2 / 0.40	2 / 0.10
Japan	1 / 1.25	4 / 0.80	8 / 0.40
Jordan	3 / 3.75	3 / 0.60	3 / 0.15
Kenya	3 / 3.75	8 / 1.60	25 / 1.25
Republic of Korea	2 / 2.50	2 / 0.40	2 / 0.10
Kuwait	2 / 2.50	2 / 0.40	2 / 0.10
Lao Democratic Republic	3 / 3.75	4 / 0.80	6 / 0.30
Lebanon	1 / 1.25	1 / 0.20	1 / 0.05
Liberia	1 / 1.25	1 / 0.20	1 / 0.05
Libya	6 / 7.50	13 / 2.60	37 / 1.85
Luxembourg	1 / 1.25	1 / 0.20	1 / 0.05
Madagascar	2 / 2.50	3 / 0.60	7 / 0.35
Malawi	2 / 2.50	2 / 0.40	4 / 0.20
Malaysia	2 / 2.50	3 / 0.60	6 / 0.30
Mali	5 / 6.25	9 / 1.80	26 / 1.30
Malta	1 / 1.25	1 / 0.20	1 / 0.05
Mauritania	4 / 5.00	5 / 1.00	17 / 0.85
Mauritius	1 / 1.25	1 / 0.20	1 / 0.05
Mexico	7 / 8.75	51 /10.20	110/ 5.50
Mongolia	6 / 7.50	12 / 2.40	34 / 1.70
Morocco	4 / 5.00	9 / 1.80	19 / 0.95
Nepal	1 / 1.25	1 / 0.20	3 / 0.15
Netherlands	2 / 2.50	2 / 0.40	2 / 0.10
New Zealand	1 / 1.25	3 / 0.60	5 / 0.25
Nicaragua	2 / 2.50	2 / 0.40	3 / 0.15
Niger	5 / 6.25	13 / 2.60	37 / 1.85
Nigeria	4 / 5.00	7 / 1.40	18 / 0.90

Norway	2 / 2.50	2 / 0.40	6 / 0.30
Pakistan	3 / 3.75	10/ 2.00	23 / 1.15
Panama	1 / 1.25	1 / 0.20	2 / 0.10
Papua New Guinea	2 / 2.50	5 / 1.00	10/ 0.50
Paraguay	2 / 2.50	2 / 0.40	5 / 0.25
Peru	4 / 5.00	18 / 3.60	39 / 1.95
Philippines	2 / 2.50	4 / 0.80	7 / 0.35
Poland	3 / 3.75	5 / 1.00	12 / 0.60
Portugal	2 / 2.50	2 / 0.40	2 / 0.10
Romania	3 / 3.75	7 / 1.40	15 / 0.75
Ruwanda	2 / 2.50	2 / 0.40	2 / 0.10
Western Samoa	1 / 1.25	1 / 0.20	1 / 0.05
San Marino	1 / 1.25	1 / 0.20	1 / 0.05
Senegal	3 / 3.75	4 / 0.80	6 / 0.30
Seychelles	1 / 1.25	1 / 0.20	1 / 0.05
Sierra Leone	2 / 2.50	2 / 0.40	2 / 0.10
Singapore	1 / 1.25	1 / 0.20	1 / 0.05
Somalia	3 / 3.75	4 / 0.80	10/ 0.50
South Africa	4 / 5.00	7 / 1.40	24 / 1.20
Spain	3 / 3.75	6 / 1.20	14 / 0.70
Sri Lanka	1 / 1.25	1 / 0.20	1 / 0.05
Sudan	5 / 6.25	16 / 3.20	45 / 2.25
Swaziland	2 / 2.50	2 / 0.40	2 / 0.10
Sweden	2 / 2.50	2 / 0.40	5 / 0.25
Switzerland	3 / 3.75	3 / 0.60	3 / 0.15
Syria	3 / 3.75	3 / 0.60	5 / 0.25
Taiwan	1 / 1.25	1 / 0.20	1 / 0.05
Tanzania	4 / 5.00	13 / 2.60	35 / 1.75
Thailand	3 / 3.75	9 / 1.80	18 / 0.90
Togo	2 / 2.50	2 / 0.40	2 / 0.10
Tonga	1 / 1.25	1 / 0.20	1 / 0.05
Trinidad & Tobago	1 / 1.25	1 / 0.20	1 / 0.05
Tunisia	3 / 3.75	5 / 1.00	9 / 0.45
Turkey	4 / 5.00	10/ 2.00	19 / 0.95
Uganda	2 / 2.50	2 / 0.40	6 / 0.30
United Kingdom	3 / 3.75	5 / 1.00	10/ 0.50
Uruguay	2 / 2.50	2 / 0.40	3 / 0.15
USA	27 /33.75	130/26.00	302 /15.10
USSR	58 /72.50	273 /54.60	668 /33.40
Venezuela	4 / 5.00	6 / 1.20	14 / 0.70
Yemen Arab Republic	2 / 2.50	2 / 0.40	5 / 0.25
Yemen Peoples rep.	2 / 2.50	2 / 0.40	7 / 0.35
Yugoslavia	2 / 2.50	3 / 0.60	6 / 0.30
Zaire	5 / 6.25	13 / 2.60	43 / 2.15
Zambia	3 / 3.75	5 / 1.00	14 / 0.70
Ocean floor/cont shelf	64 /80.00	64 /12.80	64 / 3.20

Figure 3.1.

An example of a detection threshold map, for the 3 P-wave magnitudes required here (0.5, 1.5, and 2.2). This map is for the 110 seismic stations operated by the British Geological Survey, Dublin Institute for Advanced Studies, and Leeds University (modified after Turbitt 1987). Most of these stations would be classified as 'quality 3' in this report. Solid circles; BGS and DIAS seismic stations. Solid squares; Leeds University network. Detection threshold contours are solid lines (magnitude 2.2), dashed lines (magnitude 1.5), and dotted lines (magnitude 0.5).



Figures 3.2-3.4

World maps showing the number of recommended seismograph stations in each of the PTBT States Parties' territories, for quality 1-3 stations. Exact locations would have to be determined by field- and literature-based noise surveys. As noted in the text, some adjustment to take account of the station coverage (or lack of it) in neighbouring states would revise slightly the distributions shown. The maps were drawn using the Van der Grintens projection which causes some distortion near the poles.

VERTIC,
London 1990

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

VERTIC,
London 1990

Fig 3 Seismograph network quality 2 stations, numbers per signatory state

VERTIC,
London 1990

Fig. 4 Seismograph network: quality 3 stations, numbers per signatory state

Annex A

Outline Specifications of Seismic Station network Assuming a Central Monitoring Agency

A regional seismic network shall consist of a series of small or medium-aperture seismograph arrays except under special geological, geographical, geophysical or financial circumstances where the station shall consist of a single site. Any exceptions shall be at the sole discretion of the Agency. The overall design of the network is to be such that a detection-location threshold of body-wave magnitude 2.2 (1.4 in certain specified areas) or less is achieved (at 95% confidence level) throughout the land territories of all State Parties. The network is to be installed and operational no more than 3 years after the formation of the Agency, and it is to operate for a minimum further period of 2 years before the coming into force of the Treaty.

It shall be the responsibility of the Agency to identify, revise, and update as necessary/possible the technical features of the system such that its intended capability is achieved, maintained and, as agreed desirable, improved.

A.1 Seismograph instrumentation

A.1.1 The sensing equipment at an individual seismograph station shall comprise:-

A.1.1.1 Air temperature and wind speed and direction sensors and a microbarograph air pressure sensor, sited at surface.

A.1.1.2 Air temperature, humidity and microbarograph air pressure sensors to be sited in the same chamber as the seismometers.

A.1.1.3 Some or all of the following seismometers:

(i) 3 broadband (BB) surface seismometers, with their sensing elements orientated in the 3 orthogonal directions vertical (z), north-south (NS), east-west (EW), to be located on a concrete plinth in an underground vault. The vault is to be environmentally stable in accordance with the specifications of the seismometer manufacturer's specifications

(ii) a 3 component BB system, as in A.1.1..3 (i), but emplaced in a vertical borehole at a depth of 30-100 metres

(iii) 3 short-period (SP) and long-period (LP) seismometers oriented orthogonally as in A.1.1.1.3 (i) and sited in a vault

A.1.1.4 In the case of a "quality 3" network, each seismic station shall comprise, as its minimum, a seismic station of type A.1.1.1.3 (iii) and may utilise existing stations.

A.1.1.5 In the case of a "quality 2" network, each seismic station will be termed an array and shall comprise, as its minimum, 9 individual stations (elements) of A.1.1.3. (i), distributed in a pattern designed to minimise dominant local seismic noise when the output from all elements is time-shifted and summed. The meteorological equipment of A.1.1.1 and A.1.1.2 is to be installed in at least one of the individual elements.

A.1.1.6 In the case of a "quality 1" network, the stations shall comprise a borehole seismometer of type A.1.1.3 (ii) together with the 9-element array of type A.1.1.3 (i) and all meteorological equipment.

A.1.1.7 The seismological stations are to be distributed geographically to the standard pattern defined by the agency (or technical committee), subject to the constraints of the environment around the stations laid out in A.1.5. The seismic signals from individual array BB elements are to be transmitted to the central station using dedicated land or radio links.

A.1.1.8 The minimum numbers of stations in the territory of each State Party are given in Tables 7-11 of the main study.
A.1.2 The seismographs defined in A.1.1 are to have inherent system noise less than seismic background signal at all frequencies from 0.04 Hz to 50 Hz at least, and a magnification that is flat to ground velocity over the bandwidth 0.03Hz to 50Hz at least, with the slowest possible rolloff to high and low frequencies. The overall dynamic range of the seismograph system is to be 140dB or more. Anti-alias filters starting at 50Hz are to be incorporated in their control electronics. They are to be operated at the greatest possible magnification commensurate with local background noise conditions and the range or choices of gains available in the design.

A.1.3 A radio-transmitted time code is to be received at individual stations or the central array element, and used to provide an absolute time-base with 0.01s absolute accuracy for all recordings. A local quartz-oscillator clock with maximum drift rate of 1s/day is to be available as backup and is to be calibrated against the radio time code on a daily basis.

A.1.4 The individual stations and all array elements are to be located in latitude, longitude, and elevation (relative to a specified Reference Spheroid) using GPS or equivalent satellite-derived position fixing, such that the locations of all seismometer groups can be given to an absolute accuracy of ±50m in latitude and longitude and ±10m in elevation by the time that the network enters regular operation. This location is to be checked at periodic intervals as specified by the Agency.

A.1.5 The individual stations and arrays are to be sited in regions where

(i) topographic relief is as small as possible

(ii) geological structure (including surface drift deposits) is as invariant laterally as possible

(iii) as remote as possible from any industrial, urban and other human activities

(iv) seismic background noise is as low as possible throughout the bandwidth 0.03-50Hz;

in all cases commensurate with an even geographic distribution as indicated in above. Where evolving conditions, such as encroaching industrial development, cause long term changes in the environment around any station that are prejudicial to its monitoring ability, the Agency shall re-establish the station at another more suitable site. Where these conditions are transient, the Agency shall install such numbers of supplementary portable seismic stations as it deems necessary to maintain the detection thresholds in that region.

A.1.6 The characteristics of all seismographs and other equipment are to be standardised at all stations of the network. These specifications above are to be confirmed by bench-testing all instrumentation prior to installation and again at such regular and/or random intervals as desired by the Agency. The characteristics of all stations are to be lodged with the Agency.

A.2 Seismograph network

A.2.1 All territories covered by this agreement are to divided as defined in Annex B.1, and each such area be classified geologically into to one of the following categories:

'shield'
'stable continental platform'
'orogenic belt'
'rift zone'
'deep-water island'
'salt deposits & high-risk decoupling'

In carrying out the classification, reference must be made to the geoscientific mapping data required to be exchanged under Annex B.3.1, in addition to all public-domain geologic mapping. In the case of 'salt deposits and high-risk decoupling' it is possible that isolated areas of deep dry superficial deposits and/or consolidated sediments will be identified; where numerous small such areas are identified, it is intended that a sensible overall classification be achieved. In general, where local scale variations in classification are identified, a representative single regional-scale classification should be made, favouring always the environment requiring a greater density of stations (see B.1.2.1) In the case of deep-water islands, groups of islands may be classified as a single island then according to one of the 'land' geological types if their aggregate area is suitably large.

A.2.1.1 The number of seismograph stations installed on all land territories must meet the following overall minimum spatial densities specified in Tables 7 - 11 of the main study.

A.2.1.2 All deep-water islands or groups of islands are to be occupied by a minimum of 1 array station. Where just 1 array station can be installed, that station is to be expanded to comprise at least 20 vertical BB elements in a suitable pattern and of suitable dimensions as to allow the dominant ocean microseismic noise to be effectively suppressed by the process of array summation.

A.2.2 In those areas where, for the exceptional reasons noted above, individual stations are installed instead, the minimum spatial densities of stations of A.2.1 are to be reduced by a factor of 0.65.

A.2.3 A network of seafloor hydrophones is to be established either on the seafloors and/or suspended within the water columns to detect pressure waves within the ocean. The number of hydrophones are specified in Tables 7 - 11 in the main study.

A.2.4 A network of ocean-bottom seismometers (OBS) is to be established in order to detect seismic waves travelling within the sub-sea floor rocks. Data capture from these is to be either continuous by sea-floor cable or periodic by "pop-up" data storage devices. The number of OBS are specified in Tables 7 - 11 in the main study.

A.2.5 The sites of all arrays and single stations are to have their geological and geophysical characteristics defined by

(i) surface geological mapping on a lateral resolution of 0.5km

(ii) execution of a seismic refraction survey together with borehole sampling to determine P and S wave velocities and formation densities in the uppermost 200m of the Earth

(iii) execution of a long-range seismic refraction/wide-angle reflection survey to determine gross P and S velocity structure to a depth of at least 10km below the local depth of the Mohorovicic Discontinuity; where these characteristics are not already known.

A.3 Seismograph data capture

A.3.1 All seismometers, microbarographs, and radio time codes are to be sampled at a rate of 120 samples/second. Meteorological data are to be sampled at a rate of 1 sample per minute. All of these data are to be written to computer-compatible digital mass storage in a format to be specified by the Agency. The mass storage medium is to offer the optimum long-term integrity of the data, simplicity of storage environment, and have a capacity such that uninterrupted recording for at least 30 days is allowed.

A.3.2 All digitised data are to be transmitted by satellite channel at regular intervals to to the Agency where permanent archiving of the data will be undertaken in similar format to that of A.3.1 and only upon the verified recording of this data will the on-site data record be wiped and the recording medium re-used as desired.

Annex B

Establishing a database of seismological data and the identification of anomalous events

The Agency will be charged with identifying on seismological evidence those seismic disturbances which are deemed probable nuclear explosions at a confidence level of 95% probability, using the historic databases, routinely-acquired data, and analysis methods as set out below.

It shall be the responsibility of the Agency to identify, revise, and update as necessary/possible the technical and scientific methodology, such that its intended capability as noted in Annex A is achieved, maintained, and where desirable improved.

B.1 Regional geographic divisions for monitoring; a data base of historic data

B.1.1 The Earth's surface will be divided into seismic; geographical; and local regions (in order of decreasing areal extent). It is anticipated that this hierarchy of regions will honour national territorial boundaries.

B.1.2 The Agency will collate at its central facility (or facilities) a database of seismological data for each region as defined in B.1.1. For seismic events prior to the commencement of the Agency Network ("historic data"), the database shall derive from that held by the International Seismological Centre together with any other public-domain data considered necessary thereafter, the data will be obtained from the Agency Network.

B.1.3.1 "Level I" data will comprise as much as possible of: hypocentres and origin times, magnitudes for P and Rayleigh waves; amplitudes & periods of any other reported phases; earthquake focal mechanisms. "Level II" data will comprise digital seismogram waveforms together with seismograph response characteristics for any station contributing.

B.1.3.2 The Agency shall establish a 'definitive' hypocentre and magnitude reference dataset by reprocessing historic data in the following manner:

(i) selecting from all area an event or events with some or all hypocentre parameters known, or an event large enough to have been widely recorded, and these globally-distributed events to be located in space and time

(ii) taking those events from (i) as 'reference' events and, for each area separately, locating all other events within each area relative to them;

(iii) recomputing P- and Rayleigh-wave magnitudes simultaneously for all events using the maximum-likelihood technique;

(iv) computing for each area a P-wave magnitude formula for shallow-focus events, by determining the distance-correction term, B(delta), for distances at 1-degree intervals up to 40 degrees;

(v) computing for each area an Lg-wave attenuation value and thus a Lg-wave magnitude formula and data set.

In all cases (i)-(v) an 'area' is to be taken as the smallest practicable combination of local regions as defined in B.1.1 with similar tectonic categorization while ensuring that a sufficient number of seismic events are contained within.

B.1.4 The database as described in B.1.3 is to be fully established using historic data no more than 3 years after the formation of the Agency. The addition of data from the Agency network will commence as soon as data are available from the network. The reference hypocentre and magnitude dataset may be refined at such intervals as desired by the Agency.

B.1.5 For all events either (a) determined in B.1.3 to be at a depth of less than 50km, and with an epicentre beneath or within 25km of land or (b) known from data exchanges (B.3.4) to have been underground nuclear explosions, the Agency will compile (on a regional basis) a register of: m_b:M_s scattergrams, P-wave spectra, m_b(high-frequency): m_b(low-frequency) (VFM) scattergrams and Love-wave magnitudes. Where the region includes either explosions acknowledged under the data exchanges of B.3.4, B.3.5 or B4.1.1 or any other historic events presumed to be nuclear explosions:

B.1.5.1 The choice of high- and low-frequency bandwidths for VFM scattergrams will be refined to optimise separation of explosion and earthquake populations. Optimum decision lines will be determined on both m_b:M_s, VFM, scattergrams such that any given event may be assigned a probability of being a nuclear explosion source. An estimate of the amount and character of tectonic release will be made for each explosion. An optimum linear combination of m_b, M_s, and m_b(Lg) (referred to as a "unified magnitude") will be determined to give the best precision possible for a seismic yield estimator.

Where the region does not contain such events,

B.1.5.2 Statistical estimators will be derived for the earthquake m_b:M_s and m_b(HF):m_b(LF) populations' trends in order that any given event may be assigned a measure of its closeness to the mean trend.

Furthermore the Agency shall be charged with an assessment of any other discriminant parameters suggested or implied by research results in the open literature and/or its own seismologists. Those discriminants which are applicable to regional-range (i.e. within 2000 km of source) recordings and/or which improve depth and epicentre resolution shall be prioritised in this assessment.

B.2 Data processing methods and equipment

B.2.1 Satellite transmission at regular intervals of no more than 24hrs will be used to transmit bulk data to the Agency. The data transmitted at intervals to the Agency shall comprise the digital continuous recording at all stations.

B.2.2 The means of mass storage at the Agency shall be as defined in Annex A.3.1. These data are to be archived for a time period of no less than 20 years. The storage environment is to be in accordance with the storage medium manufacturer's specifications for temperature range, humidity, frequency of tape spooling, ambient magnetic fields, etc.

B.2.3 The Agency is to be equipped with mainframe computers or computers, satellite receiving equipment, and all other data-handling and data-archiving systems to a standardised specification to be defined by the Agency at its inception.

B.2.4 All processing algorithms for the operations of:- hypocentre & origin time determination P-wave, Rayleigh-wave, and Lg-wave magnitude determination P-wave spectral analysis and VFM determination and all other data analysis and processing software, are to be standardised. The Agency shall select these algorithms as a top priority immediately following its inception.

B.2.5 A hypocentre/origin time determination will be carried out automatically using the algorithms of B.2.4 on all seismic events detected by the Agency network within 3 days of receipt of the data at the Agency. All events found to lie beneath, or within 25km of, land at a depth of 50km or less are to be declared candidate explosions on location criteria. All such events will have their m_b:M_s and m_b(HF):m_b(LF) characteristics determined and compared statistically to those of the 'reference' historic dataset and that acquired by the network. All comparisons are to be made on a regional basis as discussed in B.1.5. This comparison may be automated and all newly recorded events with a 65% or higher probability of being explosions flagged, although all m_b:M_s and m_b(HF):m_b(LF) scattergrams must be displayed graphically and examined visually. All seismic events recorded must reach this decision threshold within 30 days of their occurrence.

B.2.5.1 Those events which are assigned a 65% or greater probability of being explosions are to be subject to individual analysis by a seismologist of the Agency. This is to include as a minimum all those feasible of; precise hypocentre location; any supplementary depth estimation procedures such as higher-mode surface wave spectra; focal mechanism estimates using signal polarities, P_n:S_n amplitude ratios or any other means where appropriate; Those subsequently confirmed as being explosions at 95% confidence levels will be passed on by the Agency seismologist(s) to higher authority.

B.2.6 Those events categorised by B.2.5 as 'probable explosions' will be subjected to any/all possible further analysis upon demand/authorisation from higher authority in the light of all supportive evidence from such other means as the Agency has at its disposal, such as preferred locations based on satellite evidence.

B.2.7 In the event of geographical regions and/or specific dates/times being identified by other means available to the Agency as hosting suspicious activity, all seismic events originating from that region/time will be subjected to the higher level of scrutiny as defined in B.2.5.1. A specific array beamform search will be conducted to ensure that all possible seismic events have been detected and located and any further events analysed appropriately.

B.3 Information to be supplied by signatories and/or obtained from the public domain

All State Parties are to deposit with the Agency within 1 year of the formation of the Agency as much as possible of the data specified in B.3.1 - B.3.5 below. The remainder of the required data must be provided within a maximum of a further 2 years.

B.3.1 Relevant geoscientific mapping information, pertaining to their territory, to include: surface solid rock types and superficial deposits; depth of water table; areas of permafrost; areas of salt deposits; a topographic database, where possible in digital form; all the above to be resolved laterally to 0.5km.

B.3.2 A register of locations, depths, geological settings, and general geometries of all standing cavities of volumes:

> in excess of 55,000m^3 at depths of less than 300m,
> in excess of 40,000m^3 at depths of between 300m and 600m,
> in excess of 30,000m^3 at depths of between 600m and 1km, and
> in excess of 10,000m^3 at any greater depths;

and of all mining operations requiring vertical shaft diameters of 3m or greater extending to depths of over 1km.

B.3.3 For all geophysically distinct sites used in the past for test firing of nuclear explosives, geoscientific mapping data as defined in B.3.1 to be resolved laterally to 0.1km.

B.3.4 The dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, and yields of all previous test firings of nuclear explosives.

B.3.5 The dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, yields, and purposes of all firings of nuclear explosives at locations outside the recognised Test Sites as defined in B.3.4 - details to be given separately of all individual explosions in any aggregate or simultaneous firings.

B.3.6 All information in B.3.1-B.3.5 is to be used for designing in detail the seismic array spatial densities and geographic distributions, construction of a reference database of historic data, assigning priorities for real-time array beamform searches, and any other seismological purposes.

B.4 Information to be supplied by all signatories subsequent to the coming into operation of the network

B.4.1 All State Parties will be required to deposit with the Agency subsequent to the coming into force of the Treaty all the following:

B.4.1.1 The locations, depth of burial, emplacement medium, anticipated yields, intended detonation date/time, of all non-nuclear explosions of yields of 3 tonnes TNT-equivalent, to be supplied no less than 28 days in advance of the intended detonation date/time. The actual detonation times and dates of these explosions are to be forwarded to the Agency as soon as they are known by the host nation.

B.4.1.2 The creation or discovery of any standing cavities or deep mining shafts as defined in B.3.2.

B.4.2 The Agency shall have the automatic right and authority to deploy networks of portable seismograph installations in and around the geographic regions identified in B.4.1.1.

B.4.3 The Agency shall design and execute a programme of at least 4 non-nuclear explosions yearly, detonated routinely and (ir)regularly, with or without prior announcement, and at least 2 of these to be in the yield range 100-400 tonnes TNT-equivalent, in order to test and calibrate the detection, location, identification, and yield estimators, of the established seismic network. The Agency shall also be empowered to instal temporary portable seismic stations as defined in B.4.2.

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III MONITORING OF POTENTIAL NUCLEAR TESTING AREAS USING CIVIL REMOTE SENSING SATELLITES

This paper will explore the requirements for utilizing civil remote sensing satellites to obtain information about activities being conducted at known and suspected nuclear weapons test sites. While the primary focus is on detection of engineering activity before the test, some additional data on the confirmation of nuclear explosions by the use of multispectral sensing will also be provided.

1. Number of Sites

1.1. Existing test ranges

Nuclear weapons are presently tested by the existing nuclear weapons states, the United States, the Soviet Union, the United Kingdom, France and the People's Republic of China. One nuclear test was conducted by India, thus establishing it as a country which must also be monitored as if it were a full-fledged nuclear weapons state.

1.1.1 The United States

Within the United States, tests have been carried out in Alaska, Colorado, Nevada, New Mexico, and Mississippi. Until the ratification of the Limited Test Ban Treaty in 1963, the United States also conducted tests at its south Pacific test range including Eniwietok and Bikini atolls. The experiments conducted in Colorado and Mississippi were part of the defunct "Plowshare" program to explore the use of nuclear explosives for peaceful purposes. It is highly improbable that either area could ever be used again for nuclear testing because of the public interface problem. Those sites can be excluded from consideration. The Alaskan experiment was also probably a "one off" test, not to be repeated. Use of the site is no longer feasible because of environmental concerns. Civilization has encroached on site of the Trinity test north of Alamogordo, New Mexico; it is also not likely to be used again. The Pacific Test Range has only been used for air, space, and underwater based tests and is closed.

The United States, thus, maintains one active nuclear test range located near Mercury, Nevada, north and west of the city of Las Vegas.

1.1.2 The Soviet Union

The USSR maintains three nuclear test ranges, at Novaya Zemlya in the arctic, on the Shagan River, and at Degelen Mountain. The latter two ranges are often referred to collectively as the Semipalatinsk test area. Novaya Zemlya which also has two separate but dormant test areas has not been an active range in recent years, but the USSR announced early in 1990 that over a period of three years the Soviet testing programme will move, in total, from Semipalatinsk to Novaya Zemlya.

1.1.3 The United Kingdom

The UK formerly tested nuclear weapons in Australia. It now conducts all of its tests at the American Nevada Test Site.

1.1.4 France

France tests at its Pacific Test Range based on the island of Moruroa and more recently on Fangataufa. This site is unique in the world in that the explosions are conducted in tunnels which are themselves run beneath the ocean floor. Emplacement is through drill rigs located on the island itself and capable of drilling on a slant. It is unlikely that France would ever again be permitted to test at its former Sahara Test Range.

1.1.5 China

China operates one acknowledged range near Lop Nor.

1.1.6 India

India, having conducted only one full-scale explosion can be presumed to have only one area which has been developed as a nuclear test site. Because of the size of the country, it is not unreasonable to expect that other areas could be developed as well.

1.2 Potential Test Ranges.

All nuclear threshold countries with the exception of Israel and Taiwan are large and have sufficient sparsely settled areas to permit them to establish one or more nuclear test sites. The states counted as being on the nuclear threshold include Brazil, Argentina, Libya, Iran, Iraq, Israel, Pakistan, Taiwan, North Korea, South Korea, and South Africa (ref. 1). Consideration of this list adds ten nations with the possibility of having indigenous test sites (Taiwan is excluded on grounds of territorial size; a clandestine underground test site, used infrequently, in Israel's Negev Desert is not an impossibility).

1.3 Total Number of Test Ranges to be Monitored

There is a total of 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. Should the NPT regime fail, many additional nations which have the technological base for nuclear weaponry would have to be included.

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.

Nevertheless, at the moment the number of sites to be monitored probably does not exceed 17.

2 Utilization of Monitoring Satellites

2.1 General considerations

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. For SPOT this period is 26 days. Of nearly equal importance is the distance the satellite can look to either side of its ground track. SPOT uses mirrors on its two cameras, permitting the viewing axis to be tilted up to 27^{o} to either side of the nadir point. Thus, SPOT is able to observe target points located up to about 425 km to either side of its ground track; the resolution is slightly degraded at large off-nadir angels. In practice, this provides a revisit interval of not more than 5 days at the equator and considerably less in temperate latitudes.

The ability to peer across track is an important one for a monitoring satellite, for it greatly increases the area on the ground "at risk" of being observed on any one track. If the repeat cycle of a satellite is only 14 days, the period of the Soviet "Resource" satellites carrying KFA-1000 cameras, and if the camera is constrained to point at -- or nearly at -- the nadir point (as do the instruments on both the LANDSAT and "Resource" satellites) then workers on the ground can be confident of having two weeks or more between chances of being detected while engaging in clandestine activities. It is, therefore, almost a necessity to have the ability to point the cameras on the satellite. A concomitant necessity is the ability to keep secret the program for acquisition of imagery so that potential evaders must engage in camouflage and concealment activities whenever the observation satellite passes within visual range. The inclusion of a non-interference clause in the treaty would therefore be an important measure. A greater off-nadir capability than that possessed by SPOT would be useful in an arms control monitoring situation.

2.2 Maximum frequency of acquisition

The maximum frequency with which a single SPOT satellite can observe a given site is once in five days, or 73 times per year. If SPOT were supplemented by RADARSAT (a Canadian project with a 10 meter resolution), that frequency could be roughly doubled. It will be seen that observing a single site 140 times a year generates an overwhelming stream of data, given that interpretation of a single SPOT scene requires 40 to 80 man hours (ref. 2). Furthermore, it is unreasonable to expect SPOT or any other satellite operator to make its instruments available on such a regular basis, particularly since there are apt to be other targets of (commercial) interest which cannot be accessed if the camera is trained on the monitored areas on every possible pass.

A monitoring authority relying upon commercial image vendors such as SPOT or RADARSAT International might be able to command one image of each site during each repeat cycle. For SPOT this corresponds to 14 images per year of each site, although some images, at least, will be lost due to cloud cover. In order to complicate any possible efforts to carry out preparations for a test without detection, some of these SPOT images should be supplemented, or even replaced by images acquired from other platforms.

Fortunately, the weather requirements for nuclear test sites generally make their observation from space easier than observation of a random point on the earth. That is, test site preparation normally requires significant construction out of doors, drilling, laying of cables, etc. which has, historically, lead to test ranges being located in areas with good weather and low precipitation. Arid locations are also sparsely populated and easy to keep secure. One rule of thumb is that temperate areas have 50% or more cloud cover about half of the time; desert areas are obscured far less of the time. Images with 50% cloud cover are unlikely to have much utility for monitoring; a 20% maximum is probably the practical working limit -- although, of course, dumb luck has a role to play whether the cloud cover is 90% or 1%.

Because of cloud cover, close to 25% of acquired scenes are apt to prove less than fully useful -- based on an inspection of the LANDSAT 4 and 5 catalog of imagery over the Nevada Test Site with a 20% cover taken as the maximum permitted. Statistically, then, of 14 scenes acquired per year, only ten will be useful. While the distribution of those scenes is statistical, it is not wholly random since weather patterns are predictable, and certain periods of the year are far more apt to have obscured skies than others. However, a potential violator will be equally aware of weather patterns, both annually recurring ones and short-term developments. He can, if the monitoring agency relies upon optical reconnaissance, use his knowledge of local weather to reduce his chances of being detected before a test is carried out.

Understanding of the utility of cloud cover for concealment requires an estimate of the amount of time required to prepare a test site, information concerning the amount of time over which seismic arrays can remain tuned to optimize signal detection from a single area, and some detailed (and classified) knowledge of how to tell from inspection when a nuclear explosion is no further off than the amount of time over which the arrays can be aimed, but also no closer than the time interval required to arrange such aiming.

Further discussion of the utility of satellite observations to provide warning of a clandestine nuclear test are predicated on the assumption that the test is to be carried out in such a manner that the conventional construction and emplacement of data transmission cables, etc., are carried out in such a way that they are, in fact, visible from above. This need not be the case, particularly if the test is to be conducted in an area in which no nuclear testing has occurred previously and in which suitable underground facilities already exist.

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

- 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. (T_1)

- The time after construction begins until the purpose of the activity is unambiguous, or at least highly indicative. (T_2)

- The weather pattern (at the given season) over the suspect test site, or, alternatively, the availability of weather-independent satellites such as RADARSAT. Assume the cloud-free fraction at the local time of satellite passage to be given by f.

- The confidence, C, with which probable cause must be established before issuing an alert to the seismic system.

- 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.

- The gain in monitoring confidence obtained by tuning the seismic arrays.

Only some of the above points can be readily quantified. At least one successful observation is needed in each interval of time:

$$T_o = T_1 - T_2. \qquad (1)$$

One may guess that T_1 is on the order of three months, and that T_2 is on the order of 2 weeks to 1 month. Thus, one must obtain one useful image of each potential test site every second month.

This is a simple statistical problem:

$$(1 - C) = (1 - f)^n, \qquad (2)$$

so that n, the desired number of observations, is given by:

$$n = \log(1 - C)/\log(1 - f). \qquad (3)$$

For the nominal case of 95% confidence and 25% probability of failure (i.e., 25% of the time the site will be obscured by cloud or that technical difficulties will prevent a satisfactory image from being acquired), 2.41

attempts are required. Since acquisitions only come in integer numbers, either 2 tries or 3 tries must be made. With two attempts, C, the confidence level, is 93.75%; if a third attempt is made, C increases to 98.4%.

This example cannot quantify, except by folding into f, the possibility that a successful acquisition is made, but that the observation is thwarted by camouflage, concealment and deception (CC&D) on the part of the observed state. Given that the observed state is assumed to be engaging in prohibited behavior, the probability is very high that CC&D measures will be attempted.

T_0 is on the order of 2 months; the desired number of acquisitions within that period is roughly 2.4, leading to a desired acquisition rate of $\alpha = 1.2$ pictures per month, or about one attempt every fourth opportunity. Note that these acquisitions cannot occur on a regular and predictable schedule; if they do, CC&D is made far simpler. Thus, acquisition opportunities must be scheduled randomly, and the schedule must be held secret from the nation to be observed.

SPOT Image, however, offers a "Red Service" (called "Special Service" in North America) which permits a client to purchase the entire capability of the satellite over a significant arc of its orbit. One effective CC&D measure would simply be to purchase Red Service for the arcs from which the clandestine test site was in view for a sufficient time period before (and after) the planned detonation. Unless the monitoring authority has such quasi-governmental stature that SPOT Image cannot reject its scheduling requests, SPOT may be of very little utility since the cost of Red Service and purchase of all acquired images is minuscule compared to the cost of a nuclear test.

Profit-driven remote sensing systems, therefore, cannot always be counted upon to provide acceptable coverage unless government or UN intercession should prove successful. However, the monitoring authority might consider whether the booking of Red Service of a test site were not, itself, sufficient indication of a need for increased seismic monitoring. In the gray world of intelligence measure and countermeasure, there is no clear answer. Red Service could be booked over an innocent area in order to divert attention from clandestine test preparations occurring elsewhere.

2.3. Multispectral sensing for detection of clandestine test sites

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 the kind of obvious preparations which are seen in images of the 1989 Joint Verification Experiment in which U.S. and Soviet scientists conducted joint nuclear tests at the tests sites of each country to study means to determine the yields of nuclear explosions (ref. 3).

Such clandestine testing could be conducted in a large, deep, and active mine comparable in size to the Kirunavaara iron mine in Kiruna, Sweden 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 -- or under similar scenarios for other parts of the world -- 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 kilometers. 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 meters; 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, we must find surface indicators which can be used to identify and localize deep underground explosions. Fortunately several such signatures exist; some have been used already to locate underground tests, while others are in development (ref.4). All techniques require multispectral information, and the more sensitive ones under development require data from Landsat bands 5 and 7 as well as bands 3 and 4 because they are used to detect alterations in the morphology of surface soils caused by the passage of the shock wave produced by the explosion from the ground (where the speed of sound is high) to the air (where it is much lower).

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 center of this circle can be located with high precision, thus giving an accurate location of the epicenter of the test.

2.4 Cost of Acquisition and Monitoring

The costs of acquisition and data analysis scale linearly with the number of images obtained -- the scale factor being the price of each image as set by the supplier plus the cost of data analysis per acquired image. Both the acquisition and analysis costs will vary depending upon the satellite used. RADARSAT International might charge less for its imagery than SPOT Image, but SAR imagery requires significantly more computer processing to be useful. LANDSATs 4 and 5 provide 30 meter resolution in 6 spectral bands at far less cost per square kilometer than does SPOT -- but the increased spatial resolution from the French instrument may be crucial.

The cost of an image acquired to order by SPOT is presently approximately US$ 2,500. Between 40 and 80 man hours are required to analyze each SPOT image -- more being required while the sites of interest within the scene are being located, and fewer once the analyst has achieved a high degree of familiarity with the scene and is able to use computer-aided change detection methods. For simplicity, 60 man-hours per scene will be assumed needed for each scene acquired (not for each test area monitored).

The Nevada Test Site (which appears on U.S. maps, so its area can be readily estimated) occupies a roughly parallelogram shaped area 120 km by 150 km. If imagery could be oriented as one might wish this would require a minimum of 5 scenes for complete coverage.

The actual shape of the area, however, is such that at least 7 scenes would be required for complete coverage. The central area of the test site, which contains both Yucca Flats and Frenchman's Flats -- two of the most used test areas -- as well as the headquarters area at Mercury, NV, is much smaller, requiring only 3 scenes for coverage. [These scenes cannot be acquired on a single orbit of the satellite; indeed, they might have to be acquired over the space of a week.]

To monitor NTS, 3 x 12 x α scenes must be acquired each year. For the previously estimated rate , that means that 43 images a year must be purchased and analyzed. The cost to acquire the imagery of NTS is thus

US$ 2,500 x 43, or US$ 107,500 per year.

The analysis of 43 scenes requires 2580 man-hours (at 60 man-hours per scene). Assuming 4 weeks of paid vacation, 3 weeks of sick leave, and 10 days of paid holiday time (reasonable professional benefits in the United States), there are 43 working weeks per year, or 43 x 40 = 1720 working hours in one man-year. Monitoring NTS thus requires 1.5 man-years of photo-interpreter time. The salary of an American PI capable of exploiting computer analysis techniques is (end of 1989) roughly US$ 36,000 (plus benefits such as medical and retirement insurance, which typically add 26%-28% to personnel costs at universities and similar employers).

The personnel costs to monitor NTS alone are thus:

1.5 x $36000 x (1.28) = $69,120 per year

exclusive of any indirect costs, costs of administration, office supplies and support.

3.2 Number of computer workstations

Referring back to section 1.3 we see that the number of potential sites to be monitored, world wide, is on the close order of 20. If the sensitive area of NTS is comparable in size to that of each of the other 19 areas to be monitored, then the cost of monitoring is:

Personnel: 20 x US$ 69000	= US$ 1,380,000
Imagery: 20 x US$ 107,500	= US$ 2,150,000
Total	= US$ 3,530,000

plus administrative, equipment, maintenance and other costs including office space. Thirty photoanalysts will be needed for the project, assuming that no additional areas of concern are developed. Additional imagery may have to be acquired to establish the historical record of activity at each monitored test site, but this will be a one-time expense. One support person for every 4 analysts is probably a minimum -- including technical, maintenance, bookkeeping, clerical, etc -- although those personnel categories are generally lower paid. In addition a library and library staff will be needed to obtain, store, and retrieve the kind of collateral information which is absolutely required for good intelligence. Not fewer than four or five high-level political analysts will also be required, as well as a senior administrator and his deputy if the monitoring organization is to be included within the structure of an existing body. If the monitoring organization is to be free-standing, the number of support personnel might well double and the number of senior managers will certainly increase from two to four or more.

The base costs for operating a monitoring agency - imagery and analysis staff - are remarkably affordable so long as the area to be studied is relatively small and can be defined in advance.

3. Capital Equipment

3.1 Method of estimating required equipment

Image analysts work best in teams of two, one providing a "sanity check" on the other, and both working to bring to bear complementary types of experience. Thus, the staff of thirty PIs will be organized into fifteen teams of two, probably organized into three squads of five teams each, each squad with a designated leader.

It is possible to enforce two shift per day working in a military environment, but probably not in a civilian one. Although one work station for each team would be ideal, it is probably not necessary since much of imagery analysis takes place off-line. That is, much of the time of the analyst is spent in library research, in comparing imagery of the same site taken on different dates, in seeking and examining imagery of similar sites, and in writing reports.

While 15 workstations would be ideal, careful scheduling can allow the agency to operate with only 10. Each computer work station costs, including software, roughly US$ 50,000 - US$ 100,000, depending upon the capabilities demanded. Lower-powered work-stations are available based on "386 series" desk-top computers; a careful study must be made to determine the trade-offs between capability and cost; in general, as time goes on capability will increase and cost decrease. In addition to the computer work-stations, a "hard copy" device capable of providing photographic prints both for off-line analysis and for distribution is required. At present the 3M printer costs about US$ 250,000.

3.3 First year capital costs

The start-up price for the monitoring agency's computer work-stations and output devices is, therefore, between US$ 750,000 and US$ 1,250,000. Other capital costs for wordprocessors, furniture, and office equipment must be added to this budget. It would not be unreasonable to budget US$ 5,000 per employee for this category.

3.4 Maintenance

Annual maintenance costs equal to 10% of the price of the equipment should be considered a minimum. In addition, the annual cost of upgrading equipment to meet evolving standards of performance must not be ignored. This can range between 10% and 25% of the initial capital cost, based upon personal experience with computers ranging from IBM PCs to VAXs. At least two people for maintenance of the workstations were included in the personnel estimates made above; using outside contractors would not appear to be appropriate: first because of the need to have maintenance personnel available 24 hours a day, and second because of the need for security clearance at a very high level for all those connected with the agency.

After a monitoring agency is established, the operation of a center for the analysis of remotely sensed imagery should not cost in excess of $5 000 000 p.a., including all personnel, imagery, and maintenance but not including lease or rental of office space

4. Construction and operation of dedicated satellites

It is plausible for a well-funded monitoring agency to consider the construction of dedicated satellites for its specific purpose. The cost of such satellites need not exceed $150-$200 million per satellite for construction and launch if care is taken in the design process to avoid the inevitable temptation to push technology and produce a wholly new satellite. If a cost-effective product is to be obtained, it can only be produced by adapting an existing design to the needs of the system (ref. 5).

Given the fact that any violations of a CTBT agreement would be conducted in secrecy and with care given to present observation from above, it may well be that no observation satellites will be useful for detecting preparations for a clandestine site. Increasing the number of satellite would increase the probability of detecting preparations.

4.1 Satellite characteristics

Extremely high spatial resolution is probably not required to detect the construction needed to operate an open test site. Both SPOT and Landsat images have been used to observe activities at nuclear test sites – Landsat of the Nevada Test Site and SPOT of Semipalatinsk (ref. 6 and ref. 7). At the ten meter resolution level trailers and other temporary laboratory structures will not be readily detectable or identifiable; at 5 meters, they should be.

This indicates that a modification of the SPOT panchromatic sensor to the 5 meter level – requiring either an increase in the data transmission rate by a factor of four, a reduction in the word length describing each pixel by a factor of four, or a reduction in the covered area to a square 30 km on edge -- would be adequate. A reduction in the word length is inappropriate; SPOT already uses an efficient data compression algorithm, and any further reduction in the word length would require a reduction in the dynamic range or the detail which could be conveyed. It is important to recognize that the data transmission rate and the volume of data which can be stored on the on-board tape recorders do set the effective limits on the combination of resolution and coverage area. The data transmission rate of SPOT 1 already pushes the state of the art for unclassified systems.

Given the impossibility of searching vast areas with SPOT, Landsat or any other close-look instrument, simply doubling the focal length of the SPOT telescopes to reach 5 meter resolution and accepting the reduction in coverage area is probably the most cost-effective solution. As an added benefit, the XS resolution would also be improved, to 10 meters. One possible compromise might be to adapt a SPOT 1 satellite to have one telescope with doubled focal length and reduced coverage while the other retains its original resolution and larger coverage. Note that such a hybrid satellite would have lower revisit intervals at high resolution than would a satellite with two long focal length telescopes but it would have a higher overall revisit rate if the lower resolution instrument were included. However, the reduction in areal coverage probably would decrease over-all revisit frequencies since the maximum off-nadir distance in either direction would be decreased by 30 km, half the size of the original scene.

It is also not clear if the spectral range and resolution of the SPOT XS sensor are adequate for the detection of subtle surface changes produced by deep underground explosions fired in soft-rock geology. It may be that a sensor comparable in spectral range and resolution to that on Landsats 4 and 5 is required. A monitoring agency must be capable of localizing the epicenter of any suspicious event to within roughly 100 m if on-site inspection is to permit direct confirmation of the test by actually drilling into the cavity. Since this cannot be done seismically, it must be done with imagery or on-site inspection techniques discussed later. Furthermore, the monitoring agency will have to be able to have some capability to detect and identify nuclear explosions which were conducted in deep secrecy and with due care given to the reduction of all possible surface and seismic signatures.

It would not be easy, however, to adapt the Landsat sensor to obtain higher resolution. Thus, the problem of constructing dedicated satellites escalates since both a Landsat and a SPOT equivalent are probably needed. In all probability the needs of the agency can be met better by constructing and operating an upgraded SPOT system while relying on other suppliers for extended range multi-spectral sensors. "Lightsat" or "Minisat" (small satellites) techniques are probably not useful in this case, because of the difficulty of constructing cheap and light long wavelength IR sensors.

4.2 Number of satellites for adequate coverage

This section uses the orbital parameters and technical specifications of the SPOT 1 and SPOT 2 satellites as illustrative paradigms. Each SPOT satellite is in a sun synchronous orbit at an altitude of 832 km. And each satellite has the capability of pointing each of its two HRV cameras up to 27° off nadir. While each HRV can only image a swath 60 km wide at any given instant, the satellite is capable of imaging two simultaneous swaths located anywhere from nadir to 424 km off nadir (center point of outermost swath). Thus, on any one orbit a SPOT satellite can collect data over a swath 848 km wide. In order to obtain once a day coverage of every point on earth at the same local solar time, several satellites must be placed in the same orbital plane, their spacing in mean anomaly adjusted so that the earth rotates 848 km (at the equator) between the time one satellite departs the equator and the next arrives.

Since the circumference of the earth is 40,000 km and the day is 24 hours long, the spacing interval between satellites is 30.5 minutes. The period of revolution for satellites at 832 km altitude is 102 minutes, which indicates that three satellites are required. Two satellites spaced 180° in true anomaly can provide coverage two out of every three days, even at the equator.

In view of the long lead time to prepare a nuclear test site, it is not clear that daily or two-out-of-three day coverage is required.

4.3 Other considerations

In examining the costs and benefits to a monitoring agency of operating its own dedicated satellites, it becomes clear that the total area to be examined by the agency is very small compared to the area of the land masses of the earth. Furthermore, a monitoring agency with treaty-specific responsibilities does not have the needs of a national intelligence agency to collect information on all possible threats, world wide. It is, therefore, apparent, that a monitoring agency cannot make efficient use of a satellite system for its own account. It is natural, then, to suppose that the agency could own and operate the system but would acquire imagery for commercial clients and would distribute that imagery at reasonable cost under an "open skies, open access" policy. If the resolution, revisit rate, and other specifications of the system made it attractive to prospective customers and gave it some technical advantages over the SPOT, Landsat and other systems of the near future, such sales could be a quite attractive way to subsidize the monitoring activity.

References

1. Leonard S Spector, The Undeclared Bomb (Ballinger, New York: 1988), map on p.7. Spector lists South Korea as a "country of past concern" and classes Israel, India, Pakistan and South Africa as *de facto* nuclear weapon nations. Whatever the precise state of the nuclear weapons programs of those nations, it is clear that areas within their borders suitable for the establishment of a nuclear test range are candidates for monitoring. This includes South Korea.

2. Interview with Donald Vance, head of military photo analysis for the Washington-based firm of Greenhorne & O'Mara. Mr Vance is a highly skilled and very experienced photointerpreter himself and has carried out several assignments for civilian analysts.

3. See the article "Monitoring Underground Nuclear Tests", by William Leith and David Simpson in Commercial Observation Satellites and International Security, M. Krepon, P.D. Zimmerman, L.S. Spector and M. Umberger, editors. (St. Martin's Press, New York and Macmillan, London: 1990) [forthcoming]. The Leith article shows SPOT imagery of the Soviet test site.

4. See Leith and Simpson, *op. cit,* and B. Jasani and C. Larsson, "Security Implications of Remote Sensing", Space Policy, February 1988, p. 56 for the use of two slightly different techniques, one exploiting SPOT's near IR band to detect reduced IR reflectances caused by spallation dust covering low-lying vegetation at Semipalatinsk (Leith and Simpson) and the other which used Landsat Band 4 to find increased vigor in vegetation surrounding collapse craters in Nevada (Jasani and Larsson).

5. Pierre Bescond, President SPOT Image Corp. Talk given at the Virgina Center for Innovative Technology, Herndon, VA on 18 January 1990. Bescond estimated that the marginal cost to build and launch a duplicate of SPOT 1 would be between $150 M and $200M in present dollars.

6. Bhupendra Jasan and Christer Larsson, *op. cit*

7. William Leith and David W. Simpson, *op. cit.*

IV ON-SITE INSPECTIONS AND A GLOBAL CTB

1. Introduction

Until recently, the issue of on-site inspections was a major stumbling block in all negotiations of treaties which required verification measures. Nevertheless, the 1976 Peaceful Nuclear Explosions Treaty (PNET) has extensive provisions for on-site inspections of peaceful nuclear explosions, although they have yet to be put into practice. Such measures have direct applicability to a CTB in that they could play a part in discriminating between chemical and nuclear explosions.

On-site inspection will be an integral part of a CTB. Whilst the mainstay of verification of the test ban will be seismic monitoring, on-site inspection will play an important supplementary role. 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.

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.

There are several types of on-site inspections:

Short notice challenge inspections include challenges to declared and undeclared sites. Notice for challenge inspections should be of the order of hours. Enough time has to be allowed for the host country to make necessary accommodation, catering and transport arrangements. A pre-inspection movement restriction clause, forbidding any movement out of the site to be inspected, once the request to inspect a specific site has been made, could be monitored by aircraft and satellites.

Routine inspections are useful mainly in terms of confidence building. The knowledge that an inspection is going to take place on a particular date at a particular place down-grades political sensitivities about those inspections. On their own, routine inspections are not at all suitable for inspections to check high risk activities, but they are useful for checking any on-site remote sensing equipment such as seismic detectors etc. Routine inspections in conjunction with challenge inspections contribute to confidence in the treaty.

Routine-random inspections are inspections that the inspected side knows will occur but does not know when they will occur (also called ad hoc inspections). They can be carried out with very little notice, but because they are routine, there is no implication that the inspecting sides believes the other to be violating the treaty.

Permanent inspections include the permanent presence of an inspector and they include manned portal perimeter monitoring of a site such as a production facility. They are useful for high risk sites but they take a large amount of manpower and resources.

For a global comprehensive test ban, short notice challenge, routine and routine-random on-site inspections have most applicability. Permanent inspections would be an excessive measure, but it should be noted that many of the scientific measurements made during a challenge inspection will require the inspectors to be on-site for long periods of time.

2. Precedents for OSI

There have been a number of treaties, agreements and negotiations with provision for on-site inspection included in the monitoring and verification sections. Relevant to a Comprehensive Test Ban are the provisions contained in the 1968 Non-Proliferation Treaty (NPT), the 1976 Peaceful Nuclear Explosions Treaty (PNET), the 1985 Treaty of Rarotonga, the 1986 Stockholm Accord, the 1987 Intermediate Nuclear Forces (INF) Treaty, the current Chemical Weapons Convention (CWC) negotiations, the 1990 "Open Skies" negotiation and the 1987/1988 "Step-by-Step negotiations on Nuclear Testing.

The 1968 NPT through the International Atomic Energy Agency (IAEA) has provision to safeguard nuclear materials in civil reactors (achieved by bilateral agreements between the states party to the treaty and the IAEA). The inspections comprise of routine, ad hoc and special inspections. These allow for routine monitoring, random spot checks and challenge inspections respectively. The notice required for ad hoc and routine inspections is at least 24 hours while for special inspections no notice is laid down other than "as promptly as possible after the Agency and State have consulted". The Department of Safeguards of the IAEA has about 180 safeguards inspectors plus an additional 15 inspection assistants (Turrentine 1990, p 46).

The 1976 PNET, whilst still to be ratified at the time of publication and therefore still to take effect, has provision for on-site inspection. In Articles III, IV and V of the treaty "designated personnel" (belonging to the party not conducting the explosion) are allowed within the areas and locations associated with a peaceful nuclear explosion if the planned explosion yield is greater than 100 Kt but less than 150 Kt in order to check the yield. If the planned yield is greater than 150 Kt then designated personnel are allowed within the areas and locations to confirm that the circumstances are consistent with the stated peaceful purposes of the explosion. They are allowed to examine research and measurement data supplied by the party conducting the explosion and to examine rock core or rock fragments removed from emplacement holes. They are allowed to observe parts of the construction of the emplacement hole and to remove rock core or rock fragments from parts of the emplacement and exploratory holes. The designated personnel are allowed to observe the emplacement of each explosive and confirm the depth of emplacement and the stemming of each emplacement hole. For planned yields exceeding 150 Kt, the observers can use electrical and seismic equipment to determine the yield of the explosion. If the yield is planned to exceed 500 Kt the designated personnel may install a local seismic network (of a maximum number of seismic stations of the number of explosives plus five) within an area circumscribed by circles of radius 15 Km centred on the emplacement holes. The network can be installed no later than 20 days before the beginning of the emplacement and be in operation up to no more than 3 days following the explosion(s). Radio links can be used to transmit data and signals and designated personnel may take rapidly-developed photographs.

In 1985 eight South Pacific states signed the South Pacific Nuclear Free Zone in Rarotonga in which Article 8 establishes a control system for verifying compliance with treaty obligations. The control system includes data exchanges, the negotiation of IAEA safeguards and a complaints procedure. The complaints procedure contains a mechanism for on-site inspection. If, after consideration of a complaint and the explanation given, the Consultative Committee decides that there is sufficient substance in the complaint to warrant it, a special inspection on the territory of the party under investigation or elsewhere shall be carried out. The special inspection team shall comprise of three suitably qualified inspectors (with the proviso that none is a national of the party under investigation or a national of the complaining party) appointed by the Consultative Committee. Inspectors may be accompanied by representatives of the party under investigation and shall have full and free access to all information and places which may be relevant to the investigation. The inspector shall report directly to the Consultative Committee which would subsequently report to all members of the South Pacific Forum giving its decision on whether or not there has been compliance with the treaty.

The 1986 Stockholm Accord which is an agreement between 35 nations to notify each other of military exercises over certain sizes (depending on the type of exercise - Borawski, 1988) allows for both observation of the exercises and for inspection to check compliance with the agreement. The Stockholm inspection notice time is 36 hours maximum and the inspection duration is 48 hours with no more than 4 inspectors per inspection team. Inspection is permitted from the ground and from the air, the inspection team can divide into two parts and use maps, binoculars, cameras and dictaphones.

The 1987 INF treaty has extensive provision for on-site inspection. Inspections were carried out to verify the initial data exchange in the first two months of the treaty implementation period. Inspections are being made to witness the destruction of missiles, to check that bases have been closed as stated, to verify remaining numbers of missiles and two production facilities are continuously monitored. The challenge inspection notice is 16 hours before arrival in the host country and then, after arrival, between 4 and 24 hours to announce exactly where the inspection is to take place - the inspected side then has to transport the inspectors to the site within 9 hours. Up to 10 inspectors are allowed on a challenge inspection team and they may bring tape measures, cameras, portable weighing devices, radiation detectors and other equipment as agreed by the parties. The procedure for further agreement and discrepancies is the Special Verification Commission which meets in Geneva.

Treaties and agreements which are currently under negotiation such as the multilateral Chemical Weapons Convention, the bilateral Strategic Arms Reduction Treaty and the multilateral (23 nations) Conventional Forces in Europe Treaty all contain provisions and agreements in principle for on-site inspections.

3. Technical Considerations in OSI

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 (Heckrotte 1988) 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.

3.1 Overhead Observation

Assuming the worst case - that the ambiguous event is located only within a few hundred square kilometres - there are steps that can be taken before any on-site inspection takes place (these steps would have to be made quickly, in order for inspectors to then get to the location as soon as possible to make maximum use of any after shocks which could be detected on-site).

It would be advantageous to buy in or commission satellite images of the area under scrutiny. For best results there should be at least two images - one taken of the area before the event and at least one taken after. This may not be possible - there may not exist any pictures of the area in the archives. In any case it could be useful to commission a satellite image of the region immediately (see sections on satellite monitoring).

In addition, or as an alternative, an aerial overflight of the area (similar to "Open Skies" overflights) could be initiated. The overflight would be able to photograph a large part of the area under observation and help ascertain, in the same way as satellite imagery, where, if any, events have taken place. Observers on the overflight would also be able to survey the area looking for signs of drilling, unexpected activity, unusual geological features etc.

Images or photographs can help identify surface dislocations, surface disturbances and deformations, signs of recent activity etc. (see satellite section). 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. Airborne radiation monitoring is expensive. Assuming a medium size NaI crystal for gamma-ray spectroscopy, the cost would be approximately US$ 250,000. 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 in the rocks are gaining in popularity for geological surveys.

In addition an overflight 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. The notice required for an overflight need not be long (of the order of a few hours).

3.2 After-shocks

With the help of images, inspectors would be better able to locate the event with the aid of aftershock measurements. After-shocks are seismic disturbances which follow both explosions and earthquakes, the strength and rate of the after-shocks being dependent on the strength of the event. The after-shock waveforms from underground explosions and from earthquakes differ and, depending on the magnitude of the shocks, it could be possible to discriminate between the two. Deep aftershocks (at depths of several kilometres) would indicate that the event was an earthquake. In addition, because the location of after-shocks following an explosion tend to be around the cavity or chimney produced by the explosion, this feature would help to discriminate between an underground explosion and an earthquake - if the aftershocks clearly emanated from point located some hundreds of metres below the surface, then this would be an indication of an explosion.

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. The number of seismic detectors would depend on the strength of the signals, the size of the area to be investigated and the propagation properties of the ground. Inspectors would have to make decisions on the types and numbers of detectors to take immediately prior to the inspections. The seismic data would have to be recorded over a period ranging from a few days to a few weeks. It would be possible to leave the detectors (if suitably sealed and tamper indicating) in place and return at the end of a long period to collect recorded data or to have the data transmitted in near real-time. The seismic detectors would be removed at the end of the necessary period, although one or more could be left in place as part of confidence-building so that a potential evader would be less likely to use the site in the future. Portable seismic detectors would cost about US$ 45,000 for 24 channels or can be rented at about US$ 180 per day.

3.3 Seismic sounding for cavities

Underground nuclear explosions leave cavities and chimneys (size and type depending on the size and type of explosion) in the ground, which act as dislocations in the surrounding rock structure. In an area where many of the features indicate a possible underground explosion (e.g. after-shocks emanating from one place, radioactive traces in surrounding air or soil, signs of recent activity etc.) then it would be advantageous to carry out a seismic sounding. This technique, using the passage and reflection of seismic signals produced by the scientific team, provides a picture of below-ground features. Large cavities or chimneys would show as discontinuities in the picture. The seismic sounding equipment is portable, it consists of geophones, cabling, commercial explosives (a light drilling rig is then needed) and a recording truck, and the results can be analysed in situ. The main disadvantage of this technique is that it is slow - about 1 - 3 km per day along linear profiles can be covered - therefore it can only be useful if the location is known to within a few km. Portable seismic sounding equipment would cost in the region of US$ 60,000 - US$ 100,000, including accessories and software. Tomographic techniques can also be used if there are boreholes available (already in existence or allowed to be drilled). These techniques could add on up to US$ 25,000 for software to build up a 3-dimensional image.

3.4 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. There are three main techniques which have application. One is the Resistivity Technique which requires electrodes and an a.c. current (which can be produced by either a portable battery pack or a portable generator). The depth to which this technique can penetrate is up to approximately 70 m and the cost of the equipment is approximately US$ 10,000- 20,000. Another is the Geomagnetic Sounding Method, in which changing magnetic fields (produced or natural) induce electric fields. Both fields are monitored and the cost of this sort of equipment is approximately US$10,000 The third technique is that of Electromagnetic Methods in which a primary coil produces a primary magnetic field which induces a magnetic field in a receiving coil. There is quite a range of equipment available for this technique. Depending on the depth of penetration required, the costs range from US$ 80,000 - 100,000. Equipment for measuring electrical conductivity is portable and because the techniques are designed to spot anomalies, the analysis can be done in situ. Depending on the size of the area under investigation, these measurements could be carried out in a few days. Again as with seismic sounding tomographic techniques to build up threedimensional images can be used which would add some US$ 25,000 to the cost for software.

3.5 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 (such as Iodine-131, Strontium-90, Tungsten-181, Tungsten-185 and Caesium-137) would be a unique indication that a nuclear explosion has occurred. The absence of radioactive nucleides, however, does not prove that a nuclear explosion has not occurred, rather it may just indicate that the radiation survey was not in the right area or that an underground explosion was well contained. Ground-based portable gamma-ray spectrometers would cost approximately US$ 15,000.

Soil sampling for radioactive nucleides

Samples of soil at locations under investigation could be taken away for analysis. Revelations of radioactive gases seeping through fissures in the ground or through permeable rock could be evident in the soil samples. Similarly samples of vegetation, water, small animals and sub-surface gas should be obtained and analysed. Much of the findings from analysis would depend on the containment of any underground explosion, on the surrounding rock structure and permeability and on the length of time since the explosion.

Portable radiation detectors

Inspectors could carry hand-held radiation monitors to scan the region under investigation. Leaked gas may well be discovered through the use of these detectors, although the technique is not as sensitive as laboratory analysis of samples. The simplest of radiation detectors would just indicate the presence of radioactivity, more sophisticated scanners, complete with spectrum analysers, would also be able to reveal the types of radioactive nucleides and their relative concentrations in situ.

Drilling

Drilling into a cavity is 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 and to locations at which the drilling presents little radiation hazard. 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.

3.6 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.

3.7 The Vela Program for On-site Inspection Methods

Between 1960 and 1963 the USA, under the auspices of the Vela Program, conducted a research project on on-site inspection methods for nuclear test ban verification (Romney 1990, p 61). On-site inspection was conceived in three phases: aerial, surface and subsurface. The area for investigation was estimated to be some 500 km^2 and so the essential first step was to reduce the area for inspections. Aerial sensing techniques seemed to be the best method for this first step and the aim was to reduce the target area of ground inspections to an area of 1 or 2 km^2.

The main technical elements of the programme were:

(i) changes in the surface of the earth - technologies included multispectral photography, photogrammetry and visual inspection

(ii) aftershock monitoring - using seismic detection

(iii) seismic exploration techniques - to locate cavities or crushed zones of rock

(iv) geophysical exploration techniques - electrical, magnetic and gravity surveys to locate cavities and crushed zones

(v) ground inspection - searching for crevices, sampling for radioactive gases, searching tell tale signs in the soil and in the local plant and animal life.

After conclusion of the project the results which were presented to the US Congress contained the following conclusions (Romney 1990, p 64, Dahlman and Israelson 1977, p 327):

1. Research has shown that of all the on-site inspection techniques studied only two appear to be useful: visual inspection and radiochemical analysis

2. Deep burial of the explosion will prevent surface disturbances and seepage of radioactive gases to the surface.

3. Nevertheless, on-site inspection techniques could be a deterrent because of the evader's fear of miscalculations and mistakes.

4. Search rates will probably be slow - Reconnaissance: 14 unit-days to find 90 to 100 sites in 250 km, and Detailed search: 8.4 unit hours per site

5. Gas sampling is slow - 3 samples per site, 12 samples per day per two-man team

6. Because search and sampling rates are low, accurate seismic location would be needed to reduce the area to be inspected and to ensure that the epicentre lies in the area to be inspected.

4. Operational Aspects of On-site Inspections

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. This sort of inspection is routine in nature and contains no element of challenge.

2. The integrity and operation of in-place detection equipment would need to be checked periodically. These inspections would be random and routine in nature. There would be no element of challenge, although if evidence of tampering with the equipment were discovered on such an inspection, then the nature of the inspection would change.

3. For confidence-building purposes, there could be a number of routine visits to old nuclear test sites. Again these inspections would not contain any challenge, but their frequency could be random, so that it would not be known when they are due to occur.

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. These inspections will contain a degree of challenge. If the party under investigation has not contravened the treaty in any way, then generally that state should be relaxed about the inspection. If, however the party has something to hide then the inspection will not be welcomed. It must be realised that lack of welcome for an inspection does not necessarily imply that the treaty has been violated. There may be other reasons, entirely unconnected with a CTBT, which mean that the state is uncomfortable about an OSI.

4.1 Mandatory on-site inspections

There is a long and involved history over the issue of mandatory versus voluntary on-site inspections for a CTBT. Certainly, inspections types 1 - 3 above can all be mandatory with little sensitivity. In inspection type 4 - inspections triggered by an unexplained event or by unusual activities - there may be problems with issues oi national sensitivity.

These inspections, which contain an element of challenge, are the most important inspections and should not be open to political wranglings and sensitivities. It is at this point that the differences between inspections carried out by an agency for the monitoring of a CTB and inspections carried out by challenging countries becomes clear. As with the International Atomic Energy Agency, inspections carried out by agency inspectors are not as open to accusations of espionage as are inspections carried out by individual countries. An inspection carried out by an International Test Ban Agency could be mandatory with there being less fear and concern over espionage. If there are sensitive areas and facilities in the region to be inspected, then negotiations for access can be made between the agency or the inspected Party and the inspecting team and the inspected Party on arrival. In the case of a non-centralised framework for the verification of a CTBT, mandatory OSI would obviously be an opportunity for collateral intelligence gathering. The way around this is to not have the States Parties carry out their own inspections and send their own inspectors, but have the Technical Committee set up a Committee of Experts who act as inspectors for the States. However several states could request inspections by the Committee of Experts to several different places at once, this could make the on-site inspections unworkable.

4.2 Procedures for Inspections

There are two main types of inspections for a CTBT, one is the (random or ad hoc) routine inspection the other is the special (challenge) inspection.

The routine inspections - to check equipment, witness notified chemical explosions etc. - are low-key and carry few political difficulties with them. The special inspections arise because of anomalous events detected on the seismic, radioactivity networks or observed on overhead images.

Special inspections require a number of techniques as outlined above. The measurements of aftershocks, which is an important technique for on-site inspection, need to be conducted very soon after the event because they decrease in magnitude over a short period of time. Consequently the procedures for calling an on-site inspection have to be speedy.

A central monitoring agency which would be responsible for collecting data from the detector networks, for buying satellite imagery and for carrying out on-site inspections could respond very quickly to an event which warranted immediate investigation. A decentralised process, which required a consultative body (of all the States Parties) to decide on whether or not to carry out an on-site inspection, which would rely on data provided by a technical committee, would be slower in response. Because a request for an on-site inspection would come from one of the States Parties (and hence there would be many political sensitivities) it may be impossible for the consultative body to reach a decision in time to carry out aftershock measurements and so valuable data would be lost.

4.3 Numbers of inspectors

The numbers of inspectors needed for on-site inspections would depend on the type of inspection to be made. For simple checking of equipment or witnessing a notified chemical explosion, very few (of the order of two) inspectors would be required. For routine inspections of old nuclear test sites a larger number (say up to 10) would be required to cover the ground. For special inspections which called for aftershock measurements, seismic sounding measurements, electrical conductivity measurements, soil sampling, aerial overflights etc. a large number of inspectors would be required. In general, the larger the number of inspectors, the shorter the inspection period for a given size and type of area to be inspected, but very large numbers of inspectors would pose problems for the inspected Party in such matters as accommodation, catering and transport. A smaller number of inspectors for a longer time might put less strain on the resources of the host State. From discussions with practiced inspectors for verification of other treaties, it seems that numbers of up to 30 are manageable, beyond that the host country may find it difficult to accommodate all the inspectors.

4.4 Notice

The more notice a State Party has, the easier it is to remove evidence of any illicit activities. Notice should therefore be kept to a minimum. However some notice is obviously required to arrange escorts, transport, equipment, accommodation, catering etc. From discussions with those responsible for the operation of verification provisions for other treaties, 24 hours is the minimum time in which arrangements can be made. After notice has been given movements of vehicles around the site to be investigated should be prohibited. Aerial overflights and satellite observation could monitor the pre-inspection movement restrictions.

At the time of giving notice the reason for the inspection should be given. So should the place to be inspected, the duration of the inspection, the numbers and names of the inspectors and a comprehensive list of the equipment to be brought in (and installed) for the purposes of the inspection.

4.5 Quotas and inspection duration

How many inspections should a country be reasonably expected to accept on its territory per annum?

For routine (including ad hoc) inspections, the answer to this question is that it depends on the number of seismic detector stations and radioactivity detector stations the country has on its territory and on the number of large industrial explosions it carries out per year.

For special inspections it depends on two aspects. One is the number of anomalous events emanating from the country every year, the other is the type of verification framework. In the centralised model in which a monitoring agency is responsible for deciding whether or not to make an inspection, the number of special inspections will depend only on the scientific decisions. In the case of a decentralised decision-making process, one or more of the other Parties to the Treaty would request that the consultative body authorise an on-site inspection. In this case, as previously discussed, there are possibilities for mischief. It would be necessary then to restrict the number of special on-site inspections initiated by the same State Party that a country would have to receive each year.

Routine and ad hoc inspections should take less time than challenge inspections. Experience from the IAEA and other treaty verification regimes suggests that up to 72 hours is reasonable, although many inspections should take less time than that maximum.

For challenge OSI, the time duration would obviously be longer but it should be kept to a minimum. Up to 3 weeks (21 days) should allow enough install seismic equipment an carry out surveys. Inspectors can later return to collect equipment and data and carry out follow-on measurements. However this figure is somewhat arbitrary based on estimates made by geophysicists who carry out related work. Others (Heckrotte 1988) have the figure somewhat higher.

The passive quotas, that is the annual maximum numbers of OSI that each country would be obliged to accept would be dependent on several factors. For routine and ad hoc inspections the number would depend on the number of seismic stations and radioactive debris collection stations were installed on the territory of the state. An upper limit should be placed on the number of these inspections otherwise the regime could be unworkable and unacceptable. We suggest that, no matter how large the number of detecting stations as state party holds on its territory, there should be an upper limit of 10 ad hoc inspections and 20 routine inspections per year. For most countries with very few detecting stations this quota would be very much lower and could be lower than 1 per year.

Special or challenge inspections which should be only carried out to attempt to establish the cause of ambiguous seismic events, are very much longer in duration and more serious in implication than routine or ad hoc inspections. They should therefore be fewer in number and should have an upper limit placed on them so that the maximum number of challenge inspection days would not exceed 1/3 of a year. As we are suggesting that these inspections be up to 21 days in duration, we propose that no country be obliged to accept more than 5 challenge inspections per year.

5. Chemical explosions

Large industrial chemical explosions can create seismic signals which could appear to be possible nuclear tests. In addition a State could try to pass off a small underground nuclear explosion as an legal industrial explosion. In order to prevent this and in order to reduce the number of ambiguous seismic events per year, we suggest that dates and times of large chemical explosions be notified to the Agency or to the Secretariat (depending on the verification framework) in advance, so that inspectors can make a routine inspection to witness the legal explosion if necessary. Because chemical explosions are well coupled to the earth and because they are most likely to be mistaken for decoupled nuclear explosion, we suggest that all industrial explosions of over 3 tonnes yield be notified, at least 7 days in advance.

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V RADIATION MONITORING NETWORK

1. Introduction

Since nuclear weapons testing has been conducted underground, there have been a number of reported incidents of accidental and non-accidental release of radioactivity into the atmosphere. Many underground tests in the USA and USSR have vented radioactivity and on several occasions debris has been detected beyond national borders (Fetter, S. 1988).

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. Called RIMNET, it consists of a network of 46 stations which transmit data on radiation levels to a central point. A rainwater collection system is currently under development for use in the RIMNET network. 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.

The Harwell Laboratory, UK, operates a worldwide network of air and rain sampling stations for monitoring levels of radioactivity in the atmosphere. In operation for more than thirty years, the results are published annually in a series of reports. The programme has been designed primarily to provide a regular inventory of nuclear weapons test debris (Cambray 1988 p19) and the information it provides is used to:

1) assess population doses

2) study the relationship between deposition and levels in food, people etc.

3) study atmospheric mechanisms on a world-wide scale

4) provide background data for assessing results from studies around nuclear installations

5) detect releases of radioactivity into the atmosphere (from underground nuclear weapons tests that vent to the atmosphere, either planned or unplanned, and from nuclear installations)

2. The Harwell Worldwide Network

Table 1 and 2 list the stations on the worldwide network.

2.1 Methods of Sampling and Analysis

2.1.1 Sampling particles in the air and rain

Throughout the network (see Table 1 below), airborne particulate is sampled continuously at one metre above ground by passing appropriate quantities of air through polystyrene-fiber or polycarbonate-fibre filters. The mass of air sampled is approximately 2,000 kg/day at all stations except Chilton which is normally 10,000 kg/day.

The filter efficiency has been shown to be essentially 100% for particles in the size range 0.01 to 1.0μm (Cambray 1988 p21). Air is pumped through the filters at a rate of 15000 m^3/min. The filters have to be changed frequently (once a week or more). The uncertainty in the individual measurements of radioactivity in the air depends on uncertainties in airflow, sampling statistics and analytical uncertainties. The overall uncertainty is estimated to be less than 20%. Large particles are limited in their ability to follow a moving airstream, and the Harwell sampler is said not be able to collect representative samples when a significant proportion of the mass of the particulate material is in the range above 10μm in average wind conditions.

Rainwater samples are collected by plastic funnels mounted above polythene bottles which contain carrier solution to reduce loss by adsorption and allow the chemical yield to be calculated. When the precipitation is mainly as snow, high-walled pots of polythene or stainless-steel are used (Cambray, Playford, Lewis and Carpenter, 1989).

Analysis is performed, in a laboratory, either by gamma-ray spectrometry or by radiochemical methods. Strontium-90 determinations are performed on quarterly rainwater samples from certain stations in the United Kingdom. Tritium analyses are performed by the Nuclear Physics Division using electrolysis and gas proportional counting on rainwater samples from three stations in the UK.

Whilst it may not be appropriate for the verification system of a global CTBT to use data from a UK laboratory world-wide network, although the data is available to the public, 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.

We estimate that a network could be run on an annual budget of about US$ 1,000,000 per annum. Charges could be reduced if stationing countries were prepared to absorb some of the running costs such as manpower, electricity and postage of filters etc. To set up a station and run it for one year commercial charges would be approximately US$20,000, however setting up stations independently would result in reducing that figure by a factor between 2 - 4.

3. Remote Atmospheric Monitoring

A remote atmospheric monitoring project that uses a commercial satellite link to relay gamma radiation spectral data to a central facility for analysis has been under development by Sandia National Laboratory, USA.

A gamma spectrum is measured in the field and the resulting data are returned when the station is queried by the central station. The project uses calibrated sodium iodide (thallium doped) crystal detectors for spectral analysis, the outputs from which go to multichannel analysers using specially written software. The central computer communicates with the satellite computer every two hours to retrieve information. When a spectrum is complete, analysis is begun automatically. The standard counting period is one day and another day is required to complete the transmission across the satellite link. Field trials are underway at Perth, Australia, Cape Grim, Tasmania, Wellington, New Zealand and Norfolk Island. It is perhaps too early to say yet whether such a system is applicable on a worldwide scale, but further development of the network could prove to be useful.

4. Radiation Monitoring by Satellite

In the 1960s the USA began designing satellite based radiation detectors for verification, by National Technical Means, of the 1963 LTBT. The instrumentation included X-ray detectors, optical detectors and Electromagnetic-pulse detectors. These sensors are now scheduled for placement on the Global Positioning System (NAVSTAR) satellites in the 1990s. As such radiation monitoring by satellite has only a limited role in the verification of a CTBT. The technologies could be useful if the data they collected were made available to the Central Monitoring Agency or to a Technical Committee or if satellites were owned an operated by a Central Monitoring Agency which could be kitted out with radiation detectors.

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The Harwell Sampling Network Locations

Table 1 Airborne Dust

Station (ground level)	Sampling Frequency	Sampling Commenced
Lerwick, Scotland	Weekly	Sept 1962
Eskdalemuir, Dumfries	Weekly	Aug 1960
Conlig, Co. Down	Monthly	Jan 1986
Orfordness, Suffolk	Weekly	July 1961
Milford Haven, Dyfed	Weekly	Aug 1959
Chilton, Oxon	Daily, Weekly and Monthly	Jan,1952
Compton, Oxon	Weekly	Nov 1979
Tromso, Norway	Weekly	June 1977
Gibraltar	Weekly	Sept 1964
Hong Kong	Weekly	Sept 1961
Singapore	Weekly	Jan 1978
Darwin, Australia	Weekly	Jan 1978
Gaborone, Botswana	Weekly	Oct 1981
Pretoria, South Africa	Weekly	July 1965
Aspendale, Australia	Weekly	Feb 1966
Ohakea, New Zealand	Weekly	Jan 1978
Stanley, Falkland Is	Weekly	Sept 1979
Argentine Is, Antarctica	Weekly	Feb 1978

Table 2 Rainwater Sampling

Station (ground level)	Sampling Frequency	Sampling Commenced
Lerwick, Scotland	3-monthly	Oct 1962
Eskdalemuir, Dumfries	3-monthly	Oct 1962
Aldergrove, Antrim	3-monthly	Sept 1961
Conlig, Co. Down	Monthly	Jan 1986
Snowdon, Gwynedd	3-monthly	Oct 1956
Orfordness, Suffolk	3-monthly	Jan 1957
Milford Haven, Dyfed	monthly and 3-monthly	Aug,1959
Chilton, Oxon	Daily, Weekly,Monthly and 3-monthly	Jan,1952
Compton, Oxon	3-monthly	Nov 1979
Tromso, Norway	3-monthly	July 1957
Reykjavik, Iceland	3-monthly	Apr 1958
Esquimalt, Canada	3-monthly	Oct 1957
Ottawa, Canada	3-monthly	July 1957
Gibraltar	3-monthly	July 1955
Akrotiri, Cyprus	3-monthly	Apr 1959
Nassau, Bahamas	3-monthly	Apr 1962
Hong Kong	3-monthly	Apr 1962
Singapore	3-monthly	July 1955
Gaborone, Botswana	3-monthly	Oct 1986
Pretoria, South Africa	3-monthly	Apr 1965
Brisbane, Australia	3-monthly	Jan 1964
Melbourne, Australia	3-monthly	Jan 1956
Ohakea, New Zealand	3-monthly	Jan 1978
Stanley, Falkland Is	3-monthly	Feb 1956
Argentine Is, Antarctica	3-monthly	Jan 1964
Halley Bay, Antarctica	3-monthly	July 1964

Chapter 4

OPERATIONAL CONSIDERATIONS

4.1 Agreed Requirements

Although there may be differences of opinion regarding a few aspects of these proposals, all the scientists consulted on this study are agreed on three critical requirements for verifying a CTBT:

i) having different means of detection available to enhance confidence levels in the capability of deterring potential violation,

ii) the principle of data collected for the purpose of verifying a Comprehensive Test Ban Treaty being open to inspection by any Party, and

iii) a requirement from the Parties to supply specific geological and industrial data to facilitate verification.

4.2 Synergetic Detection Technologies

The principle behind the first requirement is that deterrence can most effectively be reinforced to a high level of confidence if data which suggest a potential violation can be cross-checked using other detection technologies.

Thus for example, if seismological detectors and radioactivity detectors both suggest a possible violation, the commission of data collection by a satellite could produce a high enough level of confidence either to declare that the event was unlikely to be a violation or to request an extensive on-site inspection and/or aerial survey.

Although single ambiguous or anomalous events will be monitored, it is a series of events or possible violations which require the highest level of confidence in the detection capabilities of the system.

4.3 Two Options on Organisation of Verification Procedures

To be effective as a deterrent at a high level of confidence, procedures for data collection need to be fast, efficient, and thorough. This is quite a new field for international co-operation and heavy reliance is placed upon the experience of the International Atomic Energy Agency (IAEA), recent work on the Chemical Weapons Convention (CWC) which is currently under negotiation, and the proposals embodied in the "Draft Treaty Banning Any Nuclear Weapon Test Explosion in Any Environment" proposed to the Conference on Disarmament in Geneva by the Swedish government (CD/381) on 14 June 1983.

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. Since the results of some technologies of data collection can be shared more easily than others, this study looked at two different types of procedure and organisation for the verification of this Treaty as amended. One is a decentralised model of data exchange which embodies most of the proposals put forward by Sweden in 1983, the other is a centralised model with a monitoring Agency empowered to collect and verify the relevant data based on the workings of the IAEA and the proposed CWC. The two models are contained as Appendix One and Two.

Both centralised and decentralised models rely upon the Parties undertaking to exchange any information which may be required to verify this Treaty through a nominated National Body. Both regimes would have a Consultative Committee on which all Parties to the Treaty would have the right to have a representative, and a Technical Committee drawn, in part, from the existing Group of Scientific Experts (GSE) attached to the Conference on Disarmament (CD) in Geneva.

The decentralised procedure, as proposed by Sweden in 1983 under rather different international conditions than those which exist today, relies upon the free exchange of seismological data at the meetings of the Consultative Committee where common standards for collection and storage of relevant data would be discussed and agreed. The Consultative Committee which would also act a channel for OSI requests by individual parties, would be supported by a permanent Secretariat and an advisory Technical Experts Group (Technical Committee).

The Technical Committee would suggest procedures for data collection/storage including the development of new parts of the verification network (including data transmission) as technical options to be accepted or rejected by the Consultative Committee. The Secretariat would carry out all administration, including that required for OSIs, monitor the status of existing seismic stations, agree data storage at International Data Centres and liaise with the nominated National Body representing each Party.

Under a centralised procedure, a Central Monitoring Agency (CMA) would be responsible to the Consultative Committee for implementing verification procedures, according to technical standards agreed with the Technical Committee. 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.

The main difference between the CMA and the combination of Secretariat, Consultative Committee and Technical Committee is the relative autonomy and independence of the CMA. In one sense the CMA could be compared to the IAEA because its day-to-day procedures would be determined by the Agency within a framework set out by the participating states. This would allow the Agency a flexibility and independence that the Secretariat would not have. The decision to carry out an on-site inspection, for instance, could be made quickly by the Agency and be based solely on technical information. The same decision of the Secretariat would involve lengthy time delays to allow consultation with the consultative and technical committees and the initiative for the process would come from one of the parties (the Swedish 1983 Draft Treaty proposes that up to one month be allowed after the party under investigation has agreed to accept the (non-mandatory) on-site inspection). 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.

4.4 Procedural Efficiency

The relatively free exchange of geological data essential to the decentralised model is quite well-established, if only because seismic signals are no respecters of national boundaries and have considerable significance outside defence interests. However, there is no comparable availability of useable satellite imagery, and these data are neither freely available to check against data obtained from seismology, nor are they likely to become available without a specific treaty obligation.

Incorporating remote sensing data into a decentralised verification system, which relies on the voluntary exchange of geological data could be impractical. The only way in which it could work, for those states without a present capability would be for each nation to build its own satellite system (maybe in cooperation with other states) or commission and purchase its own images from a commercial satellite image company. Images from commercial satellites bought by states party to the treaty could be shown to other states to support the compliance decision of the purchasing state, otherwise data from satellites would be unlikely to be shared amongst the parties.

The essence of satellite observation is that it has to be intelligently tasked since the area of observation is a"postage stamp" of 60 km x 60 km or less, depending on the resolution of the imaging system of the platform - "the world is awfully big, and 60 km is awfully small"[1]. A passive system of remote observation by satellite, would present almost insurmountable problems in the amount of data assessment subsequently required to render it useful, in a way that the passive collection of seismological may not, given the increasing availability of mass storage systems for data recorded on-site.

Similarly it is thought unlikely that data from other forms of observation, currently being developed, such as ionospheric monitoring, could be incorporated into a decentralised data exchange system. Funding for the

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1 P Zimmerman, private communication

development of such techniques currently derives from national defence budgets, and whilst results might be exchanged bilaterally, individual Parties would be unlikely to want to give such information away to all other Parties, without seeing some kind of tangible return on their investment in the necessary research.

There is no suggestion that untried techniques should be written into the the Treaty, but there is every advantage in encouraging the development of as many different forms of verification as possible, to be available for use when they have been accepted by the international scientific community, who specialise in such matters. In addition these improvements could eventually save money and reduce the burden of personnel employed for verification.

A decentralised data-collection system with only nominal international supervision might work well in a permanently benign climate of international relations, but in a more adversarial context, accusations of data falsification would be very difficult to disprove and on-site inspections would be very difficult to organise efficiently.

Organisation of on-site inspections is a procedural nightmare. Within the decentralised framework it is hard to see how on-site inspections would be effective and credible. In the first instance the request for an on-site inspection would come from one of the parties to the treaty, it is easy to see how such a request could be construed as being political in nature and possibly even for espionage purposes. For that reason it would not be reasonable to make on-site inspections, within a decentralised framework, mandatory. If the party under investigation agrees to the request for an OSI then the Consultative Committee along with the Technical Committee would discuss with the Group of Experts how to go about the inspection. Seismic record would have to be analysed and a basis for the inspection would have to be agreed. Even assuming that the committees can meet with very little notice, the discussion procedure could be lengthy and it is easy to envisage that valuable time which could be used for measuring any aftershocks could be lost.

Within the centralised framework a decision to carry out a challenge on-site inspection would be made on the basis of scientific analysis of the seismic data, radiation network data or the overhead image data which would be routinely carried out by the Agency. The inspectors, not having to rely on convening an international committee could act quickly and give notice to inspect as soon as it was decided that an on-site inspection could help to resolve ambiguities in the data. The request to inspect would not be as politically charged if it came from the Agency than if it came from a participating state to the Consultative Committee.

4.5 Co-operation with the use of national technical means

Verification can best be assured if all the different types of data collected, and also perhaps any subsequent independent analysis of that data, is made available to any Party, so that they may compare it with their own (often confidential) data collected by national technical means.

The availability of such data would both reassure those few Parties with highly developed NTMs that multilateral measures of verifying the Treaty were adequate, and increase the chances of accurate assessment by all Parties of ambiguous events, which have in the past been the source of friction, as for example in arguments over compliance with the 1974 Threshold Test Ban Treaty.

4.6 Confidentiality of OSI Inspection Reports

The only data which might be kept confidential could be part of the reports from inspectors at on-site inspections. These reports would have two parts:

1. A factual public statement of what observations were made and the resulting data, countersigned by the party on whose territory they took place;

2. A confidential report to the Director-General of the Agency or to the Chair of the Consultative Committee which would contain observations on the cooperation of the host party, any extraneous observations that might point to a different conclusion than that of the open report. The purpose of this confidential report would be to allow the Director-General (Chair of Consultative Committee) to personally intervene with the host country so that similar problems are not encountered at a later date. It would also point out issues which may need to be raised within the Agency or with the Technical Committee in order to improve procedures.

4.7 Rights of Challengers to attend on-site inspections

The right of representatives of a nation who had called a challenge inspection to attend an OSI creates a number of problems, such as fear of espionage.

Such arrangements could therefore be left to bilateral arrangements between individual Parties. Under a centralised framework there would be no need for a requesting country in the first place as the initiative for the inspection should be taken by the Monitoring Agency as a result of information gathered by the monitoring network. If a state were to request the Agency to carry out an inspection then there should still be no need for that state to attend the inspection because the Agency inspectors would carry out the inspection on their behalf. However there should be nothing to prevent the requesting state attending the inspection if the inspected state has no objections.

In a decentralised framework the the Consultative Committee could post an annual list of experts from which an inspection team could be chosen with the minimum of reasonable objections from the Party being investigated. Again there should be nothing to prevent the requesting state attending the inspection if the inspected state has no objections.

4.8 Responsibilities of Parties to supply relevant data

If individual Parties have the right of open access to verification data they would also have the concomitant responsibility to provide geological, industrial and other relevant data. This should include large scale drilling operations, exact locations of previous test sites, including, possibly, a register of personnel concerned and notification of events likely to produce an ambiguous seismic signal such as salvo-fired chemical explosions over a certain magnitude in order to facilitate the process of verification and reduce the number of ambiguous or anomalous events.

4.9 Installation of detectors on existing sites

The suggestion from the Six Nation Initiative in the Ixtapa Statement (Six Nation Initiative, 1986) that internationally supervised seismic detectors be placed on uncollapsed underground sites previously used for nuclear testing is adopted and extended to include all previous underground nuclear test sites, since again it would reduce ambiguities and anomalies without being very expensive or particularly intrusive.

4.10 Costs as a function of certainty of detection

Increasing the level of confidence in verification through cross checking of the data obtained using different techniques has a significant financial implication. Generally speaking the higher the level of confidence obtained, the more extensive and expensive the technologies need to be. It is now technically possible to detect an explosion of any size (Dahlman, 1989), but below a certain magnitude, costs of equipment and data processing required for possible detection could be entirely disproportionate to the task.

This study has taken a fully decoupled nuclear explosion of 0.4kT as the lowest magnitude which a global seismic network ought to be able to detect. This is the smallest magnitude for a primary device which can be cited from declassified data, and it is also the size of the device tested in Salmon - Stirling test, the only experiment in decoupling a nuclear explosion known to have taken place.

Costs must not be underestimated. The time required for the interpretation of ambiguous signals recorded by seismic stations and the interpretation of multi-spectral images obtained by remote sensing is extensive and expensive, and images obtained by synthetic aperture radar (SAR) equipped satellites take about 9 times longer to analyse than conventional images. There is also some concern about the availability of trained personnel to undertake this interpretation but the availability of trained personnel on the labour market may increase.

While intelligent co-ordination of different techniques of detection could produce an acceptable level of verification at a reasonable cost, a high level of confidence in the data produced by a single technology (such as seismology) without sufficient reference to other detection methods is likely to have a very high and probably disproportionate cost.

4.11 Speed of Response

In order to maximise the deterrent capability of available detection methods, a rapid response to an ambiguous event or suspicious activity is essential. While seismic analysis and photo-interpretation are highly skilled and lengthy procedures (Marshall, Stewart and Lilwall 1989), if the initiation of any investigation were dependent upon an annual consultative committee meeting, this would probably allow adequate time for any potential violator to hide much, if not all, the useful evidence.

The same argument is applied to On-Site Inspection. Seismic aftershocks, potentially of considerable significance for discriminating between explosions and earthquakes need to be monitored very quickly, preferably within about two weeks of the event taking place, and ideally should be initiated within hours.

If a technically qualified director of the central organisation (be it Agency, technical committee or Secretariat) is empowered to order further investigation of an ambiguous event or suspicious circumstance, within a short time period, the detection and hence deterrent capability of the Treaty would be greatly enhanced.

4.12 Installation time required for a global CTB verification system

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 three years for this process should be built into the Treaty as amended. This could be done through an Instrument of Ratification which also includes provision for the nomination of a national body by each Party, to deal with technical relations between individual Parties and any central organisation.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

I Conclusions

1. A major concern of this work has been the long standing contention that a Comprehensive Test Ban is not verifiable. The main conclusion of this study, after a review of all the available evidence is that while this may be true if seismology is the only method of verification available, the current level of detection technologies is such that if they are taken together, a CTBT can be adequately and effectively verified providing that more than one type of data is used to monitor the Treaty.

2. 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.

3. 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 monitoring of airborne radioactivity. Active and passive monitoring of acoustic waves in the ionosphere and other detection techniques may be included in future, when they have been experimentally proven.

4. With an effective verification regime it is unlikely that any Party to a CTBT would undertake a series of undetected clandestine tests, knowing the high risk of discovery.

5. For a number of years, seismologists led by distinguished teams from Sweden and Canada have been proposing a seismological data exchange system which is similar to the information exchange undertaken by academics in the geological community. The underlying principle in this process is that the exchange of nationally-collected data will explain apparent anomalies by providing data that can be compared with and will complement that collected by states through their by national technical means.

6. As a confidence building measure, an international seismic data exchange system has many virtues. It will also produce much important data for the earth sciences, particularly since the idea of in-country seismic stations contributing to such a network is now generally acceptable.

7. However, it is clear that such an exchange of data will only function in an atmosphere of good will and could not be used to verify an international Treaty under adversarial conditions.

8. Further, such a data exchange system will operate effectively only where there is a large number of different input sources. This is certainly the case with seismology. Many nations require their own seismic detection networks for earth science research and/or monitoring of earthquakes and the principle of international co-operation in the collection of such data goes back almost to the beginning of this century.

9. With more recent technologies, however such as satellite observation, there is no such tradition of data exchange. The sale of such data, under circumscribed conditions, is only a very recent innovation depending on a commercial approach which has appeared as international tensions have begun to relax. Should international tensions return to their previous levels, the availability of such data may cease.

10. High Quality satellite data has been and will probably continue to be, one of the most expensive methods of non-intrusive data collection. Because of the sheer cost of the technology involved, it is very unlikely that such images collected by satellite will ever be generally shared. The same strictures may apply to other relevant forms of data collection, such as ionospheric monitoring.

11. The critical problem with a verification system depending upon free exchange of geological data is the question of on-site inspections (OSIs). A draft CTBT proposed by Sweden in 1983 made a series of suggestions about possible OSI techniques and suggested that an OSI would have to be agreed by a meeting of the Consultative Committee of all Parties. Because of the inevitable time delays involved, this cannot be regarded as a practical means of verifying a potential violation. OSIs depend for their effectiveness on being rapid, specific and discrete.

12. All the technologies other than seismology depend for their effectiveness on an organised and coordinated approach to data collection and analysis. In the case of satellites, for example, a data collection system without specific tasking would not be an adequate method of verification, because the amount of available data is potentially enormous, yet the amount of useful data is actually very small.

13. Effective verification using technologies, other than seismology, depends upon having an organisation, such as a Central Monitoring Agency, technically capable of organising the technological means available to search for useful and useable data. Such an Agency would not be responsible for any assessment on compliance, those decisions would rest with the States party to the Treaty.

14. The credibility of such an Agency's ability to detect potential violations would be a significant element in the deterrence of non-compliance. This has been the experience of the International Atomic Energy Agency which is now being incorporated into efforts to create a Chemical Weapons Convention.

II Recommendations

This study recommends that:

A. Seismic Network

* A global network of seismic detectors be installed to monitor seismic activity in the territories of States Party to a Comprehensive Test Ban Treaty.

* Seismic detectors should also be placed on the ocean floors.

* Wherever possible the seismic stations should be situated at locations already in use as seismic stations.

* The number and distribution of seismic stations should depend on:

  a. geological characteristics of the territories of the States Party to the Treaty.

  b. on the specifications of seismic stations available for installation in the network.

  c. the existence of sites previously used for the purposes of nuclear testing in the territories of the States Party to the Treaty.

  d. the availability of territory for stationing of seismic stations in a distributed global network.

* For immediate application the seismic network should consist of current off-the-shelf technology (9-element arrays of broad-band, 3-component, low-noise seismometers).

* Such stations may be up graded directly to a higher quality with the addition of a bore-hole site if they are in suitably quiet environments.

* The seismic network should consist, wherever possible, of the most up-to-date, bore-hole seismic stations.

* The number of seismic stations (including the ocean floors and continental shelves) shall be in the range of [520] to [3,100] in total, depending on the specifications of individual seismic detectors in the network.

* The network for immediate application would consist of less than 1,350 stations worldwide, including the ocean floors and continental shelves.

* There should generally be at be at least one seismic station on the territory of each state party to the Treaty.

* Where small countries, which have been assigned only one station, have no state parties adjacent to them, up to 3 seismic stations could be installed.

* In other cases where States Parties are neighbours less than one seismic station per state could be acceptable.

* The time allowed for installation and calibration of the seismic network should not be less than [2.5 years].

B Radioactivity monitoring network

* A global network of ground-based detectors be used to monitor radioactivity in the territories of States Party to the Treaty.

* Wherever possible the ground-based radioactivity monitors should be those already in existence in a global network.

C Observation by satellite

* Satellite imagery should be collected for the purposes of monitoring the Treaty.

* Data should also be obtained from radiation detectors installed on satellites, as available.

* Multispectral images should be taken routinely and randomly of a number of specific areas in the territories of the State Parties.

* If available, synthetic aperture radar images should be taken routinely and randomly of a number of specific areas in the territories of the State Parties.

* The number of sites which need to be monitored depends on:

  a. The number of sites previously used for the purposes of nuclear testing in the territories of the States Party to the Treaty

  b. The number of sites potentially capable of being used for the purposes of nuclear testing in the territories of the States Party to the Treaty

* The number of sites to be monitored routinely and randomly is expected to be about [20].

* In the event of unidentified and ambiguous events recorded on the seismic or radioactivity detection networks, satellite images (multispectral or radar) should be taken of the area from which the events are calculated to have originated.

* Prior to an on-site inspection, satellite images should be provided to the inspectors to aid them in location techniques.

* If possible, that there be a cost-effective dedicated imaging satellite system for the purposes of monitoring the Treaty.

* The dedicated satellite system should have the capability to fulfill other (commercial) functions.

* If a dedicated satellite system is not possible, images should be bought and commissioned from commercial satellite agencies.

D On-site inspections

* On-site inspections are necessary for effective verification of a CTBT.

* There should be two types of on-site inspection

  a. Routine (and ad-hoc routine) inspections.

  b. Special (challenge) inspections.

* Routine/ad hoc inspections should be used for:

  - checking equipment

  - witnessing notified chemical explosions

  - checking that sites used previously as nuclear test sites are no longer functioning as such

  - checking that other sites are not being used as nuclear test sites

  - verifying information provided by the States Parties

* Special (challenge) inspections should be used for:

  - verifying information provided by the States Parties

  - identifying and verifying the cause of signals detected by the seismic and radioactivity detection network

* Notice for all on-site inspections should be [24] hours.

* Special inspections to identify and verify the cause of signals detected by the seismic and radioactivity detection network should take place as soon as is practical after the signals are detected.

* Special inspections should be carried out purely on scientific grounds.

* During on-site inspections, inspectors may:

(a) Examine records kept in pursuant to previous nuclear tests, drilling operations, chemical explosions and seismic detection.

(b) Make independent measurements.

(c) Take samples of gas, water, rock, soil, vegetation and animal life in the area under investigation, provide similar samples to the inspected party and take samples away for analysis.

(d) Verify the functioning and calibration of instruments and other equipment.

(e) Apply and make use of surveillance measures.

(f) Use aircraft to fly over and survey the area under inspection.

(g) Install new equipment.

(h) Apply seals and other identifying and tamper indicating devices.

(i) Calibrate and re-calibrate equipment.

(j) Arrange for the shipping of samples and equipment.

(k) Use other methods considered to be technically feasible.

* There should be two levels of on-site inspection report:

(a) A public report, detailing factual information about the inspection.

(b) A confidential report to the monitoring agency or to the committee in charge of on-site inspections.

E Data collection, correlation and analysis

* Data from all the collection and monitoring methods should be collected and analysed coherently and impartially.

* For scientifically correct analysis, the data should be collated, stored and analysed at a central point.

* For scientifically correct data collection, the initiation of on-site inspections should be carried out by an agency, which operates independently from the States Parties.

* For scientifically correct data collection, the decisions on which sites to monitor by satellite imaging should be made by an agency which operates independently from the States Parties.

* An agency should be created to monitor the Treaty, to collect and analyse the data to facilitate useful provision of the data to the States Parties.

* The final decisions on compliance should not rest with Agency, rather those decisions are national decisions and should be made by the States

Parties in the light of information collected and disseminated by the Monitoring Agency.

F Improvement of monitoring techniques

* There should be provision in the Treaty to allow improvements to the technologies and methods used to monitor compliance.

* There should be provision in the Treaty to allow the introduction, with the agreement of States Parties, of new technologies and methods to monitor compliance.

* There should be a budget made available for research into new techniques which may be useful for monitoring compliance.

Appendix 1

An illustration of a verification protocol in a centralised framework

Note

The following appendix, written by VERTIC, serves only as an illustration of how a verification regime might work in a centralised framework, under the auspices of a central monitoring agency. VERTIC recognises that the illustration is incomplete and is not at the standard of international law and asks that it should be read with that in mind.

FRAMEWORK PROTOCOL FOR CENTRALISED VERIFICATION OF A CTBT

Preamble:

This Treaty requires the establishment of a Central Monitoring Agency (Agency) by the Parties to provide technical verification of the provisions of this Treaty, and the establishment of a Consultative Committee to endorse the procedures and budget of that Agency, and a Technical Committee to advise the Consultative Committee on available technical choices.

Definitions

The term "Agency" means the Central Monitoring Agency, and any organisation seconded by it or to it.

The term "Director General" means the Director General of The Central Monitoring Agency.

The term "Nominated National Body" means the organ nominated by a State Party to act as the representative of the State Party to the Central Monitoring Agency.

The term "inspected Party" means the Party to the Treaty whose sites are subject to inspection.

The term "inspector" means an individual on one of the designated list of inspectors prepared by the Agency to conduct on-site inspections in accordance with the relevant provisions of the Treaty and who is also on the approved list of inspectors agreed by the parties

The term "inspection team" means the group of inspectors assigned by the Agency to conduct a particular inspection.

The term "inspection site" means the area, location or facility at which an inspection is carried out.

The term "period of inspection" means the period of time from arrival of the inspection team at the inspection site until its departure from the inspection site, exclusive of any pre- and post-inspection procedures.

The term "point of entry" means the airfield or airfields designated by each Party as the route of entry into the territory of that Party.

The term "in-country period" means the period of time from the arrival of the inspection team at the point of entry until its departure from the country through the point of entry.

The term "in-country escort" means individuals specified by the inspected Party to accompany and assist inspectors and aircrew members as necessary during the in-country period.

The term "aircrew member" means an individual who performs duties related to the operations of an aircraft used for transportation of an inspection team to a point of entry and who is on the list of designated Agency aircrew members.

1. Establishment of a Agency and Consultative Committee

1.1 Parties to the Treaty agree to the establishment of a Agency and agree to provide the Agency with the necessary financial, technical and diplomatic support as specified in this Treaty and in any associated annexes and appendices.

1.2 Not less than [three] weeks after this amendment has been accepted according to the terms of this Treaty, the Depositories, through the office of the Secretary General of the UN will advertise internally and externally to fill the post of Director General of the Agency and other necessary administrative and secretarial positions according to the usual terms and conditions of UN salary scales and appointments.

1.3 The activities of the Agency will be subject to the rulings of a Consultative Committee, on which all Parties will have the right to be represented by any individual nominated by the National Body named in the Instrument of Ratification of each Party.

1.4 All data collected by the Agency will be made available to any Party according to a scale of fees proposed by the Agency and agreed annually by the Consultative Committee. Any Party may buy any of this data for the sole purpose of that Party verifying the provisions of this Treaty using national technical means (NTMs) of verification.

1.5 The Agency shall provide an annual written report on its activities, to the Consultative Committee. This report must contain a description of all events investigated, whether by non-routine analysis or by on-site inspection.

1.6 The report shall also contain an itemisation of expenditure, a proposed budget for the next fiscal year with a list of any new equipment required, including a note of its cost, technical capabilities and limitations. The report shall also contain a proposed scale of fees for the provision of data and analysis to any Party. The report shall be endorsed or amended by the Consultative Committee.

1.7 Within three months after the appointment of a Director General, the Agency will formally ask members and observers of the Group of Scientific experts on the Conference on Disarmament, Geneva to nominate a list of people suitable to form the Technical Committee, who will then be approached by the Agency and asked if they would be willing to stand. Any Party to this Treaty may at this or any future time give to the Agency the name of any scientific expert they wish to join the Technical Committee. The Agency will then prepare a list of all scientific experts with their relevant experience and qualifications from all the names suggested to them and will circulate this list to all members of the Consultative Committee to be endorsed, agreed and if the meeting so decides, elected by due proportion of votes at the next meeting of the Consultative Committee.

1.8 Responsibilities of the Technical Committee shall include consulting with the Agency and advising the Consultative Committee on any technical proposals from the Agency for verifying the provisions of this Treaty.

2. Duties of the Agency

2.1 The Agency will be responsible for coordinating and monitoring data from a global seismic network for the purposes of verifying this Treaty according to the terms of Annexe One (A&B) of this. For this purpose the Agency will employ existing seismic stations, which have been checked and calibrated according to the procedures established by the agency and endorsed by the Parties through the Consultative Committee.

2.2 The Agency will also be responsible for the establishment of seismic stations on sites previously used for nuclear explosions by Parties to this Treaty. The Agency will also be responsible for the installation of seismic stations as part of a global network in areas where it deems the existing network is inadequate.

2.3 The Agency will also be responsible for the collection and analysis of appropriate data from Earth-orbiting satellites for the purpose of verifying this Treaty.

2.4 The Agency will also be responsible for the collection and analysis of appropriate data from a global network of sensors to detect radio-activity in the atmosphere for the purpose of verifying this Treaty.

2.5 The Agency will also be responsible for requesting information from the National Body nominated in the Instrument of Ratification of each Party in order to compile a list of chemical explosions or other activities which could give rise to suspicion of nuclear testing.

2.6 The Agency will also be responsible for the collection and analysis of appropriate data from on-site inspections in consultation with the nominated National Body of the Parties concerned. Such inspections may be either:

i) routine in the case of sites previously employed for nuclear explosions by Parties to this Treaty,

or ii) be challenge inspections initiated by any Party to this Treaty by a request to the Agency, and undertaken at the discretion of the Agency,

or iii) be initiated by the Agency in order to further analysis of ambiguous or anomalous events.

The names of individuals entitled to undertake such inspections, whether routine or challenge, shall be proposed by the Agency and individual Parties and endorsed or rejected annually by the Consultative Committee.

3. Installation of a Global Seismic Network

3.1 The Agency will co-ordinate and regulate the collection of data from seismic stations on the territory of any Party according to the provisions of Annexe One of this Treaty. The Agency will propose and execute the installation of any new equipment on existing seismic stations on the territory of any Party for the purpose of verifying this Treaty in consultation with the National Body nominated by each Party in the Instrument of Ratification.

3.2 The Agency will establish new seismic stations on sites previously used for nuclear explosions by any Party as necessary to verify the provisions of this Treaty.

3.3 The Agency will establish any new seismic stations on any territory of any Party as necessary to verify the provisions of this Treaty in consultation with the nominated National Body of that Party.

3.4 The Agency will establish a data storage and communication system for all data produced by the seismic stations used to verify the provisions of this Treaty.

3.5 The Agency may request from any Party geological information available in the public domain which relates to the territory of that Party, through the nominated National Body of that Party.

3.6 The Agency will receive, store, process and analyze data received to verify that the provisions of this Treaty are honoured by all Parties. The Agency will make that data and its analysis available to any Party, on request, according to a scale of fees endorsed annually by the Consultative Committee.

3.7 The Agency will receive advance notification from the nominated National Body of any Party of any event, such as a planned chemical explosion, likely to generate an anomalous seismic signal on the territory of that Party. In the event of an accident which generates an anomalous or ambiguous seismic signal, the nominated National Body shall inform the Agency as soon as possible. The Agency will compile a list of such events to be made available, on request, to any Party to this Treaty.

3.8 The Agency will also compile a list of the locations of current commercial drilling activities on the territory of any Party from information supplied by the nominated National Body of that Party.

3.9 The Agency shall analyse any seismic event which it regards as anomalous in consultation with the nominated National Body of the Party on whose territory the event has occurred. If, after such consultation, the Agency still regards the event as sufficiently anomalous to give rise to suspicions of clandestine testing of nuclear explosives, it may initiate an on-site inspection according to the terms of Annexe Two of this Treaty.

4. Data collected from Earth orbiting satellites

Within a period of not more than one year, the Agency shall prepare and circulate a report to the Consultative Committee not less than three months before the next meeting of that Committee on the purchase of data from any agency willing to supply images obtained by remote inspection (satellites):

This report shall include an assessment of:

i) Available specifications and estimated costs per image of remote optical (multi-spectral) observation,

and ii) Available specifications and estimated costs per image of remote synthetic aperture radar observation,

and iii) Estimated time and cost of analysis of both types of image,

and iv) Estimated cost of equipment required to analyse such data,

and v) Current limitations on geographical availability of images, listed by the agency willing to supply them.

At the same time the Agency will prepare and circulate a report to the Consultative Committee which outlines the costs and dis/advantages of a dedicated system of remote inspection. This report will cover *inter alia:*

i) Possible specifications and estimated related costs of equipment for remote optical (multi-spectral) observation and image transmission to a central data base,

and ii) Qualifications and estimated related costs of technicians required to process remote optical (multi-spectral) observation

and iii) Possible specifications and estimated related costs of equipment for remote synthetic aperture radar observation and image transmission to a central data base,

and iv) Qualifications and estimated related costs of personnel required to process remote synthetic aperture radar observation,

and v) Specific options of sharing the costs and availability of such systems with other international agencies.

In the conclusion of its report the Agency shall recommend a specific option or series of options which shall be endorsed, amended or rejected by the Consultative Committee. If its recommendation is rejected, the Agency shall prepare a further recommendation to be circulated not less than three months before the next meeting of the Consultative Committee for the consideration of the Committee, until agreement is reached.

5. Data collection from ground-based sensors to detect airborne radioactivity

5.1 The Agency shall operate a network of ground-based sensors to detect radioactivity and radioactive debris in the atmosphere.

5.2 The radioactivity detector network shall be operated in conjunction with the seismic monitoring network.

5.3 Data from the radiation and radioactivity monitoring network shall be analysed by the

Agency in conjunction with data obtained from the seismic detection network.

6. Data collection from on-site inspections

General

The Agency shall have the right to make inspections as provided in the paragraphs below.

Purposes of inspections

6.1 The Agency may make ad hoc inspections in order to:

(a) Verify that previous nuclear testing sites are no longer functioning as such

(b) Verify that other sites are not operating as nuclear test sites

(c) Verify the integrity of detection equipment operated by the agency

6.2 The Agency may make routine inspections to:

(a) Verify that previous nuclear testing sites are no longer functioning as such

(b) Verify the integrity of detection equipment operated by the agency

(c) Observe the operation of conventional chemical explosions as notified by State Parties to the Agency through the Nominated National Body.

6.3 The Agency may make special inspections to:

(a) Identify and verify the cause of signals detected by the detection network operated by the agency

(b) Verify information given to the Agency by State Parties.

Scope of inspections

6.4 For the purpose stated in paragraphs 1 to 3 (above) the Agency may:

(a) Examine records kept pursuant to previous nuclear tests, drilling operations, chemical explosions and seismic detection.

(b) Make independent measurements

(c) Take samples of gas, water, rock, soil, vegetation and animal life in the area under investigation, provide similar samples to the inspected party and take samples away for analysis.

(d) Verify the functioning and calibration of instruments and other equipment owned or operated by the Agency.

(e) Apply and make use of surveillance measures

(f) Use aircraft to fly over and survey the area under inspection

(g) Install new equipment

(h) Apply seals and other identifying and tamper indicating devices

(i) Calibrate and re-calibrate equipment

(j) Arrange for the shipping of samples and equipment taken for the Agency's use.

(k) Use other methods considered to be technically feasible by the Agency.

6.5 The inspection team may bring onto the inspection site such documents and equipment as needed to conduct the particular type of inspection. All equipment shall be operated by the inspection team.

6.6 In the case of equipment designed for measurement, no calibration settings may be altered or reset during the period of inspection by any personnel other than those of the inspecting party. The inspected Party may provide items with known measurable properties in order that equipment calibration may be verified.

6.7 Measurements recorded during inspections shall be certified by the signature of a member of the inspection team and a member of the in-country escort at the time the measurements are taken. All such certified measurements shall be included in the inspection report as in paragraph 45.

6.8 Inspectors shall have the right to request clarifications in connection with ambiguities that arise during an inspection. Such requests shall be made promptly through the in-country escort to the Nominated National Body.

Access for inspections

6.9 The Agency inspectors shall have access to:

(a) Any location where Agency equipment is stationed

(b) Any location where a notified chemical explosion takes place

(c) Any location which is subject to a special inspection as stated in paragraph 3 above

Frequency, intensity and duration of inspections

6.10 The number, intensity, duration and timing of inspections shall be kept to the minimum consistent with procedures for effective verification set forth herein and the Agency shall make the optimum and most economical use of available inspection resources.

6.11 The number, intensity duration timing and mode of inspections shall be determined on the basis that the inspection régime shall be no more intensive than is necessary and sufficient to monitor and verify the treaty.

6.12 Routine inspections shall be of a duration of less than or equal to [72 hours]

6.13 Ad hoc inspections shall be of a duration of less than or equal to [72 hours]

6.14 Special inspections shall be of a duration of less than or equal to [21 days]

6.15 For ad hoc inspections the number of inspectors shall be less than or equal to [10]

6.16 For routine inspections the number of inspectors shall be less than or equal to [10]

6.17 For special inspections the number of inspectors shall be less than or equal to [30]

6.18 No Party will be obliged to receive more than [10] ad hoc inspections per annum

6.19 No Party will be obliged to receive more than [20] routine inspections per annum

6.20 No Party will be obliged to receive more than [5] special inspections per annum

Notice of Inspections

6.21 Notification of intention to conduct an inspection shall be made by the Agency to the Nominated National Body. The receipt of this notification shall be acknowledged within one hour of receipt.

6.22 The Agency shall give advance notice to the state before arrival of inspectors:

(a) For ad hoc inspections pursuant to paragraph 1 above, the notice shall be at least 24 hours

(b) For routine inspection pursuant to paragraph 2 above the notice shall be at least 24 hours

(c) For special inspections pursuant to paragraph 3 above the notice shall be at least 24 hours

Such notice of inspections shall include the type and purpose of the inspection, the names of the inspectors, the area to be inspected, the time and place of arrival of the inspectors, the type of equipment to be brought by the inspecting team and the equipment and facilities required by the inspecting team to be supplied by the inspected Party.

Notification of flight plan

6.23 On arrival in the territory of the state, a flight plan for the purposes of inspection and aerial surveillance shall be filed, in accordance with ICAO procedures.

6.24 The State shall clear the flight plan with internal aviation authorities within a period of [6 hours].

Designation of inspectors

6.25 No less than [30] days after the treaty comes into force and thereafter no less than [30] days before the start of each calendar year, the Director General shall inform each State Party, through the Nominated National Body, in writing, of the name, qualifications, nationality, grade and other such particulars as may be relevant, of each Agency official who is proposed by the Agency for designation as an inspector.

6.26 Each Party, through the Nominated National Body, shall inform the Director General within [30] days of the receipt of the proposals which of the inspectors on the list of proposed inspectors shall be on the list of inspectors approved for inspection in the territory of that Party. Each Party's list of approved inspectors shall contain at least half of the list of designated inspectors.

6.27 The Director General may designate each official who has been accepted by a State as one of the inspectors for that State and shall inform the State of such designations.

6.28 The Director General, acting in response to a request by a State Party or on his own initiative, shall immediately inform the State of the withdrawal of the designation of any official as an inspector for the State.

6.29 The State Party shall grant or renew as quickly as possible appropriate visas, where required, for each inspector designated for the State.

Designation of Aircrew

6.30 No less than [30] days after the treaty comes into force and thereafter no less than [30] days before the start of each calendar year, the Director General shall inform each State Party, through the Nominated National Body in writing, of the name, qualifications, nationality, grade and other such particulars as may be relevant, of each Agency official who is proposed by the Agency for designation as aircrew.

6.31 Each Party, through the Nominated National Body shall inform the Director General within [30] days of the receipt of the proposals which of the aircrew on the list of proposed aircrew shall be on the list of aircrew approved for flying in the territory of that Party. Each Party's list of approved aircrew shall contain at least half of the list of designated aircrew.

6.32 The Director General may designate each official who has been accepted by a State as one of the aircrew for that State and shall inform the State of such designations.

6.33 The Director General, acting in response to a request by a State Party or on his own initiative, shall immediately inform the State of the withdrawal of the designation of any official as aircrew for the State.

6.34 The State Party shall grant or renew as quickly as possible appropriate visas, where required, for each aircrew designated for the State.

Conduct and visits of inspectors

6.35 Inspectors, in discharging their functions, shall not interfere directly with activities at the inspection site and shall avoid unnecessarily hampering or delaying the operation of a facility or taking actions affecting its safe operation.

6.36 In carrying out their activities, inspectors shall observe internationally recognised safety regulations established at the inspection site, including those for the protection of controlled environments within a facility and for personal safety.

6.37 When inspectors require services available in the State, including the use of equipment, in connection with the performance of inspections, the State shall facilitate the procurement of such services and the use of such equipment by inspectors.

6.38 The State Party shall have the right to have inspectors accompanied during inspections by representatives of the State, provided that the inspectors shall not thereby be delayed or otherwise impeded in the exercise of their functions.

6.39 The State Party shall, on request, be able to examine Agency equipment brought on-site for the purposes of inspection and shall return the equipment, in tact, to the inspectors within [4 hours].

6.40 The State shall provide food, work space, overnight accommodation, emergency medical care and other such services for inspectors for the entire duration of the inspection period.

6.41 Inspectors shall have the right, throughout the period of inspection, to be in communication with the Headquarters of the Agency or the relevant regional office of the Agency using voice and data communications systems provided by the Agency.

Privileges and immunities of inspectors

6.42 Agency inspectors shall be granted the privileges and immunities necessary for the performance of their functions.

Inspection Report

6.43 At the end of the inspection period, the inspecting team shall write an inspection report which will be signed by the representatives of the State Party under investigation. A copy shall be retained by the inspected party and a copy shall be given to the Director General.

6.44 The inspection report shall contain an account of the inspection including an account of any measurements, samples, photographs, new equipment installed and material and equipment shipped.

Inspection Expenses

6.45 Inspection expenses will be incurred by the receiving State except when the Agency uses its own aircraft and/or land vehicles. The travel expenses from outside the inspected country to the point of entry and from the point of entry to a destination outside the inspected country will be borne by the Agency.

7. Data handling and reporting

All data collected by the Agency are to be held in a central databank. A report containing proposals for the location, technical personnel requirements and equipment both for transmission and analysis of these data by the Agency is to be prepared and circulated by the Director General [three] months before the first meeting of the Consultative Committee, where it will be endorsed, amended or rejected. If the report is rejected, the Director General shall prepare a further proposals for the next meeting of the Committee until agreement is reached.

8. Designation of a National Authority

8.1 Parties to the Treaty shall nominate a National Body to:

i) provide a representative to the meetings of the Consultative Committee,

and ii) to liaise with the Agency and the Technical Committee on any matter directly affecting that Party,

and iii) to provide any technical and geological data available in the public domain requested by the Agency or the Technical Committee, including a list of current drilling facilities, planned and accidental chemical explosions above a magnitude specified by the Agency on the territory of that Party,

and iv) to consult with and agree with the Agency the incorporation of existing seismic stations into the global verification network,

and v) to consult with and agree the installation of any new equipment on the territory of that Party requested by the Agency for the purpose of verifying this Treaty as amended,

and vi) to consult with and agree specific locations and timing of any on-site inspection requested by the Agency,

and vii) to forward to the Agency any challenge OSI requested by that Party on the territory of another Party and to provide the technical justification for such a request at the time of making it.

ANNEXE ONE/A: OUTLINE SPECIFICATIONS OF SEISMIC STAION DENSITY REQUIRED IN A GLOBAL VERIFICATION NETWORK

A regional seismic network shall consist of a series of small or medium-aperture seismograph arrays except under special geological, geographical, geophysical or financial circumstances where the station shall consist of a single site. Any exceptions shall be at the sole discretion of the Agency. The overall design of the network is to be such that a detection-location threshold of body-wave magnitude 2.2 (1.4 in certain specified areas) or less is achieved (at 95% confidence level) throughout the land territories of all State Parties. The network is to be installed and operational no more than 3 years after the formation of the Agency, and it is to operate for a minimum further period of 2 years before the coming into force of the Treaty.

It shall be the responsibility of the Agency to identify, revise, and update as necessary/possible the technical features of the system such that its intended capability is achieved, maintained and, as agreed desirable, improved.

A.1 Seismograph instrumentation

A.1.1 The sensing equipment at an individual seismograph station shall comprise:-

A.1.1.1 Air temperature and wind speed and direction sensors and a microbarograph air pressure sensor, sited at surface.

A.1.1.2 Air temperature, humidity and microbarograph air pressure sensors to be sited in the same chamber as the seismometers.

A.1.1.3 Some or all of the following seismometers:

(i) 3 broadband (BB) surface seismometers, with their sensing elements orientated in the 3 orthogonal directions vertical (z), north-south (NS), east-west (EW), to be located on a concrete plinth in an underground vault. The vault is to be environmentally stable in accordance with the specifications of the seismometer manufacturer's specifications

(ii) a 3 component BB system, as in A.1.1..3 (i), but emplaced in a vertical borehole at a depth of 30-100 metres

(iii) 3 short-period (SP) and long-period (LP) seismometers oriented orthogonally as in A.1.1.1.3 (i) and sited in a vault

A.1.1.4 In the case of a "quality 3" network, each seismic station shall comprise, as its minimum, a seismic station of type A.1.1.1.3 (iii) and may utilise existing stations.

A.1.1.5 In the case of a "quality 2" network, each seismic station will be termed an array and shall comprise, as its minimum, 9 individual stations (elements) of A.1.1.3. (i), distributed in a pattern designed to minimise dominant local seismic noise when the output from all elements is time-shifted and summed. The meteorological equipment of A.1.1.1 and A.1.1.2 is to be installed in at least one of the individual elements.

A.1.1.6 In the case of a "quality 1" network, the stations shall comprise a borehole seismometer of type A.1.1.3 (ii) together with the 9-element array of type A.1.1.3 (i) and all meteorological equipment.

A.1.1.7 The seismological stations are to be distributed geographically to the standard pattern defined by the agency (or technical committee), subject to the constraints of the environment around the stations laid out in A.1.5. The seismic signals from individual array BB elements are to be transmitted to the central station using dedicated land or radio links.

A.1.1.8 The minimum numbers of stations in the territory of each State Party are given in Tables 7-11 of the main study.

A.1.2 The seismographs defined in A.1.1 are to have inherent system noise less than seismic background signal at all frequencies from 0.04 Hz to 50 Hz at least, and a magnification that is flat to ground velocity over the bandwidth 0.03Hz to 50Hz at least, with the slowest possible rolloff to high and low frequencies. The overall dynamic range of the seismograph system is to be 140dB or more. Anti-alias filters starting at 50Hz are to be incorporated in their control electronics. They are to be operated at the greatest possible magnification commensurate with local background noise conditions and the range or choices of gains available in the design.

A.1.3 A radio-transmitted time code is to be received at individual stations or the central array element, and used to provide an absolute time-base with 0.01s absolute accuracy for all recordings. A local quartz-oscillator clock with maximum drift rate of 1s/day is to be available as backup and is to be calibrated against the radio time code on a daily basis.

A.1.4 The individual stations and all array elements are to be located in latitude, longitude, and elevation (relative to a specified Reference Spheroid) using GPS or equivalent satellite-derived position fixing, such that the locations of all seismometer groups can be given to an absolute accuracy of ±50m in latitude and longitude and ±10m in elevation by the time that the network enters regular operation. This location is to be checked at periodic intervals as specified by the Agency.

A.1.5 The individual stations and arrays are to be sited in regions where

(i) topographic relief is as small as possible

(ii) geological structure (including surface drift deposits) is as invariant laterally as possible

(iii) as remote as possible from any industrial, urban and other human activities

(iv) seismic background noise is as low as possible throughout the bandwidth 0.03-50Hz;

in all cases commensurate with an even geographic distribution as indicated in above. Where evolving conditions, such as encroaching industrial development, cause long term changes in the environment around any station that are prejudicial to its monitoring ability, the Agency shall re-establish the station at another more suitable site. Where these conditions are transient, the Agency shall install such numbers of supplementary portable seismic stations as it deems necessary to maintain the detection thresholds in that region.

A.1.6 The characteristics of all seismographs and other equipment are to be standardised at all stations of the network. These specifications above are to be confirmed by bench-testing all instrumentation prior to installation and again at such regular and/or random intervals as desired by the Agency. The characteristics of all stations are to be lodged with the Agency.

A.2 Seismograph network

A.2.1 All territories covered by this agreement are to divided as defined in Annex B.1, and each such area be classified geologically into to one of the following categories:

'shield'
'stable continental platform'
'orogenic belt'
'rift zone'
'deep-water island'
'salt deposits & high-risk decoupling'

In carrying out the classification, reference must be made to the geoscientific mapping data required to be exchanged under Annex B.3.1, in addition to all public-domain geologic mapping. In the case of 'salt deposits and high-risk decoupling' it is possible that isolated areas of deep dry superficial deposits and/or consolidated sediments will be identified; where numerous small such areas are identified, it is intended that a sensible overall classification be achieved. In general, where local scale variations in classification are identified, a representative single regional-scale classification should be made, favouring always the environment requiring a greater density of stations (see B.1.2.1) In the case of deep-water islands, groups of islands may be classified as a single island then according to one of the 'land' geological types if their aggregate area is suitably large.

A.2.1.1 The number of seismograph stations installed on all land territories must meet the following overall minimum spatial densities specified in Tables 7 - 11 of the main study.

A.2.1.2 All deep-water islands or groups of islands are to be occupied by a minimum of 1 array station. Where just 1 array station can be installed, that station is to be expanded to comprise at least 20 vertical BB elements in a suitable pattern and of suitable dimensions as to allow the dominant ocean microseismic noise to be effectively suppressed by the process of array summation.

A.2.2 In those areas where, for the exceptional reasons noted above, individual stations are installed instead, the minimum areal densities of stations of A.2.1 are to be reduced by a factor of 0.65.

A.2.3 A network of seafloor hydrophones is to be established either on the seafloors and/or suspended within the water columns to detect pressure waves within the ocean. The number of hydrophones are specified in Tables 7 - 11 in the main study.

A.2.4 A network of ocean-bottom seismometers (OBS) is to be established in order to detect seismic waves travelling within the sub-sea floor rocks. Data capture from these is to be either continuous by sea-floor cable or periodic by "pop-up" data storage devices. The number of OBS are specified in Tables 7 - 11 in the main study.

A.2.5 The sites of all arrays and single stations are to have their geological and geophysical characteristics defined by

(i) surface geological mapping on a lateral resolution of 0.5km

(ii) execution of a seismic refraction survey together with borehole sampling to determine P and S wave velocities and formation densities in the uppermost 200m of the Earth

(iii) execution of a long-range seismic refraction/wide-angle reflection survey to determine gross P and S velocity structure to a depth of at least 10km below the local depth of the Mohorovicic Discontinuity; where these characteristics are not already known.

A.3 Seismograph data capture

A.3.1 All seismometers, microbarographs, and radio time codes are to be sampled at a rate of 120 samples/second. Meteorological data are to be sampled at a rate of 1 sample per minute. All of these data are to be written to computer-compatible digital mass storage in a format to be specified by the Agency. The mass storage medium is to offer the optimum long-term integrity of the data, simplicity of storage environment, and have a capacity such that uninterrupted recording for at least 30 days is allowed.

A.3.2 All digitised data are to be transmitted by satellite channel at regular intervals to to the Agency where permanent archiving of the data will be undertaken in similar format to that of A.3.1 and only upon the verified recording of this data will the on-site data record be wiped and the recording medium re-used as desired.

ANNEX ONE/B: ESTABLISHING A DATABASE OF SEISMOLOGICAL DATA AND THE IDENTIFICATION OF ANOMALOUS EVENTS

The Agency will be charged with identifying on seismological evidence those seismic disturbances which are deemed probable nuclear explosions at a confidence level of 95% probability, using the historic databases, routinely-acquired data, and analysis methods as set out below.

It shall be the responsibility of the Agency to identify, revise, and update as necessary/possible the technical and scientific methodology, such that its intended capability as noted in Annex A is achieved, maintained, and where desirable improved.

B.1 Regional geographic divisions for monitoring; a data base of historic data

B.1.1 The Earth's surface will be divided into seismic; geographical; and local regions (in order of decreasing areal extent). It is anticipated that this hierarchy of regions will honour national territorial boundaries.

B.1.2 The Agency will collate at its central facility (or facilities) a database of seismological data for each region as defined in B.1.1. For seismic events prior to the commencement of the Agency Network ("historic data"), the database shall derive from that held by the International Seismological Centre together with any other public-domain data considered necessary thereafter, the data will be obtained from the Agency Network.

B.1.3.1 "Level I" data will comprise as much as possible of: hypocentres and origin times, magnitudes for P and Rayleigh waves; amplitudes & periods of any other reported phases; earthquake focal mechanisms. "Level II" data will comprise digital seismogram waveforms together with seismograph response characteristics for any station contributing.

B.1.3.2 The Agency shall establish a 'definitive' hypocentre and magnitude reference dataset by reprocessing historic data in the following manner:

(i) selecting from all area an event or events with some or all hypocentre parameters known, or an event large enough to have been widely recorded, and these globally-distributed events to be located in space and time

(ii) taking those events from (i) as 'reference' events and, for each area separately, locating all other events within each area relative to them;

(iii) recomputing P- and Rayleigh-wave magnitudes simultaneously for all events using the maximum-likelihood technique;

(iv) computing for each area a P-wave magnitude formula for shallow-focus events, by determining the distance-correction term, B(delta), for distances at 1-degree intervals up to 40 degrees;

(v) computing for each area an Lg-wave attenuation value and thus a Lg-wave magnitude formula and data set.

In all cases (i)-(v) an 'area' is to be taken as the smallest practicable combination of local regions as defined in B.1.1 with similar tectonic categorization while ensuring that a sufficient number of seismic events are contained within.

B.1.4 The database as described in B.1.3 is to be fully established using historic data no more than 3 years after the formation of the Agency. The addition of data from the Agency network will commence as soon as data are available from the network. The reference hypocentre and magnitude dataset may be refined at such intervals as desired by the Agency.

B.1.5 For all events either (a) determined in B.1.3 to be at a depth of less than 50km, and with an epicentre beneath or within 25km of land or (b) known from data exchanges (B.3.4) to have been underground nuclear explosions, the Agency will compile (on a regional basis) a register of: m_b:M_s scattergrams, P-wave spectra, m_b(high-frequency): m_b(low-frequency) (VFM) scattergrams and Love-wave magnitudes. Where the region includes either explosions acknowledged under the data exchanges of B.3.4, B.3.5 or B.4.1.1 or any other historic events presumed to be nuclear explosions:

B.1.5.1 The choice of high- and low-frequency bandwidths for VFM scattergrams will be refined to optimise separation of explosion and earthquake populations. Optimum decision lines will be determined on both m_b:M_s, VFM, scattergrams such that any given event may be assigned a probability of being a nuclear explosion source. An estimate of the amount and character of tectonic release will be made for each explosion. An optimum linear combination of m_b, M_s, and m_b(Lg) (referred to as a "unified magnitude") will be determined to give the best precision possible for a seismic yield estimator.

Where the region does not contain such events,

B.1.5.2 Statistical estimators will be derived for the earthquake m_b:M_s and m_b(HF):m_b(LF) populations' trends in order that any given event may be assigned a measure of its closeness to the mean trend.

Furthermore the Agency shall be charged with an assessment of any other discriminant parameters suggested or implied by research results in the open literature and/or its own seismologists. Those discriminants which are applicable to regional-range (i.e. within 2000 km of source) recordings and/or which improve depth and epicentre resolution shall be prioritised in this assessment.

B.2 Data processing methods and equipment

B.2.1 Satellite transmission at regular intervals of no more than 24hrs will be used to transmit bulk data to the Agency. The data transmitted at intervals to the Agency shall comprise the digital continuous recording at all stations.

B.2.2 The means of mass storage at the Agency shall be as defined in Annex A.3.1. These data are to be archived for a time period of no less than 20 years. The storage environment is to be accordance with the storage medium manufacturer's specifications for temperature range, humidity, frequency of tape spooling, ambient magnetic fields, etc.

B.2.3 The Agency is to be equipped with mainframe computers or computers, satellite receiving equipment, and all other data-handling and data-archiving systems to a standardised specification to be defined by the Agency at its inception.

B.2.4 All processing algorithms for the operations of:- hypocentre & origin time determination P-wave, Rayleigh-wave, and Lg-wave magnitude determination P-wave spectral analysis and VFM determination and all other data analysis and processing software, are to be standardised. The Agency shall select these algorithms as a matter of urgency immediately following its inception.

B.2.5 A hypocentre/origin time determination will be carried out automatically using the algorithms of B.2.4 on all seismic events detected by the Agency network within [3] days of receipt of the data at the Agency. All events found to lie beneath, or within 25km of, land at a depth of 50km or less are to be declared candidate explosions on location criteria. All such events will have their m_b:M_s and m_b(HF):m_b(LF) characteristics determined and compared statistically to those of the 'reference' historic dataset and that acquired by the network. All comparisons are to be made on a regional basis as discussed in B.1.5. This comparison may be automated and all newly recorded events with a 65% or higher probability of being explosions flagged, although all m_b:M_s and m_b(HF):m_b(LF) scattergrams must be displayed graphically and examined visually. All seismic events recorded must reach this decision threshold as soon as possible and in any case in less than [30] days of their occurrence.

B.2.5.1 Those events which are assigned a 65% or greater probability of being explosions are to be subject to individual analysis by a seismologist of the Agency. This is to include as a minimum all those feasible of; precise hypocentre location; any supplementary depth estimation procedures such as higher-mode surface wave spectra; focal mechanism estimates using signal polarities, P_n:S_n amplitude ratios or any other means where appropriate; Those subsequently confirmed as being explosions at 95% confidence levels will be passed on by the Agency seismologist(s) to higher authority.

B.2.6 Those events categorised by B.2.5 as 'probable explosions' will be subjected to any/all possible further analysis upon demand/authorisation from higher authority in the light of all supportive evidence from such other means as the Agency has at its disposal, such as preferred locations based on satellite evidence.

B.2.7 In the event of geographical regions and/or specific dates/times being identified by other means available to the Agency as hosting suspicious activity, all seismic events originating from that region/time will be subjected to the higher level of scrutiny as defined in B.2.5.1. A specific array beamform search will be conducted to ensure that all possible seismic events have been detected and located and any further events analysed appropriately.

B.3 Information to be supplied by signatories and/or obtained from the public domain

All State Parties are to deposit with the Agency within 1 year of the formation of the Agency as much as possible of the data specified in B.3.1 - B.3.5 below. The remainder of the required data must be provided within a maximum of a further 2 years.

B.3.1 Relevant geoscientific mapping information, pertaining to their territory, to include: surface solid rock types and superficial deposits; depth of water table; areas of permafrost; areas of salt deposits; a topographic database, where possible in digital form; all the above to be resolved laterally to 0.5km.

B.3.2 A register of locations, depths, geological settings, and general geometries of all standing cavities of volumes:

in excess of 55,000m^3 at depths of less than 300m,
in excess of 40,000m^3 at depths of between 300m and 600m,
in excess of 30,000m^3 at depths of between 600m and 1km, and
in excess of 10,000m^3 at any greater depths;

and of all mining operations requiring vertical shaft diameters of 3m or greater extending to depths of over 1km.

B.3.3 For all geophysically distinct sites used in the past for test firing of nuclear explosives, geoscientific mapping data as defined in B.3.1 to be resolved laterally to 0.1km.

B.3.4 The dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, and yields of all previous test firings of nuclear explosives.

B.3.5 The dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, yields, and purposes of all firings of nuclear explosives at locations outside the recognised Test Sites as defined in B.3.4 - details to be given separately of all individual explosions in any aggregate or simultaneous firings.

B.3.6 All information in B.3.1-B.3.5 is to be used for designing in detail the seismic array spatial densities and geographic distributions, construction of a reference database of historic data, assigning priorities for real-time array beamform searches, and any other seismological purposes.

B.4 Information to be supplied by all signatories subsequent to the coming into operation of the network

B.4.1 All State Parties will be required to deposit with the Agency subsequent to the coming into force of the Treaty all the following:

B.4.1.1 The locations, depth of burial, emplacement medium, anticipated yields, intended detonation date/time, of all non-nuclear explosions of yields of 3 tonnes TNT-equivalent, to be supplied no less than 28 days in advance of the intended detonation date/time. The actual detonation times and dates of these explosions are to be forwarded to the Agency as soon as they are known by the host nation.

B.4.1.2 The creation or discovery of any standing cavities or deep mining shafts as defined in B.3.2.

B.4.2 The Agency shall have the automatic right and authority to deploy networks of portable seismograph installations in and around the geographic regions identified in B.4.1.1.

B.4.3 The Agency shall design and execute a programme of at least 4 non-nuclear explosions yearly, detonated routinely and (ir)regularly, with or without prior announcement, and at least 2 of these to be in the yield range 100-400 tonnes TNT-equivalent, in order to test and calibrate the detection, location, identification, and yield estimators, of the established seismic network. The Agency shall also be empowered to install temporary portable seismic stations as defined in B.4.2.

Appendix 2

An illustration of a verification protocol in a de-centralised framework

Note

The following appendix, written by VERTIC, serves only as an illustration of how a verification regime might work in a de-centralised framework. It includes all the substantive points from the Swedish draft CTB Treaty tabled at the Committee on Disarmament, 1983 (CD/381). VERTIC recognises that the illustration is incomplete and is not at the standard of international law and asks that it should be read with that in mind.

DRAFT PROTOCOL FOR DECENTRALISED VERIFICATION OF CTBT

Definitions

The term "International Data Centre (IDC)" means a centre where seismological data are stored

The term "Consultative Committee" means the body on which all parties have the right to be represented through a Nominated National Body

The term "Nominated National Body" means a national organisation named by a party in its instrument of ratification to represent its interests in any matter related to the Treaty

The term "Technical Committee" means a body of scientific experts to advise the Parties on scientific and technical aspects of the Treaty

The term "Committee of Experts" means the committee formed from a list of individuals recommended by the Technical Committee and subsequently endorsed annually by the Consultative Committee.

The term "inspected Party" means the Party to the Treaty whose sites are subject to inspection.

The term "inspector" means an individual to conduct on-site inspections in accordance with the relevant provisions of the Treaty and who is also on the approved list of inspectors agreed by the parties

The term "inspection team" means the group of inspectors assigned to conduct a particular inspection.

The term "inspection site" means the area, location or facility at which an inspection is carried out.

The term "period of inspection" means the period of time from arrival of the inspection team at the inspection site until its departure from the inspection site, exclusive of any pre- and post-inspection procedures.

The term "point of entry" means the airfield or airfields designated by each Party as the route of entry into the territory of that Party.

The term "in-country period" means the period of time from the arrival of the inspection team at the point of entry until its departure from the country through the point of entry.

The term "in-country escort" means individuals specified by the inspected Party to accompany and assist inspectors and aircrew members as necessary during the in-country period.

The term "aircrew member" means an individual who performs duties related to the operations of an aircraft used for transportation of an inspection team to a point of entry and who is on the list of designated aircrew members.

PREAMBLE

P.1 Verification of this treaty, depends upon the free exchange of relevant data between the Parties for inspection by the national technical means (NTMs) of any Party.

P.2 Relevant data to be exchanged under the provisions of this Treaty will be deemed to include both geophysical data and any form and method of monitoring the obligation on all Parties to desist from any form of nuclear explosion for the purpose of testing nuclear or other weapons.

P.3 General supervision of the collection, transmission and storage of this data shall be the responsibility of a Consultative Committee of representatives of national bodies nominated by each Party.

P.4 The Consultative Committee shall meet to seek agreement by consensus on the implementation of this Treaty, Particularly in regard to common technical standards in the collection, transmission and storage of relevant data. The Consultative Committee shall also seek to resolve any questions or disputes arising from the implementation of this Treaty. To this end they are empowered to request an On Site Inspection (OSI) of any Party and to nominate a team of experts to undertake such an inspection.

P.5 The Consultative Committee shall be supported by a permanent Secretariat to carry out all administration connected with its work and a Technical Committee who will supervise the technical standards of the collection and storage of relevant data and make recommendations on any technical aspect of the implementation of the Treaty as requested by the Consultative Committee.

ARTICLE ONE: GENERAL PROVISIONS

1.1 Each Party to this Treaty will use national technical means of verification at its disposal in a manner consistent with generally recognised principles of international law to verify compliance with the Treaty and undertakes not to interfere with such means of verification.

1.2 Each Party undertakes to co-operate in good faith in an effective international exchange of seismological data, atmospheric activity and other measures in order to facilitate the monitoring of this Treaty.

ARTICLE TWO: CONSTITUTION AND ORGANISATION

2.1 The Consultative Committee, Secretariat and Technical Committee shall be constituted according to the terms of this Protocol including the provisions contained in Appendix One.

2.2 Parties to this Treaty agree to nominate at least one representative to the Consultative Committee through a nominated national body according to the above terms. The Consultative Committee, at its first meeting, shall *inter alia* agree the names of the Technical Committee according to the terms of Appendix One of this Protocol.

2.3 Within five months of this Treaty coming into force the Technical Committee shall meet and prepare and circulate recommendations to the Consultative Committee regarding the collection of and storage of geophysical and other data for the purpose of monitoring the operation of this Treaty.

2.4 All Parties to the Treaty agree to provide any geophysical or other data deemed relevant to the monitoring of this Treaty by the Technical Committee and requested in writing by the Technical Committee. This data will normally include compiled and preanalysed recordings from existing seismic stations and atmospheric monitoring stations nominated by the Technical Committee. Subject to its available budget, the Technical Committee may also purchase or obtain by other means images collected by remote observation from any agency willing to supply them.

2.5 The Technical Committee shall recommend to the Consultative Committee the installation and location of any new seismic stations, and new international data centres and other data collection and transmission facilities which the Technical Committee considers necessary for adequate implementation of this Treaty in accordance with Annexe One (A&B) of this treaty. The Consultative Committee shall discuss any such proposal from the Technical Committee at its next scheduled meeting providing the proposal has been circulated to representatives of the Consultative Committee at least six weeks beforehand.

2.6 The recommendations of the Technical Committee shall include an estimate of costs, benefits and disadvantages of any technical option suggested to the Consultative Committee. The Consultative Committee shall decide by consensus or by a simple majority at its next scheduled meeting which technical options will be adopted and will instruct the Secretariat to implement them in consultation with the Technical Committee, and the nominated national body of any Party concerned.

2.7 The Secretariat shall:

(i) supervise that the participating seismological stations are operated and data are reported as specified according to the terms of Annex One of this Protocol;

(ii) act as a contact with any body endorsed by the Consultative Committee on matters of data exchange and supervise and review with any nominated body the data exchange specified in this Treaty;

(iii) compile and present operational statistics and report on experiences of the International Data Exchange, Seismological and other relevant data collection, transmission and storage;

(iv) organise and conduct international on site inspections as specified in this Treaty and report the result of such inspections to the Consultative Committee;

(v) maintain lists of experts supplied by the Group of Scientific Experts to the Conference on Disarmament Geneva and the bodies nominated by the Parties to this Treaty available to conduct on site inspections and the equipment specified by the Technical Committee and endorsed by the Consultative Committee necessary for such inspections.

ARTICLE THREE: JOINT RESPONSIBILITIES AND RIGHTS OF PARTIES

3.1 Each Party Participating in the international data exchange shall provide geographical co-ordinates, geological site description and a description of the instrumentation of each seismological station designated by the Technical Committee. Any changes in these specifications shall be immediately reported by the nominated national body to the Secretariat and Technical Committee, who will report regularly to the Consultative Committee on the state of equipment employed to implement this Treaty.

3.2 The seismological stations designated for Participation shall have the technical capabilities as specified in Annex One of this amended Treaty, and shall be operated, calibrated and maintained by the nominated national body in accordance with Annex One of this Treaty, who will send regular reports on the operation of such facilities to the Secretariat.

3.3 Seismological data from each designated station shall routinely and regularly be reported through the appropriate National Body as specified in Annex One of this Treaty.

3.4 In addition to routinely submitted data each Party Participating in the international data exchange shall provide any additional seismological data from its designated stations requested through International Data Centres by any Party to the Treaty. The procedures for making such requests are specified in Annex One of this Protocol.

3.5 Seismological data shall be transmitted through the Global Telecommunication System of the World Meteorological Organisation, WMO/GTS or other body nominated and agreed by the Consultative Committee. The procedures for exchanging data will be proposed to the inaugural meeting of the Consultative Committee by the Technical Committee.

ARTICLE FOUR: INTERNATIONAL DATA CENTRES

4.1 International Data Centres (IDC) will hold any available copies of relevant transmitted data and will be established according to requirements suggested by the Technical Committee and agreed and/or amended by the Consultative Committee according to the procedures laid down in the Protocol.

4.2 Any new seismic or other data collection and/or transmission facility proposed by the Technical Committee shall be owned by the country on whose territory it is situated, and shall be operated according to the written requirements of the Technical Committee within the terms of Annex One of this protocol.

4.3 Each IDC shall be under the jurisdiction of the state in whose territory it is located, and the cost of establishing it and operating shall be borne by that state.

4.4 Easy and free access for representatives from all Parties to the Treaty and for officers of the Secretariat of the Consultative Committee shall be guaranteed to all facilities of all IDCs.

4.5 Each IDC shall receive all seismological data contributed to the international exchange by its participants, process these seismological data without interpreting the nature of the seismological events, make the processed seismological data available to all participants and maintain all seismological data contributed by participants as well as the results of the processing at the centres, according to the procedures laid down by the Technical Committee and endorsed by the Consultative Committee.

4.6 A similar exchange of data on atmospheric radioactivity shall be established according to the same procedures as those indicated in this Treaty for the exchange of geophysical data.

4.7 With a view to improving the verification of this Treaty, negotiations on additional international measures such as the exchange of data on atmospheric radioactivity, hydro-acoustic signals in the oceans and infrasound and micro-barographic signals in the atmosphere, shall be undertaken by the Parties to the Treaty through the Consultative Committee as advised by the Technical Committee.

4.8 Any Party may request copies of any relevant data collected by the Secretariat on behalf of the Consultative Committee and stored at any nominated International Data Centre on payment of a fee on a scale proposed by the Technical Committee and Secretariat and agreed annually by the Consultative Committee.

ARTICLE FIVE: ON SITE INSPECTIONS

General

States Party to the Treaty shall have the right to request on-site inspections to be carried out by a Committee of Experts as provided in the paragraphs below.

Any Party may request an On Site Inspection to be carried out by a Committee of Experts from a list of individuals recommended by the Technical Committee and subsequently endorsed annually by the Consultative Committee.

Purposes of inspections

5.1 The Commitee of Experts may make routine inspections in order to:

(a) Verify that previous nuclear testing sites are no longer functioning as such

(b) Verify that other sites are not operating as nuclear test sites

(c) Verify the integrity of detection equipment

(d) Observe the operation of conventional chemical explosions as notified by State Parties

5.2 The States, through the Nominated National Body to the Secretariat, may request the Committee of Experts to make special inspections in order to:

(a) Verify that sites are not operating as nuclear test sites

(b) Identify and verify the cause of signals detected by the detectors installed

Scope of inspections

5.3 For the purpose stated in paragraphs 5.1 to 5.2 (above) the Committee of Experts may send inspectors to:

(a) Examine records kept in pursuant to previous nuclear tests, drilling operations, chemical explosions and seismic detection.

(b) Make independent measurements

(c) Take samples of gas, water, rock, soil, vegetation and animal life in the area under investigation, provide duplicate sample to the inspected party and take the samples away for analysis.

(d) Verify the functioning and calibration of instruments and other equipment

(e) Apply and make use of surveillance measures

(f) Use aircraft to fly over and survey the area under inspection

(g) Install new equipment

(h) Apply seals and other identifying and tamper indicating devices

(i) Calibrate and re-calibrate equipment

(j) Arrange for the shipping of samples and equipment

(k) Use other methods which are considered by the Technical Committee to be technically feasible.

5.4 The inspection team may bring onto the inspection site such documents and equipment as needed to conduct the particular type of inspection. All equipment shall be operated by the inspection team.

5.5 In the case of equipment designed for measurement, no calibration settings may be altered or reset during the period of inspection by any personnel other than the inspecting party. The inspected Party may provide items with known measurable properties in order that equipment calibration may be verified.

5.6 Measurements recorded during inspections shall be certified by the signature of a member of the inspection team and a member of the in-country escort at the time the measurements are taken. All such certified measurements shall be included in the inspection report as in paragraph 5.47.

5.7 Inspectors shall have the right to request clarifications in connection with ambiguities that arise during an inspection. Such requests shall be made promptly through the in-country escort to the Nominated National Body.

Access for inspections

5.8 The inspectors shall have access to:

(a) Any location where detection equipment is stationed

(b) Any location where a notified chemical explosion takes place

(c) Any location where an ambiguous event is estimated, by the Technical Committee, to have originated

Frequency, intensity and duration of inspections

5.9 The number, intensity, duration and timing of inspections shall be kept to the minimum consistent with procedures for effective verification set forth herein and the inspectors shall make the optimum and most economical use of available inspection resources.

5.10 The number, intensity duration timing and mode of inspections shall be determined on the basis that the inspection régime shall be no more intensive than is necessary and sufficient to monitor and verify the treaty.

5.11 Routine inspections shall be of a duration of less than or equal to [72 hours]

5.12 Special inspections shall be of a duration of less than or equal to [21 days]

5.13 For routine inspections the number of inspectors shall be less than or equal to [10]

5.14 For special inspections the number of inspectors shall be less than or equal to [30]

5.15 No Party will be obliged to receive more than [20] routine inspections per annum

5.16 No Party will be obliged to receive more than [5] special inspections per annum

5.17 No Party will be obliged to accept more than [2] routine inspections per annum requested from the same Party

5.18 No Party will be obliged to accept more than [1] special inspections per annum requested from the same Party

Procedures for requesting special on-site inspections

5.19 Any request by a Party for an on-site inspection shall be made, with relevant documentation, to the Secretariat

5.20 The Secretariat shall inform the Technical Committee of the request on receipt of the request.

5.21 The Technical Committee shall meet within [3 days] to consider the request.

5.22 The Technical Committee shall inform the Consultative Committee of its recommendations.

5.23 The Consultative Committee, or a nominated sub-committee, shall meet within [48 hours] to consider the recommendations from the Technical Committee and shall either:

(a) Decide that the secretariat should request a special on-site inspection

(b) Decide that a special on-site inspection is unwarranted.

5.24 In the case of subparagraph 5.23(a), the Secretariat shall notify both the requesting State and the State to be inspected that a special inspection will take place.

5.25 In the case of sub-paragraph 5.23(b), the Secretariat shall notify the requesting State of the Consultative Committee's decision.

Procedures for requesting routine inspections

5.26 In pursuant to paragraphs 1 and 3 above, the Technical Committee shall instruct the Committee of experts to carry out routine inspections.

5.27 The Technical Committee shall inform the Consultative Committee and the Secretariat of plans for routine inspections, on an annual basis.

Notice of Inspections

5.28 Notification of intention to conduct an inspection shall be given from the Secretariat to the nominated National Body. The receipt of this notification shall be acknowledged within one hour of receipt.

5.29 The Secretariat shall give advance notice before arrival of inspectors. The notice shall be at least [24 hours]

Such notice of inspections shall include the type and purpose of the inspection, the names of the inspectors, the area to be inspected, the time and place of arrival of the inspectors, whether the inspection will be conducted from the ground, from the air or both, the type of equipment to be brought by the inspecting team and the equipment and facilities required by the inspecting team to be supplied by the inspected Party.

Notification of flight plan

5.30 On arrival in the territory of the state, a flight plan for the purposes of inspection and aerial surveillance shall be filed by the inspectors, in accordance with ICAO procedures.

5.31 The State shall clear flight plan the flight plan with internal aviation authorities within a period of [4 hours].

Designation of inspectors

5.32 No less than [30] days after the treaty comes into force and thereafter no less than [30] days before the start of each calendar year the Technical Committee shall inform the Consultative Committee, in writing, of the name, qualifications, nationality, grade and other such particulars as may be relevant, of names of officials who the Technical Committee proposes for designation as an inspector.

5.33 The Consultative Committee shall inform the State Parties, within [30] days of the receipt of the proposals, which of the inspectors on the list of proposed inspectors shall be on the list of inspectors approved for inspection in the territory of that Party.

5.34 States shall grant or renew as quickly as possible appropriate visas, where required, for each inspector designated.

Designation of Aircrew

5.35 No less than [30] days after the treaty comes into force and thereafter no less than [30] days before the start of each calendar year the Technical Committee shall inform the Consultative Committee, in writing, of the name, qualifications, nationality, grade and other such particulars as may be relevant, of names of officials who the Party is proposing for designation as aircrew.

5.36 The Consultative Committee shall inform the other parties within [30] days of the receipt of the proposals which of the aircrew on the list of proposed aircrew shall be on the list of aircrew approved for inspection in the territory of that Party.

5.37 States shall grant or renew as quickly as possible appropriate visas, where required, for each aircrew designated.

Conduct and visits of inspectors

5.38 Inspectors, in discharging their functions, shall not interfere directly with activities at the inspection site and shall avoid unnecessarily hampering or delaying the operation of a facility or taking actions affecting its safe operation.

5.39 In carrying out their activities, inspectors shall observe internationally recognised safety regulations established at the inspection site, including those for the protection of controlled environments within a facility and for personal safety.

5.40 When inspectors require services available in the State, including the use of equipment, in connection with the performance of inspections, the State shall facilitate the procurement of such services and the use of such equipment by inspectors.

5.41 The State shall have the right to have inspectors accompanied during inspections by representatives of the State, provided that the inspectors shall not thereby be delayed or otherwise impeded in the exercise of their functions.

5.42 The State shall, on request, be able to examine equipment brought on-site for the purposes of inspection and shall return the equipment, in tact, to the inspectors within [4 hours].

5.43 The State shall provide food, work space, overnight accommodation, emergency medical care and other such services for inspectors for the entire duration of the inspection period.

5.44 Inspectors shall have the right, throughout the period of inspection, to be in communication with each other, and with the Secretariat using voice and data communications systems provided by the inspected Party.

Privileges and immunities of inspectors

5.45 Inspectors shall be granted the privileges and immunities necessary for the performance of their functions.

Inspection Report

5.46 At the end of the inspection period, the inspecting team shall write an inspection report which will be signed by the representatives of the State Party. A copy shall be retained by the inspected party and a copy shall be given to the Technical and Consultative Committees.

5.47 The inspection report shall contain an account of the inspection including an account of any measurements, samples, photographs, new equipment installed and material and equipment shipped.

Inspection Expenses

5.48 Inspection expenses will be incurred by the receiving State except when the Committee of Experts uses its own aircraft and/or land vehicles. The travel expenses to and from the point of entry will be borne by the Secretariat.

APPENDIX ONE: Creation of the Consultative Committee, Technical Committee and Secretariat and procedure for nominating a national body for each Party.

A.I Not less than [three] weeks after this Treaty has entered into force, the Depository States to fill the post of General Secretary of the Secretariat and other necessary administrative and secretarial positions according to the usual terms and conditions of UN salary scales and appointments.

A.II At the same time the Depository States will write to all Parties to the Treaty requesting them to provide a representative to the Consultative Committee, for an inaugural meeting not later than three months after the date when the request is made.

A.III At the same time Depository States will formally ask members and observers of the Group of Scientific experts on the Conefernce on Disarmament, Geneva to nominate a list of people suitable to form the technical committee, who will then be approached by the Secretariat and asked if they would be willing to stand. Any Party to this Treaty may at this or any future time give to the Secretariat the name of any scientific expert they wish to join the Technical Committee. The Secretariat will then prepare a list of all scientific experts with their relevant experience and qualifications from all the names suggested to them and will circulate this list to all members of the Consultative Committee to be endorsed, agreed and if the meeting so decides, elected by due proportion of votes at the inaugural meeting of the Consultative Committee.

A.IV The Consultative Committee shall consist of a representative of each Party to the Treaty selected by a national body nominated by the relevant government department or legal authority of that country and accredited by the diplomatic mission of each Party to the United Nations.

A.V The Consultative Committee shall meet initially in [Geneva] and thereafter at any other location agreed by a majority of its members. At its first and inaugural meeting the Consultative Committee will be chaired by the Depository or his/her representative and will consider an agenda which will include proposals regarding organisation previously prepared and circulated by the Secretariat and will agree the location, date, length and periodicity of its meetings and will discuss and where possible decide on location, budget and responsibilities of the Secretariat and any other organisational proposals put forward by the Secretariat.

A.VI Where possible the chair will endeavour to ensure that the Consultative Committee reaches agreement by consensus but when this is not possible in the opinion of the chair, decisions will be taken by a simple majority of representatives at any quorate meeting. Meetings of the Consultative Committee where no fewer than [two thirds] of all officially accredited representatives are present shall be considered to be quorate. The ruling of the chair on any single issue may be challenged only at that time by a procedural motion, proposed and seconded by two representatives which will move immediately to the vote after it has been proposed and the chair has replied, without further discussion. The chair's ruling may be overturned only if it is supported by two thirds of those present. If two thirds of any quorate meeting so agree, a proposal to replace the chair with another named candidate may be proposed to the Secretariat for inclusion on the agenda of the next scheduled meeting of the Consultative Committee and will be decided by simple majority of that meeting, if it is quorate.

ANNEXE ONE/A:

OUTLINE SPECIFICATIONS OF SEISMIC STATION DENSITY REQUIRED IN A GLOBAL VERIFICATION NETWORK

A regional seismic network shall consist of a series of small or medium-aperture seismograph arrays except under special geological, geographical, geophysical or financial circumstances where the station shall consist of a single site. The overall design of the network is to be such that a detection-location threshold of body-wave magnitude 2.2 (1.4 in certain specified areas) or less is achieved (at 95% confidence level) throughout the land territories of all State Parties. The network is to be installed and operational for a minimum period of 2 years before the coming into force of the Treaty.

It shall be the responsibility of the Secretariat, on the advice of the Technical Committee, to identify, revise, and update as necessary/possible the technical features of the system such that its intended capability is achieved, maintained and, as agreed desirable, improved.

A.1 Seismograph instrumentation

A.1.1 The sensing equipment at an individual seismograph station shall comprise:-

A.1.1.1 Air temperature and wind speed and direction sensors and a microbarograph air pressure sensor, sited at surface.

A.1.1.2 Air temperature, humidity and microbarograph air pressure sensors to be sited in the same chamber as the seismometers.

A.1.1.3 Some or all of the following seismometers:

(i) 3 broadband (BB) surface seismometers, with their sensing elements orientated in the 3 orthogonal directions vertical (z), north-south (NS), east-west (EW), to be located on a concrete plinth in an underground vault. The vault is to be environmentally stable in accordance with the specifications of the seismometer manufacturer's specifications

(ii) a 3 component BB system, as in A.1.1..3 (i), but emplaced in a vertical borehole at a depth of 30-100 metres

(iii) 3 short-period (SP) and long-period (LP) seismometers oriented orthogonally as in A.1.1.1.3 (i) and sited in a vault

A.1.1.4 In the case of a "quality 3" network, each seismic station shall comprise, as its minimum, a seismic station of type A.1.1.1.3 (iii) and may utilise existing stations.

A.1.1.5 In the case of a "quality 2" network, each seismic station will be termed an array and shall comprise, as its minimum, 9 individual stations (elements) of A.1.1.3. (i), distributed in a pattern designed to minimise dominant local seismic noise when the output from all elements is time-shifted and summed. The meteorological equipment of A.1.1.1 and A.1.1.2 is to be installed in at least one of the individual elements.

A.1.1.6 In the case of a "quality 1" network, the stations shall comprise a borehole seismometer of type A.1.1.3 (ii) together with the 9-element array of type A.1.1.3 (i) and all meteorological equipment.

A.1.1.7 The seismological stations are to be distributed geographically to the standard pattern defined by the Technical Committee, subject to the constraints of the environment around the stations laid out in A.1.5. The seismic signals from individual array BB elements are to be transmitted to the central station using dedicated land or radio links.

A.1.1.8 The minimum numbers of stations in the territory of each State Party are given in Tables 7-11 of the main study.

A.1.2 The seismographs defined in A.1.1 are to have inherent system noise less than seismic background signal at all frequencies from 0.04 Hz to 50 Hz at least, and a magnification that is flat to ground velocity over the bandwidth 0.03Hz to 50Hz at least, with the slowest possible rolloff to high and low frequencies. The overall dynamic range of the seismograph system is to be 140dB or more. Anti-alias filters starting at 50Hz are to be incorporated in their control electronics. They are to be operated at the greatest possible magnification commensurate with local background noise conditions and the range or choices of gains available in the design.

A.1.3 A radio-transmitted time code is to be received at individual stations or the central array element, and used to provide an absolute time-base with 0.01s absolute accuracy for all recordings. A local quartz-oscillator clock with maximum drift rate of 1s/day is to be available as backup and is to be calibrated against the radio time code on a daily basis.

A.1.4 The individual stations and all array elements are to be located in latitude, longitude, and elevation (relative to a specified Reference Spheroid) using GPS or equivalent satellite-derived position fixing, such that the locations of all seismometer groups can be given to an absolute accuracy of ±50m in latitude and longitude and ±10m in elevation by the time that the network enters regular operation. This location is to be checked at periodic intervals as specified by the Technical Committee.

A.1.5 The individual stations and arrays are to be sited in regions where

(i) topographic relief is as small as possible

(ii) geological structure (including surface drift deposits) is as invariant laterally as possible

(iii) as remote as possible from any industrial, urban and other human activities

(iv) seismic background noise is as low as possible throughout the bandwidth 0.03-50Hz;

in all cases commensurate with an even geographic distribution as indicated in above. Where evolving conditions, such as encroaching industrial development, cause long term changes in the environment around any station that are prejudicial to its monitoring ability, the Consultative Committee shall re-establish the station at another more suitable site. Where these conditions are transient, the Consultative Committee shall install such numbers of supplementary portable seismic stations as it deems necessary to maintain the detection thresholds in that region.

A.1.6 The characteristics of all seismographs and other equipment are to be standardised at all stations of the network. These specifications above are to be confirmed by bench-testing all instrumentation prior to installation and again at such regular and/or random intervals as desired by the Consultative Committee. The characteristics of all stations are to be lodged with the Secretariat.

A.2 Seismograph network

A.2.1 All territories covered by this agreement are to divided as defined in Annex B.1, and each such area be classified geologically into to one of the following categories:

'shield'
'stable continental platform'
'orogenic belt'
'rift zone'
'deep-water island'
'salt deposits & high-risk decoupling'

In carrying out the classification, reference must be made to the geoscientific mapping data required to be exchanged under Annex B.3.1, in addition to all public-domain geologic mapping. In the case of 'salt deposits and high-risk decoupling' it is possible that isolated areas of deep dry superficial deposits and/or consolidated sediments will be identified; where numerous small such areas are identified, it is intended that a sensible overall classification be achieved. In general, where local scale variations in classification are identified, a representative single regional-scale classification should be made, favouring always the environment requiring a greater density of stations (see B.1.2.1) In the case of deep-water islands, groups of islands may be classified as a single island then according to one of the 'land' geological types if their aggregate area is suitably large.

A.2.1.1 The number of seismograph stations installed on all land territories must meet the following overall minimum spatial densities specified in Tables 7 - 11 of the main study.

A.2.1.2 All deep-water islands or groups of islands are to be occupied by a minimum of 1 array station. Where just 1 array station can be installed, that station is to be expanded to comprise at least 20 vertical BB elements in a suitable pattern and of suitable dimensions as to allow the dominant ocean microseismic noise to be effectively suppressed by the process of array summation.

A.2.2 In those areas where, for the exceptional reasons noted above, individual stations are installed instead, the minimum spatial densities of stations of A.2.1 are to be reduced by a factor of 0.65.

A.2.3 A network of seafloor hydrophones is to be established either on the seafloors and/or suspended within the water columns to detect pressure waves within the ocean. The number of hydrophones are specified in Tables 7 - 11 in the main study.

A.2.4 A network of ocean-bottom seismometers (OBS) is to be established in order to detect seismic waves travelling within the sub-sea floor rocks. Data capture from these is to be either continuous by sea-floor cable or periodic by "pop-up" data storage devices. The number of OBS are specified in Tables 7 - 11 in the main study.

A.2.5 The sites of all arrays and single stations are to have their geological and geophysical characteristics defined by

(i) surface geological mapping on a lateral resolution of 0.5km

(ii) execution of a seismic refraction survey together with borehole sampling to determine P and S wave velocities and formation densities in the uppermost 200m of the Earth

(iii) execution of a long-range seismic refraction/wide-angle reflection survey to determine gross P and S velocity structure to a depth of at least 10km below the local depth of the Mohorovicic Discontinuity; where these characteristics are not already known.

A.3 Seismograph data capture

A.3.1 All seismometers, microbarographs, and radio time codes are to be sampled at a rate of 120 samples/second. Meteorological data are to be sampled at a rate of 1 sample per minute. All of these data are to be written to computer-compatible digital mass storage. The mass storage medium is to offer the optimum long-term integrity of the data, simplicity of storage environment, and have a capacity such that uninterrupted recording for at least 30 days is allowed.

A.3.2 All digitised data are to be transmitted by satellite channel at regular intervals to to international data centres where permanent archiving of the data will be undertaken in similar format to that of A.3.1 and only upon the verified recording of this data will the on-site data record be wiped and the recording medium re-used as desired.

ANNEX B

ESTABLISHING A DATABASE OF SEISMOLOGICAL DATA AND THE IDENTIFICATION OF ANOMALOUS EVENTS

It shall be the responsibility of the Secretariat, on advice from the Technical Committee, to identify, revise, and update as necessary/possible the technical and scientific methodology, such that its intended capability as noted in Annex A is achieved, maintained, and where desirable improved.

B.1 Regional geographic divisions for monitoring; a data base of historic data

B.1.1 The Earth's surface will be divided into seismic; geographical; and local regions (in order of decreasing areal extent). It is anticipated that this hierarchy of regions will honour national territorial boundaries.

B.1.2 The Secretariat will collate a database of seismological data for each region as defined in B.1.1. For seismic events prior to the commencement of the Seismic Network ("historic data"), the database shall derive from that held by the International Data Centre together with any other public-domain data considered necessary thereafter, the data will be obtained from the Seismic Network.

B.1.3.1 "Level I" data will comprise as much as possible of: hypocentres and origin times, magnitudes for P and Rayleigh waves; amplitudes & periods of any other reported phases; earthquake focal mechanisms. "Level II" data will comprise digital seismogram waveforms together with seismograph response characteristics for any station contributing.

B.1.3.2 The Technical Committee shall establish a 'definitive' hypocentre and magnitude reference dataset by reprocessing historic data in the following manner:

(i) selecting from all area an event or events with some or all hypocentre parameters known, or an event large enough to have been widely recorded, and these globally-distributed events to be located in space and time

(ii) taking those events from (i) as 'reference' events and, for each area separately, locating all other events within each area relative to them;

(iii) recomputing P- and Rayleigh-wave magnitudes simultaneously for all events using the maximum-likelihood technique;

(iv) computing for each area a P-wave magnitude formula for shallow-focus events, by determining the distance-correction term, B(delta), for distances at 1-degree intervals up to 40 degrees;

(v) computing for each area an Lg-wave attenuation value and thus a Lg-wave magnitude formula and data set.

In all cases (i)-(v) an 'area' is to be taken as the smallest practicable combination of local regions as defined in B.1.1 with similar tectonic categorization while ensuring that a sufficient number of seismic events are contained within.

B.1.4 The database as described in B.1.3 is to be fully established using historic data no more than 3 years after the Treaty comes into force. The addition of data from the Seismic network will commence as soon as data are available from the network. The reference hypocentre and magnitude dataset may be refined at such intervals as desired by the Consultative Committee.

B.1.5 For all events either (a) determined in B.1.3 to be at a depth of less than 50km, and with an epicentre beneath or within 25km of land or (b) known from data exchanges (B.3.4) to have been underground nuclear explosions, the Secretariat will compile (on a regional basis) a register of: m_b:M_s scattergrams, P-wave spectra, m_b(high-frequency): m_b(low-frequency) (VFM) scattergrams and Love-wave magnitudes. Where the region includes either explosions acknowledged under the data exchanges of B.3.4 or B.3.5 or any other historic events presumed to be nuclear explosions:

B.1.5.1 The choice of high- and low-frequency bandwidths for VFM scattergrams will be refined to optimise separation of explosion and earthquake populations. Optimum decision lines will be determined on both mb:Ms, VFM, scattergrams such that any given event may be assigned a probability of being a nuclear explosion source. An estimate of the amount and character of tectonic release will be made for each explosion. An optimum linear combination of m_b, Ms, and m_b(Lg) (referred to as a "unified magnitude") will be determined to give the best precision possible for a seismic yield estimator.

Where the region does not contain such events,

B.1.5.2 Statistical estimators will be derived for the earthquake m_b:M_s and m_b(HF):m_b(LF) populations' trends in order that any given event may be assigned a measure of its closeness to the mean trend.

Furthermore the Technical Committee shall be charged with an assessment of any other discriminant parameters suggested or implied by research results in the open literature and/or its own seismologists. Those discriminants which are applicable to regional-range (i.e. within 2000 km of source) recordings and/or which improve depth and epicentre resolution shall be prioritised in this assessment.

B.2 Data processing methods and equipment

B.2.1 Satellite transmission at regular intervals of no more than 24hrs will be used to transmit bulk data from International Data Centres to the State Parties. The data transmitted at intervals to the State Parties shall comprise the digital continuous recording at all stations under the control of the International Data Centre. In addition to this routine complete transmission, the International Data Centres will supply, on request from the State Parties, specific time windows and/or station recording.

B.2.2 The means of mass storage at the International Data Centres shall be as defined in Annex A.3.1. These data are to be archived for a time period of no less than 20 years. The storage environment is to be accordance with the storage medium manufacturer's specifications for temperature range, humidity, frequency of tape spooling, ambient magnetic fields, etc.

B.2.3 The International Data Centres are to be equipped with mainframe computers or computers, satellite receiving equipment, and all other data-handling and data-archiving systems to a standardised specification.

B.2.4 All processing algorithms for the operations of:- hypocentre & origin time determination P-wave, Rayleigh-wave, and Lg-wave magnitude determination P-wave spectral analysis and VFM determination and all other data analysis and processing software, are to be standardised among all International Data Centres.

B.2.5 A hypocentre/origin time determination will be carried out automatically using the algorithms of B.2.4 on all seismic events detected by the seismic network within [3] days of receipt of the data at the International Data Centres. All events found to lie beneath, or within 25km of, land at a depth of 50km or less are to be declared candidate explosions on location criteria. All such events will have their $m_b:M_s$ and $m_b(HF):m_b(LF)$ characteristics determined and compared statistically to those of the 'reference' historic dataset and that acquired by the network. All comparisons are to be made on a regional basis as discussed in B.1.5. This comparison may be automated and all newly recorded events with a 65% or higher probability of being explosions flagged, although all $m_b:M_s$ and $m_b(HF):m_b(LF)$ scattergrams must be displayed graphically and examined visually. All seismic events recorded must reach this decision threshold as soon as possible and in less than [30] days of their occurrence.

B.2.5.1 Those events which are assigned a 65% or greater probability of being explosions are to be subject to individual analysis by seismologists of the State Parties. This is to include as a minimum all those feasible of; precise hypocentre location; any supplementary depth estimation procedures such as higher-mode surface wave spectra; focal mechanism estimates using signal polarities, $P_n:S_n$ amplitude ratios or any other means where appropriate; Those subsequently confirmed as being explosions at 95% confidence levels will be passed on by the seismologists to higher authority.

B.2.6 Those events categorised by B.2.5 as 'probable explosions' will be subjected to any/all possible further analysis upon demand/authorisation from higher authority in the light of all supportive evidence from such other means as the State Party has at its disposal, such as preferred locations based on satellite evidence.

B.2.7 In the event of geographical regions and/or specific dates/times being identified by other means available to the State Party as hosting suspicious activity, all seismic events originating from that region/time will be subjected to the higher level of scrutiny as defined in B.2.5.1. A specific array beamform search will be conducted to ensure all possible seismic events have been detected and located and any further events analysed appropriately.

B.3 Information to be supplied by signatories and/or obtained from the public domain

All State Parties are to deposit with the Secretariat, within 1 year of the coming into force of the Amended Treaty, as much as possible of the data specified in B.3.1 - B.3.5 below. The remainder of the required data must be provided within a maximum of a further 2 years.

B.3.1 relevant geoscientific mapping information, pertaining to their territory, to include: surface solid rock types and superficial deposits; depth of water table; areas of permafrost; areas of salt deposits; a topographic database, where possible in digital form; all the above to be resolved laterally to 0.5km.

B.3.2 a register of locations, depths, geological settings, and general
geometries of all standing cavities of volumes:

in excess of 55,000m^3 at depths of less than 300m,

in excess of 40,000m^3 at depths of between 300m and 600m,

in excess of 30,000m^3 at depths of between 600m and 1km, and

in excess of 10,000m^3 at any greater depths;

and of all mining operations requiring vertical shaft diameters of 3m or greater extending to depths of over 1km.

B.3.3 for all geophysically distinct sites used in the past for test firing of nuclear explosives, geoscientific mapping data as defined in B.3.1 to be resolved laterally to 0.1km.

B.3.4 the dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, and yields of all previous test firings of nuclear explosives.

B.3.5 the dates, shot instants, locations, depths of burial, overburden P-wave velocities, S-wave velocities and densities, emplacement medium, yields, and purposes of all firings of nuclear explosives at locations outside the recognised Test Sites as defined in B.3.4, the details to be given separately of all individual explosions in any aggregate or simultaneous firings.

B.3.6 All information in B.3.1-B.3.5 is to be used for designing in detail the seismic array spatial densities and geographic distributions, construction of a reference database of historic data, assigning priorities for real-time array beamform searches, and any other seismological purposes.

B.4 Information to be supplied by all signatories subsequent to the coming into operation of the network

B.4.1 All State Parties will be required to deposit with the Secretariat subsequent to the coming into force of the Treaty all the following:

B.4.1.1 The locations, depth of burial, emplacement medium, anticipated yields, intended detonation date/time, of all non-nuclear explosions of yields of 3 tonnes TNT-equivalent, to be supplied no less than 28 days in advance of the intended detonation date/time. The actual detonation times and dates of these explosions are to be forwarded to the Secretariat as soon as they are known by the State Party.

B.4.1.2 The creation or discovery of any standing cavities or deep mining shafts as defined in B.3.2

B.4.2 The Secretariat, on advice from the Technical Committee, shall have the automatic right and authority to deploy networks of portable seismograph installations in and around the geographic regions identified in B.4.1.1. The temporary network may be sited in the territory of any State Party

B.4.3 The Secretariat, on advice from the Technical Committee, shall design and execute a programme of at least 4 non-nuclear explosions yearly, detonated routinely, with or without prior announcement, and at least 2 of these to be in the yield range 100-400 tonnes TNT-equivalent, in order to test and calibrate the detection, location, identification, and yield estimators, of the established seismic network. The Secretariat shall also be empowered to install temporary portable seismic stations as defined in B.4.2