



**Independent Commission
on the Verifiability of the CTBT**

annex

final report

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**SPEECH TO OPENING MEETING OF THE INDEPENDENT
COMMISSION ON THE VERIFIABILITY OF THE CTBT***

26 OCTOBER 2000

Rt. Hon. Peter Hain, MP

**Minister of Foreign & Commonwealth Affairs
UK**

***Amended during delivery**

Let me start by paying tribute to VERTIC's initiative in organising this Commission, in particular the Chairman, Trevor Findlay.

I should also like to thank the Executive Secretary of the Provisional Technical Secretariat, Mr Hoffman for his co-operation and for allowing his officials to take part today and to the Commissioners who have agreed to provide their time and experience for this important work.

The fact that you are here in your individual capacities as independent experts is important in the light of the differing national views on the CTBT.

By banning all nuclear test explosions, the Treaty will constrain the development and qualitative improvement of nuclear weapons and the development of advanced new types of nuclear weapons. It will be a major step on the road towards ridding the world of the means to destroy itself.

The importance of this treaty and the desire of the International Community to see it enter into force has been underlined on numerous occasions this year such as the NPT Review Conference, the G8 Summit in Okinawa and the ongoing UNGA. There is widespread consensus that this treaty should and must enter into force as soon as possible.

Unfortunately, almost exactly four years after the Treaty was opened for signature, progress towards entry into force has been patchy. To date, only 30 out of the 44 States whose ratification is necessary for the Treaty to enter into force have deposited their Instruments of Ratification and three of those 44 States have yet to sign the Treaty. The UK is, of course, one of the 30 as are two other Nuclear Weapons States, France and Russia. We take every opportunity to encourage others to join us and I would again today urge all States to sign and ratify the Treaty as soon as possible.

India and Pakistan have announced unilateral moratoria on further nuclear explosions. I welcome these announcements. But, they cannot be a substitute for signature and ratification of the CTBT. I hope that efforts in both countries to build consensus in favour of signature will soon result in a positive outcome.

We attach great importance to the push towards entry into force, the so-called Article XIV process, currently being ably guided by our Japanese colleagues. Last year's conference in Vienna, which I attended, was designed specifically to encourage further Treaty signatures and ratification, did just that. We are keen to see another Article XIV conference next year and encourage Ambassador Abe [who is with us today] in his efforts to take forward arrangements. We must use this Conference to maintain the political momentum in support of the Treaty.

Clearly, a major obstacle in persuading others to sign was the vote in October last year by the US Senate not to ratify the Treaty. That was a matter of deep regret to us, and an obvious set back to the Treaty. But it is important that it should be seen as no more than that: a set back. We must not let the Senate's decision be an excuse for others to delay their own signature and ratification of the Treaty.

Equally importantly, we must not let the Senate's vote be an excuse to delay the work necessary to prepare for the Treaty's entry into force. We welcome and support the efforts being made by the US Administration to take forward the debate in their country, particularly the appointment of General Shalikashvili [General Shali] to head the Task Force. I hope that these efforts, together with the work of this Commission will clarify issues raised during the US' consideration of the Treaty. I further hope that the incoming Administration will continue these policies and make the ratification of the CTBT a priority.

The basis for the verification system is, as you well know, set out in the treaty itself

"In order to verify compliance with this Treaty, a verification regime shall be established consisting of the following elements:

- (a) An International Monitoring System;
- (b) Consultation and clarification;
- (c) On-site inspections; and
- (d) Confidence-building measures."

Britain is confident that the verification regime described in the Treaty will provide a credible, effective and cost effective way to monitor compliance with the Treaty. But, we acknowledge that others may not share that view. We also acknowledge that technology has changed, even in the short time since the CTBT was negotiated. We believe that it is right therefore for independent experts such as yourselves to take a fresh look at the verifiability of the Treaty and to give us the benefit of your expertise.

The CTBT exists because of the political will of the negotiating States to negotiate the treaty. But the work, the desire to see a functioning Treaty did not end with the conclusion of the negotiations. It only began. We must now address issues such as providing the Provisional Technical Secretariat with adequate resources to enable it to fulfil the requirement of the Treaty. The Provisional Technical Secretariat must be given the means to have a verification regime in place at entry into force capable of meeting the verification requirements of this treaty.

I know that the amount of financial resources that the Provisional Technical Secretariat needs to carry out its functions has been a subject of some debate in the course of the year and indeed in previous years. Britain has already made clear our belief that the level of budget and programme for 2001 as now proposed by the Provisional Technical Secretariat is reasonable. We will support this budget when it comes up for discussion at the Preparatory Commission in November. We hope that others, particularly those who are the leading proponents of nuclear disarmament will do likewise.

The work of establishing the verification system also means dealing with other issues such as how the key work of putting together the On Site Inspection Manual can gain badly needed momentum. I understand that there has been recent progress during discussions in Vienna in at least agreeing the process by which we can do this. Next year, it will be vital to tackle the substance.

Your work will by definition concentrate on technical aspects of CTBT verification. But Governments must maintain the political momentum which brought the CTBT into being. We must make sure that the technical discussions in Vienna do not become bogged down or delayed. Beyond that, we have a wider duty to create the conditions which remove the need to develop nuclear weapons and other weapons of mass destruction. We must build on the results achieved at the NPT Review Conference earlier this year to advance towards our common goal: the global elimination of nuclear weapons and other weapons of mass destruction. We must consolidate progress made towards eliminating chemical warfare – 136 countries are now participating in the OPCW. We have a Verification Protocol for the Biological Weapons Convention that is within our grasp. We must ensure that humankind is denied the tools to for self-destruction. The British Government is committed to playing an active and positive role in achieving these goals. We will continue to play this role to the full.

All the WMD instruments are underpinned by verification systems. Each has their critics. But, I leave you with one thought. Those who criticise the Treaty need to consider whether they prefer the alternative: the proliferation of nuclear weapons. I prefer that our discussion today should be about how best to verify a Treaty banning nuclear test explosions than about how best to monitor the explosions that the absence of the treaty would permit.

COMPLETING THE CTBT's VERIFICATION REGIME: PROGRESS AND CHALLENGES

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INTRODUCTION

Four years after the Comprehensive Nuclear Test Ban Treaty (CTBT) was opened for signature, the treaty's verification system is being progressively established. After a slow start, which was mainly due to the novelty of setting up a verification system based on a global network of monitoring stations, implementation is now making good progress. The Preparatory Commission (PrepCom), which marked its third anniversary in April 2000, and the Provisional Technical Secretariat (PTS), both of which are in charge of setting up the International Monitoring System (IMS) and its associated components, have identified the major hurdles which stand in the way of completing the system and have begun to allocate resources accordingly. The Provisional CTBTO is evolving quickly into a fully-fledged international organisation. As of 25 September 2000 the PTS employed 242 staff from 70 signatory states—making it more than two-thirds complete. Although there are still political and technical hurdles to be overcome, such as the development of on-site inspection arrangements, the PTS could complete its work before the treaty enters into force. This will, however, require the undiminished political, technical and financial support of all states signatories.

THE INTERNATIONAL MONITORING SYSTEM (IMS)

BACKGROUND

The IMS will consist of 321 monitoring stations and 16 radionuclide laboratories located in some 90 countries. Some of these already exist, while others will have to be constructed. Two hundred and one of these stations belong to the primary network, which will be providing data to the IDC which has been collected on a continuous, round-the-clock basis. In many cases IMS stations use existing infrastructure, upgraded and certified for use by the IMS. Sixty-two per cent of the network of 120 auxiliary seismic stations, which will supply data only on request, essentially meet technical specifications already.

Four types of stations are to be established—seismological, infrasound, hydroacoustic and radionuclide. The seismic network will form the core of the verification system. Seismic waves generated by earthquakes, explosions or other phenomena will be detected using 50 primary and 120 auxiliary seismic stations, distributed worldwide. In addition, 11 underwater hydroacoustic stations are being set up. Sixty land-based infrasound stations will use sonar to detect atmospheric tests, while 80 radionuclide stations will measure radioactive particles in the atmosphere from atmospheric nuclear tests or underground tests that vent. Sixteen radionuclide laboratories will analyse filters from the stations, as well as samples taken by inspectors.

The four different technologies operated by the IMS are complementary and are able to detect tests in different environments. Seismic monitoring is best at detecting underground tests—although it might also be able to discern atmospheric tests conducted at low altitudes. Hydroacoustic technology primarily monitors the oceans and infrasound is most efficient at detecting atmospheric tests—although it may also detect some underwater and shallow underground events. Seismic and acoustic detection technologies under specific circumstances might not provide enough conclusive data to reveal whether a large conventional explosion or small nuclear test has taken place. Radionuclide stations could be the most powerful tool in clarifying the nature of an event by detecting radioactive particles.

States parties may also contribute data to the IMS from so-called Co-operating National Facilities (CNFs). CNFs are national stations which can be called on by the CTBTO to clarify suspicious events. Such stations are operated by treaty parties but have undergone the same certification procedures, including the authentication of communication links, as IMS station.

PROGRESS IN STATION ESTABLISHMENT AND CERTIFICATION

After a slow start, the setting up of the required IMS stations is progressing steadily. In the early days of the PTS, many legal and bureaucratic hurdles had to be overcome before construction and/or certification of a station could begin. The PTS first had to establish the legal procedures for setting up stations and establish links with National Authorities and scientific co-operating partners in IMS participating countries.

Another impediment is the complex certification process. In order to certify a station, the PTS has to be assured that technical specifications are substantially met and data from the stations can be authenticated. Finally, a proper link to the global communications infrastructure (GCI) has to be established. Setting up a new IMS station—from the planning stage to certification—takes at least two years.

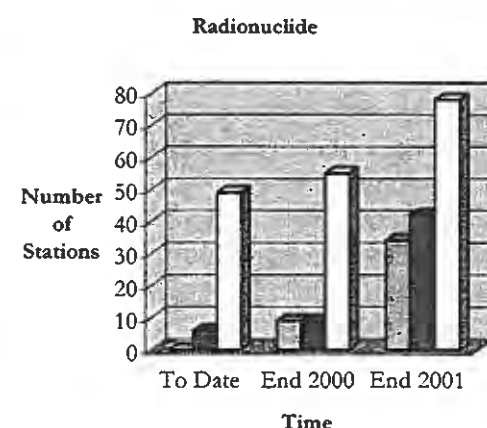
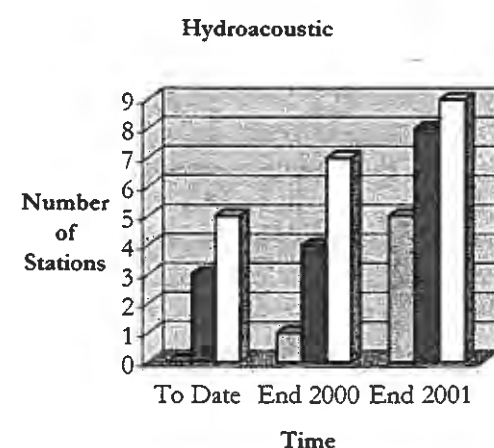
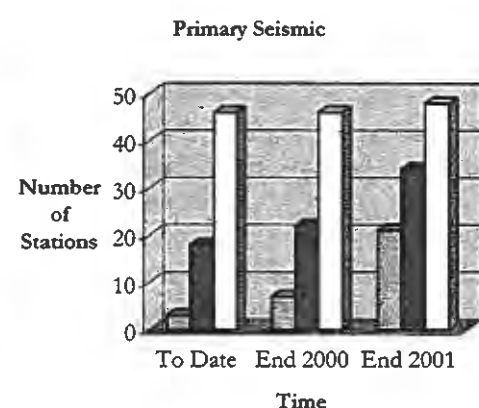
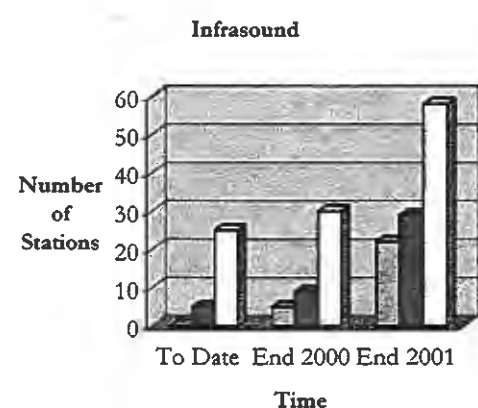
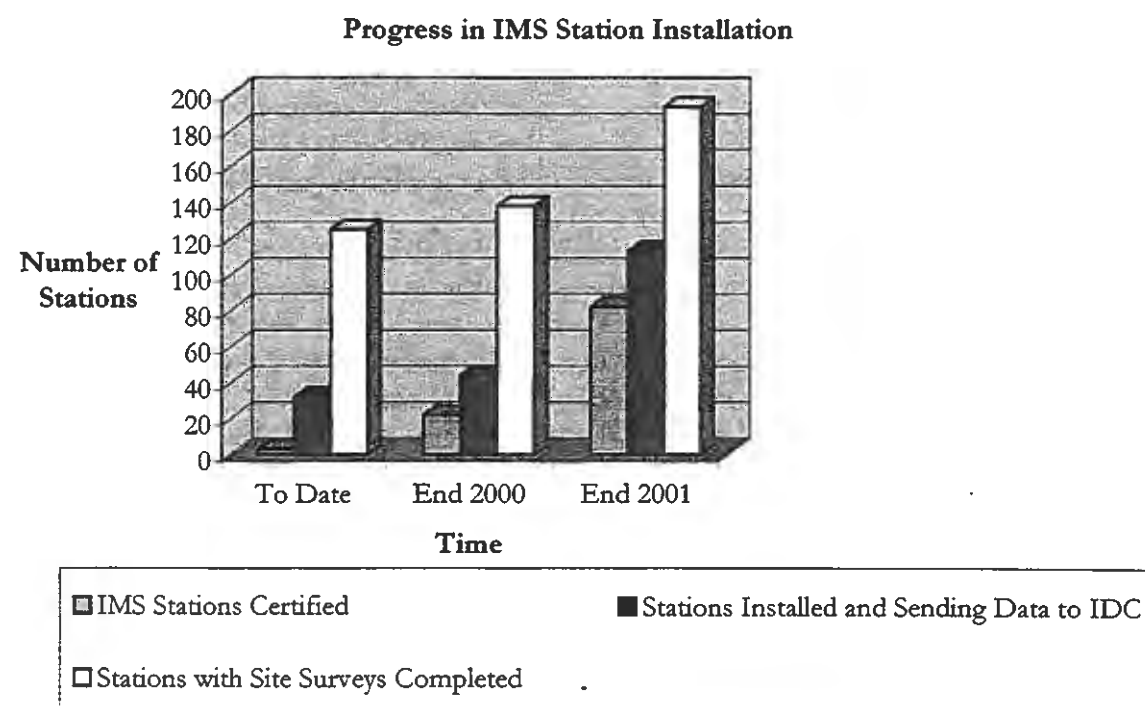
On 28 July 2000, the first three IMS stations (primary seismic facilities in Canada, Norway and the United States) were certified. The PTS estimates that the number of IMS station that have a site survey completed, are installed, or are certified, will increase dramatically over the next couple of years. As the figures below show, this is true for all four monitoring technologies. Current plans are that by the end of 2001, ninety-six per cent of site surveys will be completed, 56 per cent of stations will be installed and sending data to the IDC, and 41 per cent of the stations will have been certified.¹

Calibration of IMS stations has been slow. Four conventional explosions have been conducted to calibrate IMS stations, three in Kazakhstan, in cooperation with the United States, and one in the Red Sea conducted by Israel. An explosion in Kazakhstan in October 1999 was also used for an on-site inspection exercise by the PTS. The most recent explosion in Kazakhstan destroyed the last tunnel at the former Soviet nuclear test site Semipalatinsk, which is now officially dismantled.

LEGAL FRAMEWORKS

Certification of stations must be covered by an agreed legal framework, 'facility agreements or arrangements', between the PrepCom and host states. These must be approved by the PrepCom if they differ substantially from the model agreement provided by the Secretariat. The Executive Secretary of the PTS has urged those governments that have not yet negotiated facility agreements to do so.² So far, fourteen have been concluded. Two hundred and eighty IMS facilities in 60 countries were covered by some kind of legal arrangement by the end of September 2000.³ Site surveys for 125 of the 201 IMS stations in the primary network are complete.⁴

For about 30 stations, and one radionuclide laboratory, new sites had to be found when site surveys revealed that the co-ordinates given in Annex 2 of the treaty were unsuitable. The reasons included excessive background noise or because the locations were at sea or in other unsuitable areas.⁵



Source: Data from Peter Basham, 'The Current Status of the CTBTO Monitoring System', Contribution to the Independent Commission on CTBT Verifiability, <http://www.ctbtcommission.org/bashampaper.htm>

INTERNATIONAL DATA CENTRE (IDC) AND GLOBAL COMMUNICATIONS INFRASTRUCTURE (GCI)

Integrating data on a large scale from many different sources poses a completely new monitoring and verification challenge to an international organisation, but is also likely to result in great synergies. The IDC, which is being progressively commissioned in Vienna, will receive and process data from all IMS monitoring facilities via a dedicated Global Communications Infrastructure (GCI).

The GCI will use very small aperture terminals (VSATs) to ensure the swift and secure transport of up to 11.4 gigabytes of data between facilities, the IDC and states parties. By March 2000, VSATs had been installed at 25 IMS facilities. Fifty are expected to be installed by the end of 2000.⁶ Three communications 'hubs', which receive data from IMS stations in a particular region and forward it to the IDC, are located in Germany (European hub), Italy (Atlantic and Indian Ocean hubs) and California (Pacific Ocean hub). They are all complete and transmitting data.

Data from seismic and acoustic stations will be received by the IDC in near real time and be available within a few hours to states parties which wish to receive it. Data processing will be largely automated. The second of four software releases for this purpose was installed at the IDC in late 1999. On 20 February 2000 the IDC assumed responsibility for collecting and disseminating data from the IMS stations in operation. Of the 201 stations in the primary network, 32 are sending data to the IDC. This number is expected to rise sharply over the next few years, with more than 50 per cent of stations reporting to the IDC by the end of 2001.

Unlike the four types of 'wave form' data, radionuclide data will be available after a delay of several days because samples have to be physically collected and analysed. New technologies currently being developed may automate data transmission from stations in remote areas, but this will not shorten the time necessary for analysis.

It is the IDC's responsibility to screen out events which are clearly of natural origin, as well as those which are clearly non-nuclear and man-made, such as large conventional explosions. A large percentage of all earthquakes, for instance, occur at depths at which it is impossible to conduct clandestine nuclear tests. By applying screening criteria to the vast amount of data delivered to the IMS, the number of potentially suspicious events can be dramatically reduced. The IDC will issue Standard Event Bulletins, which indicate the degree to which each detected event meets specific screening criteria.⁷ States without significant national technical and analytical means will naturally look to the IDC for more precise information if suspicions are aroused concerning a particular event. The IDC is expected to assist any state party in the technical analysis of IMS data as well as data provided by other states parties.⁸

Forty-four signatory states are currently receiving IMS data and 'products' on a trial basis. On 21 February 2000 the IDC started to distribute Reviewed Event Bulletins (REBs) to member states. They have been issued daily for the past few months, even though this was not planned for the current Phase 4 of the establishment of the IDC. Due to a shortage of staff and the constraints of a 5-day working week, REBs are currently being distributed with several days' delay.

Some member states have urged the PTS to ensure that the IDC distributes products on a more timely basis. In order to do this under current operational limitations, PrepCom Working Group B (responsible for verification) suggested the IDC do this for 5 daily REBs per week. This will be done by expanding the IDC's work schedule to a 6-day working week. The immediate goal is to demonstrate that the IDC is capable of distributing data in near-real time, around the clock, without implementing this on a permanent basis prior to entry into force. It is planned that during Phase 5 of the IDC's installation (commencing in early 2001), the timely production of REBs will be increased from 5 to 7 per week.

To evaluate the work of the IDC, Working Group B has commissioned an external expert evaluation. Led by the UK's Ian Kenyon, formerly of the Organization for the Prohibition of Chemical Weapons (OPCW), six international experts will spend two to three weeks in Vienna to evaluate whether the IDC is fulfilling its mandate and what possible improvements could be made. Topics to be considered by the Evaluation Team include: the implementation of PrepCom guidelines by the IDC; the overall state of the IDC and the GCI; as well as the interaction between the IDC and other parts of the PTS, states signatories and the broader scientific community; and possible improvements in the scientific methods and software used by the IDC. The experts will report to the PrepCom in November 2000. If successful, external consultants might be used to evaluate other parts of the PTS.

THE CONTRIBUTION OF NON-IMS CAPABILITIES

Member states can also submit data from national technical means (NTM) of verification to the Executive Council in the course of consultation and clarification procedures or to support a request for an on-site inspection. It is likely that states will use a very broad definition of NTM, enabling them to table almost any information that they deem relevant and politically acceptable. Thus, a state could, for example, table information from its own signals intelligence, satellite imagery obtained from its own satellites or those operated commercially, or data collected by scientists anywhere in the world.

Data from scientific networks might carry greater weight because they will have been collected transparently and been peer reviewed. In any case, whatever information states might table in the Executive Council, suspicious events are likely to be detected, discussed, analysed and evaluated outside the Council. As has happened in past, for example when India and Pakistan conducted their nuclear tests in May 1998 and when the US government accused Russia of having conducted clandestine nuclear tests in August 1997, data from non-IMS stations will be distributed and discussed widely within the international scientific community.

While the CTBT does not explicitly ban nuclear test preparations, commercial satellite pictures can provide an important addition to the IMS because they can detect such preparations. Non-governmental organisations are already monitoring nuclear test sites using such data.⁹

The question is therefore not whether non-IMS capabilities can strengthen monitoring of compliance with the nuclear test ban but how this can be best achieved. Attempts to introduce new monitoring techniques would complicate the task of the PrepCom as it seeks to fully establish the verification system already provided for in the treaty. On the other hand, the treaty does commit states parties to 'cooperate with the Organization and with other States Parties in the improvement of the verification regime and in the examination of the verification potential of additional monitoring technologies...with a view to developing, when appropriate, specific measures to enhance the efficient and effective verification of this Treaty'.¹⁰ It specifically mentions electromagnetic pulse detection and satellite monitoring in this context.

ISSUES TO BE RESOLVED

ON-SITE INSPECTIONS MANUAL

In parallel to setting up the IMS, the PrepCom is also laying the groundwork for on-site inspections (OSIs). OSIs may be ordered by the Executive Council to clarify suspicious events—on the basis of signals detected by the IMS and /or information from NTMs submitted by a state party. The CTBTO will not, unlike the OPCW, have a standing OSI inspectorate, but will draw on a pool of trained inspectors nominated by member states. This pool needs to be geographically representative and large enough to provide a team of up to 40 inspectors within six days. Inspectors will require a diverse range of skills and the ability to work in harsh climates or terrain. By October 2000 one hundred and fifty participants from 69 states signatories had successfully undertaken three introductory courses conducted by the PTS.

OSI teams will be permitted to spend up to 130 days on an inspected state's territory and will therefore require significant in-country support. Substantial amounts of portable equipment will also be needed, including geophysical and radionuclide equipment, drilling equipment, communications equipment and the means to conduct overflights.

The development of an Operations Manual (OpsMan) for on-site inspections is proving one of the most difficult areas of the PrepCom's work, largely because too many fundamental issues were left unresolved by the treaty negotiators. While OSI provisions received insufficient attention during the early days, when establishing the IMS was the first priority, in November 1999 the PrepCom took steps to speed up the development of OSI procedures. The budget for developing an OSI capacity was doubled and a group of Friends of the OSI Programme Coordinator was established, open to participation by all signatories, to draft a text for an OSI manual.

This process faces several difficulties. First, there is no agreed understanding of the scope and the purpose of the manual. Israel, which is wary of intrusive OSIs for reasons unrelated to the CTBT, favours a minutely detailed manual which explains the purpose, methodology and parameters of the activities to be undertaken by inspectors. Others, including the United States, prefer a manual that outlines general responsibilities of the inspectors, but leaves room for flexibility and is within the spirit of the treaty's OSI provisions. Specific questions which need to be resolved include: should an inspection team only be allowed to look for evidence relating to an ambiguous event, or should it be allowed to 'look around' the inspection area? What kind of data should it be allowed to collect? What kind of managed access provisions are necessary in case the team needs to access or inspect a facility? What are the rules for inspecting so-called restricted access areas?¹¹

Decisions about equipment to be used by inspectors are also affected by disagreement about the nature of OSIs. Thus, it has been argued that inspection equipment must not reveal information irrelevant to the inspection's purpose. This has made it more difficult to use off-the-shelf technology for OSIs, for example to analyse samples for radionuclide traces.

Second, the development of the manual has until very recently depended on national contributions, since the PTS was not allowed to propose language. Fortunately, this is no longer the case and the PTS has contributed several working papers to the OpsMan draft.

Third, the current drafting method, in which national contributions are simply compiled into a rolling text that now amounts to 1,000 pages, is too slow and ineffective. Working Group B has initiated a new process intended to speed up the drafting. Based on contributions received so far, the Chairman of the Friends of the OSI Programme Coordinator will compile a draft Rolling Text for the OpsMan with the assistance of others. Discussions on the basis of this Rolling Text will be initiated at a special meeting of Working Group B in February 2001. More time in the intersessional periods has been allocated to the drafting process and it is hoped that more delegations will be drawn into the drafting process at the February meeting.

Finally, there is a danger of linkage between completion of the OSI manual and entry into force of the treaty. At least one state whose ratification is required for entry into force has indicated that it might not ratify before substantial parts of the OSI arrangements have been agreed. It would be deplorable if disagreement over the least important element of the CTBT's verification system for day-to-day monitoring of compliance were to delay entry into force.

Clearly, any attempt to renegotiate the CTBT through the back door of negotiations on the OSI provisions is a cause for concern. A flexible mandate for inspectors, within clearly defined boundaries, will increase the chances that clandestine tests are identified. Experience in other verification regimes also shows that many of the fears articulated during treaty negotiations and the preparatory process prior to entry into force turn out to be exaggerated when regimes begin functioning. This is even true where intrusive inspections are conducted on a regular basis and affect private companies, as is the case with the 1993 Chemical Weapons Convention.

CONFIDENTIALITY RULES

Because the IDC will soon start to distribute data and products to member states on a large scale—including daily 'Fused Event Bulletins', *ad hoc* event bulletins and analyses of data—the implementation of the 'confidentiality' provisions of the treaty has become a controversial issue in the PrepCom. The treaty itself provides only that it is the duty of the Technical Secretariat to 'make available all data, both raw and processed, and any reporting products, to all States Parties' (Article IV paragraph 14.e). It is unclear whether this excludes the possibility of making information available to others.

Scientific and humanitarian relief organisations are especially interested in receiving data from IMS stations. Data from the seismic network is of interest to seismologists in improving their ability to predict earthquakes and other natural phenomena. Hydroacoustic stations could give early warning of tsunamis, while infrasound stations could warn of volcanic eruptions.

China and other states have argued that for security reasons access should be restricted to governments. Some Western states and others favour a more open policy, arguing that IMS data has little national security relevance. It will in any case be difficult to prevent leakage of the data, since data centres in all CTBT parties will have direct access to it. In order to evaluate confidentiality rules, the PTS is planning a phased release of certain types of data to a limited number of non-state recipients. Thus, humanitarian organisations could promptly receive IMS data for disaster relief operations, while others would have only delayed access. The proposed test of a delayed release of certain types of IMS data beyond states parties' National Data Centres has not begun because of the continued resistance of at least one state party.

COSTS

The 2000 PrepCom budget is \$US 79.9 million, compared with \$US 74.7 million in 1999 and \$US 58.4 million in 1998. The collection rate for assessed contributions to the budget was approximately 96 per cent for the 1999 budget and 92 per cent for 2000. This is a good record compared with most international organisations, but needs to be maintained.

Even though the PrepCom's two Working Groups and the PrepCom itself still define the parameters of the work of the PTS, it is gradually becoming more independent. While the PTS has generally accepted responsibility for paying for the operating and maintenance costs of primary IMS stations after certification, a question remains as to whether it should wholly or partially pay the operating costs for auxiliary seismic stations after their certification. These stations are 'dual use' and mostly serve scientific purposes. They need to be certified by PTS, but will only report to the IDC on request (for example to clarify a suspicious event).

Some auxiliary stations are also nominated to back up primary stations in case they cannot report. If entry into force is substantially delayed, states might decide to switch off stations already reporting to the IDC to save costs. One way to resolve this question would be for the PTS to provide financial assistance to states having trouble funding their auxiliary stations.

Cost estimates for non-seismic stations made during negotiations on the CTBT have been consistently too low because expenditures for installation, especially in remote locations, were not taken into account and because little experience with novel monitoring technologies existed.

PrepCom 2000 Budget (\$US 79.9 million)

- \$US 40.2 million for establishing or upgrading IMS stations
- \$US 12.6 million for the IDC
- \$US 7.3 million for establishing the global communications infrastructure
- \$US 2.8 million towards developing an on-site inspection capacity
- \$US 13 million on administration.

Source: CTBTO PrepCom document CTBT/PC-10/1/Annex V '2000 Programme and Budget', Tenth Session, Vienna, 15-19 Nov. 1999.

In its 2001 budget projection the PTS has called for a moderate increase to \$US 94.9 million. Some signatories have insisted on a smaller budget and it now seems more likely that the 2001 budget (which will be approved during the November 2000 session of the PrepCom) will be in the order of \$US 85 million. While it is positive that there will be an increase in real terms compared to the 2000 budget, the fact that some member states have again insisted on cuts is worrying, for several reasons.

First, a static or shrinking PTS budget is hard to reconcile with the investment required to have the verification system fully functioning at entry into force. The PTS has estimated that the

investments necessary for fully establishing the IMS require over \$US 100 million per year for at least two years.

Second, budgetary pressures are likely to increase as more IMS stations are certified and the PTS assumes operational and maintenance costs for them. This will make it harder to maintain a rising level of investment in new stations, an important yardstick for assessing progress in completing the verification system.

Third, member states' insistence on budget cuts may signal reduced political support for the treaty and its verification system. It is especially worrisome if those states that are otherwise prominent in promoting the nuclear disarmament agenda insist on budget cuts. In some cases, attempts to micromanage the PTS budget have also led to problems by limiting the time available for discussions on the future of the PTS. In general the PTS should be given more leeway in managing its budget.

THE WAY AHEAD

According to Article IV of the CTBT, the IMS must be able to meet verification requirements at entry into force of the treaty, which will occur six months after all 44 states required to ratify the treaty have done so. From a legal perspective this requires that all three operational manuals—for the IMS, the IDC and OSIs—are ready for adoption by the first conference of states parties. In practical terms, it means that the verification system needs to be workable and have global coverage.

While the exact date of entry into force is unpredictable, the PTS is now planning on the basis that the IMS will need to be completed by 2005 at the latest. However, contingency plans exist should entry into force be achieved earlier. This will depend on the political support of signatories, as well as on their willingness to make the necessary technical and financial contributions.

NOTES AND REFERENCES

¹ Peter Basham, 'The Current Status of the CTBTO Monitoring System', Contribution to the Independent Commission on CTBT Verifiability, <http://www.ctbtcommission.org/bashampaper.htm>

² CTBTO PrepCom document CTBT/PC-9/1/Annex III, 2 Sept. 1999, p. 8.

³ 'Comprehensive Nuclear-Test-Ban Treaty – Four Years Old' Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization, Provisional Technical Secretariat, Press Release, 25 September 2000.

⁴ Peter Basham, 'The Current Status of the CTBTO Monitoring System', Contribution to the Independent Commission on CTBT Verifiability, <http://www.ctbtcommission.org/bashampaper.htm>

⁵ CTBTO PrepCom document CTBT/PC-10/1/Annex II, 24 Nov. 1999.

⁶ Peter Basham, 'The Current Status of the CTBTO Monitoring System', Contribution to the Independent Commission on CTBT Verifiability, <http://www.ctbtcommission.org/bashampaper.htm>.

⁷ Protocol to the CTBT, Part I, Section F, paragraph 18.

⁸ Protocol to the CTBT, Part I, Section F, paragraph 20.

⁹ The Institute for Science and International Security, for example, has published recent images of the Pakistani test site in the Kharan Desert on the internet. These can be found at <http://www.isis-online.org/publications/southasia/satindex.html>

¹⁰ CTBT, Article IV.11.

¹¹ On these questions see Mordechai Melamud, 'Background Paper on On-Site Inspections (OSI) Main Elements and Expectations', <http://www.ctbtcommission.org/melamudpaper.htm>

**THE CURRENT STATUS OF THE CTBTO INTERNATIONAL
MONITORING SYSTEM**

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INTRODUCTION

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) was opened for signature at the United Nations in New York on 24 September 1996. At the time of writing (October 2000) the Treaty has been signed by 160 States and ratified by 63 States. The Preparatory Commission for the CTBT Organization was established on 19 November 1996 at a meeting of States Signatories. The Provisional Technical Secretariat (PTS) of the CTBTO, the agency responsible for establishing the verification system for the CTBT, took up its work in Vienna on 17 March 1997.

This paper presents a brief account of the current status of the development of the International Monitoring System (IMS), including the International Data Centre (IDC) and the Global Communications Infrastructure (GCI). It also presents a projection of the expected status of the IMS stations at the end of 2001, assuming Preparatory Commission approval of the draft 2001 Programme and Budget, which is currently under consideration by States Signatories, at its November 2000 session.

THE INTERNATIONAL MONITORING SYSTEM STATIONS

Establishment of the 321 IMS stations in 90 countries is considered to be among the most challenging tasks in establishing the verification system. Progress in establishing the IMS stations may be measured in three categories: (1) site surveys completed, (2) stations installed and sending data to the IDC, and (3) stations certified. The site surveys are important in establishing that the sites chosen during the Treaty negotiations, or nearby sites if the Treaty locations are found to be unsuitable, are suitable for IMS stations. The number of stations installed and sending data is important because it measures the proportion of the final networks that are contributing to IDC products. The number of stations certified is important because it indicates the number of stations that have been accepted as meeting all PTS standards and are officially incorporated into the verification system. The number of primary seismic, infrasound, hydroacoustic and radionuclide stations in each of these categories is shown in Table 1. "To date" indicates the current status; projections are also made for the end of 2000 and the end of 2001. Auxiliary seismic stations are described separately below.

Site surveys have been completed, or were found unnecessary for some existing stations, for a large majority of the primary seismic stations (Table 1(a)). In the other technologies, roughly half of the site surveys have been completed. In the infrasound and hydroacoustic technologies these have all been new stations requiring site surveys. In the radionuclide technology all of the site surveys have also been done anew, but some data was available for some sites from previously existing national environmental monitoring stations.

TABLE 1(a) NUMBERS OF IMS STATIONS WITH SITE SURVEYS COMPLETED

Technology	To Date	End 2000	End 2001
Primary Seismic (50)	46	46	48
Infrasound (60)	25	30	58
Hydroacoustic (11)	5	7	9
Radionuclide (80)	49	55	78

TABLE 1(b) NUMBERS OF IMS STATIONS INSTALLED AND SENDING DATA TO THE IDC

Technology	To Date	End 2000	End 2001
Primary Seismic (50)	18	22	34
Infrasound (60)	5	9	29
Hydroacoustic (11)	3	4	8
Radionuclide (80)	6	9	42

TABLE 1(c) NUMBERS OF IMS STATIONS CERTIFIED

Technology	To Date	End 2000	End 2001
Primary Seismic (50)	3	7	21
Infrasound (60)	0	5	22
Hydroacoustic (11)	0	1	5
Radionuclide (80)	0	9	34

The number of stations installed and sending data to the IDC to date indicated in Table 1(b) are the numbers of stations upgraded or established by the PTS, or through gifted or reduced assessment national funding. They do not include additional stations in all technologies that are contributing data voluntarily to the prototype IDC and onward to the IDC (see IDC section below).

Certification of stations, the formal process of accepting stations as meeting all technical requirements of the PTS, is considered by States Signatories as an important measure of progress in developing the IMS. These have been slow in coming primarily because the implementation plan for authentication, required for certification, was not available until mid 1999. This process is now advancing quickly, with three primary seismic stations having been certified in July 2000, and as many as 20 stations, including all technologies, may be certified before the end of the year.

The 120 auxiliary seismic stations selected during the Treaty negotiations were selected primarily from lists of existing stations. With these stations operated for other national purposes, it was considered that money would be saved by the PTS in not having to build or

operate these stations. The PTS has recently undertaken a detailed assessment of the technical state of the auxiliary seismic stations. It found that 62% of these stations essentially meet PTS technical specification, except for authentication devices and a GCI connection to the IDC. The other 38% will require substantial work, ranging from a major upgrade to some new stations that will need to be constructed at new sites. Because of the wide range of conditions that we find with the auxiliary seismic stations they did not fit easily into the categories of Table 1 and were therefore not included in that table. The PTS work on auxiliary seismic stations has been concentrated on, firstly, establishing new stations where they previously did not exist or were in a very poor technical state, and, secondly, undertaking the developments that would provide authentication and a GCI connection for many of the stations operated by national and international network operators that essentially meet PTS technical specifications. This strategy will likely continue, and it is expected that the auxiliary seismic network can be brought to completion in the same time frame as the other networks.

The statistics provided for radionuclide stations in Table 1 refers to radionuclide particulate stations. The Treaty states that 40 of the 80 radionuclide stations will also have noble gas monitoring equipment at entry-into-force of the Treaty. The PTS is currently experimenting with four brands of noble gas monitoring equipment, operated side by side, at the Institute for Atmospheric Radioactivity in Freiburg, Germany. Phase 3 of this experiment, to begin in early 2001, will place the four experimental units in actual station environments which will sample a variety of climatic conditions. Decisions will be made in late 2001 on a possible extension of Phase 3 of the experiment.

THE INTERNATIONAL DATA CENTRE

The physical facilities for the IDC were essentially completed in 1999 at the Vienna International Centre. The IDC build-out is now at the end of Phase 4 (Initial Testing of the IDC) of the seven phases that will bring the IDC to operational readiness. The applications software for the IDC is being developed at the prototype IDC in Arlington VA, USA, and delivered to the Vienna IDC in four Releases. The IDC staff are currently installing and testing Release 3, which will provide for Phase 5 of the commissioning plan, full scale testing of the IDC.

About 100 IMS stations in all four technologies are now contributing data to the IDC. These include stations in addition to those described above as established by the PTS, stations that began contributing data voluntarily to the prototype IDC under the GSETT-3 experiment, or, at a later stage began contribution voluntarily in order for the IDC to have sufficient data to test and develop processing procedures.

In February 2000 the IDC began, and the prototype IDC stopped, distributing test products. There are currently 44 secure signatory accounts established with States Signatories to receive IMS data and IDC products.

THE GLOBAL COMMUNICATIONS INFRASTRUCTURE

Global satellite coverage for the GCI was established in June 1999 with the commissioning of communications hubs to cover the Middle East and Europe, Atlantic Ocean, Indian Ocean and Pacific Ocean regions. Terrestrial links have been established to the independent sub-networks in a number of countries and very small aperture terminals (VSAT satellite dishes) have been established at about 20 National Data Centres for purposes of receiving IDC products. VSATs are being installed at IMS stations in States Signatories that have opted for the basic GCI topology, in coordination with the buildup of the stations; about 50 such VSATs are expected to be installed at IMS stations by the end of 2000.

PROJECTED STATUS OF IMS STATIONS AT THE END OF 2001

Table 1 shows the projected status of the IMS stations at the end of 2001. This is based on the current draft of the 2001 Programme and Budget and assumes that the Preparatory Commission will approve this budget at its final meeting in November 2000. Overall, the figures suggest that by the end of 2001 96% of the site surveys will be completed, 56% of the stations will be installed and sending data to the IDC, and 41% of the stations will have been certified.

RADIONUCLIDE MONITORING SYSTEM

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The radionuclide monitoring system has three components, particulate detection at 80 stations, noble gas detection at 40 out of the 80 stations and 16 laboratories for additional analysis of samples.

The objective of the radionuclide network of stations is to detect radionuclides from a nuclear weapon's test as a proof that a nuclear explosion has taken place. The combination of particulate and noble gas detection will provide a very high probability to identify an event as nuclear weapons test. Even the differential diagnosis against releases from fresh-fueled nuclear reactors should be possible.

To install and operate a radionuclide station is much more sophisticated than doing gamma spectroscopy in a well-established laboratory. State-of-Health Monitoring, continuous power supply, maintenance etc. is a significant part of the whole undertaking in order to assure 95% availability of data meeting all requirements.

THE PARTICULATE RADIONUCLIDE STATIONS

Particulate Radionuclide Stations consist basically of an air sampler, a highly sensitive Gamma Ray Detector, control and auxiliary equipment.

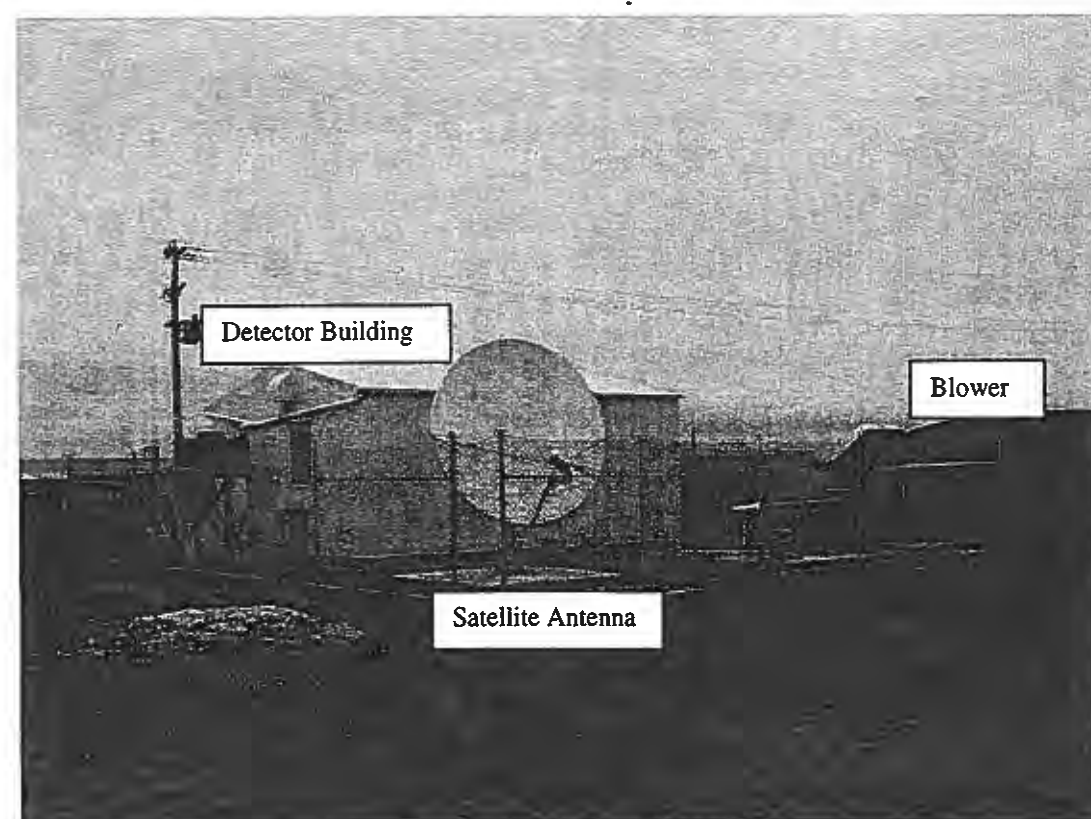


Fig. 1: A Radionuclide Station (RN46, Chatham Islands, New Zealand).

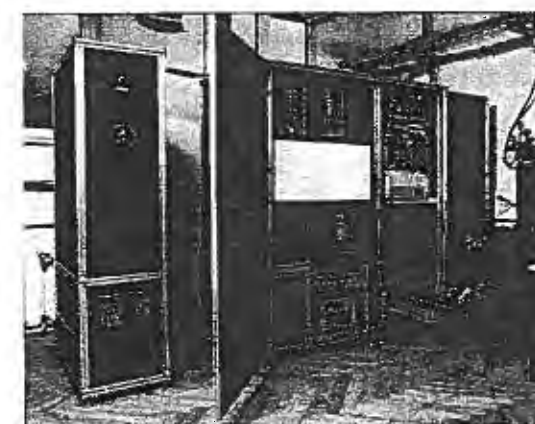
Six particulate systems are installed and currently sending data through the CTBTO GCI system. Five of them establish the South Pacific Mini-network with two stations in Australia, two in New Zealand and one in Cook Islands. The certification visits have been performed successfully and the stations will probably be certified in November 2000. Spectra and State-of-Health data can be checked in Vienna anytime. The stations monitor Central and South Australia, the Tasman Sea and New Zealand.

The 6 stations sending data together with 8 other quite advanced installations form 18% of the particulate network.

The detection limit of 10-30 $\mu\text{Bq}/\text{m}^3$ for Ba-140 particulates is a quite ambitious requirement and it is not expected that this limit can be significantly improved in the near future.

NOBLE GAS SYSTEMS

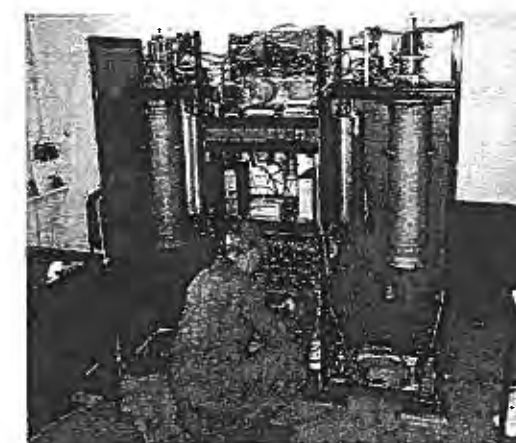
The four recently developed noble gas systems undertake currently a demonstration in Freiburg/Germany. The experiment is quite successful. The systems seem to achieve their goals and there is quite good agreement between measurements of the four systems.



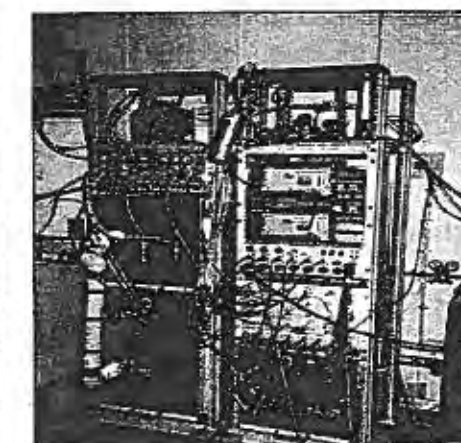
ARSA (USA)



SPALAX (France)



ARIX (Russian Federation)



Swedish System (Sweden)

Fig. 2: The four automatic Xe Detection Systems being tested.

There is a first interesting result from these noble gas measurements with high time resolution in Freiburg. Every few weeks a quite sharp Xenon cloud passes this area, which was not as visible before because of lower time resolution.

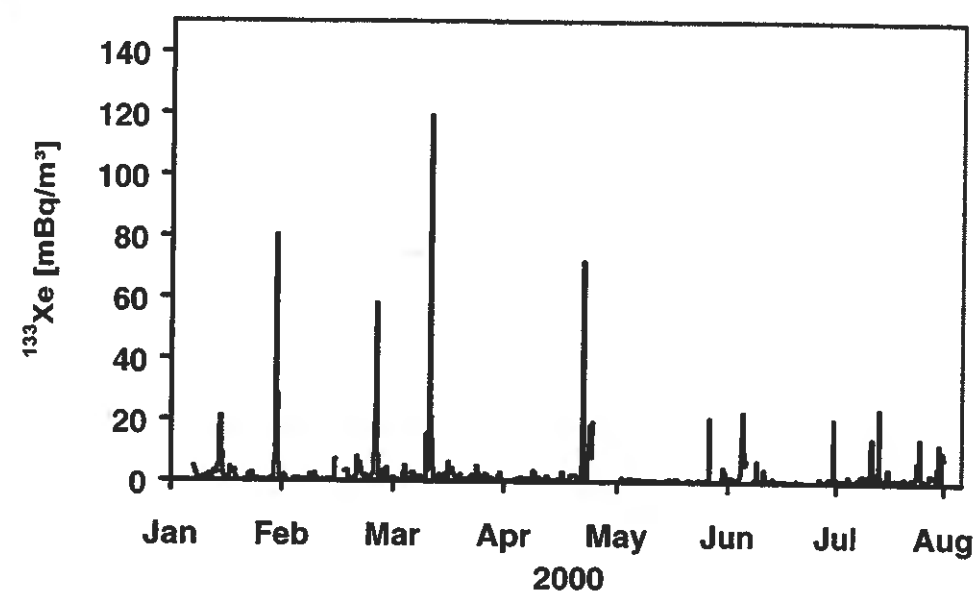


Fig. 3: ARSA Xe measurement results in the Freiburg experiment.

There are no noble gas systems installed at Treaty locations but it is envisaged to have the 4 systems installed at four sites for an experiment to estimate the properties under realistic conditions in different climates.

The required detection limit for Xe-133 is 1 mBq/m³. Noble gas systems could be able to reach sensitivities around 100 µBq/m³. For this a Beta-Gamma coincidence counting is needed and probably enhanced Xe purification methods. However, every enhancement makes operation and maintenance of the systems more difficult and needs to be balanced against the advantages of higher sensitivities.

RADIONUCLIDE LABORATORIES

The laboratories are existing and need to be certified. Procedures taking into account national accreditation are under development. Basis for preparation of the PTS document on certification is the draft document of ISO 17025.

Part of the laboratory certification will be the evaluation of spiked sample and intercomparison tests. The first spiked sample test is just under preparation and will be completed by the end of the year 2000. 16 radionuclide laboratories have expressed their willingness to participate in the test.

OUTLOOK

It is expected to have more than 20 particulate stations certified by the end of 2001 and more than 30 stations by the end of 2002 which will then form about 40% of the total particulate network.

To locate an event is the weak point of radionuclide monitoring compared to other technologies. Meteorologists estimate an uncertainty of 1000 by 1000 km² to locate an event by backtracking the path of detected radionuclides. The Canadian Meteorological Centre Montreal and other Regional Specialized Meteorological Centres might support backtracking of detected radionuclides in the future and improve this uncertainty somewhat. However, it is not the task of the radionuclide network to locate events. Backtracking could better serve for other technologies to reduce the area to focus on.

THE INFRASOUND MONITORING SYSTEM

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Under the implementation of the CTBT (Comprehensive Test Ban Treaty), monitoring systems must be set up to provide worldwide coverage for the detection of nuclear explosions with a yield of at least 1 kt. Methods based on infrasound measurements allow the detection and localisation of the explosions in the atmosphere. The international infrasound monitoring system comprises 60 stations located on all continents and several islands, especially in the southern hemisphere, in order to provide a global coverage (Figure 1).

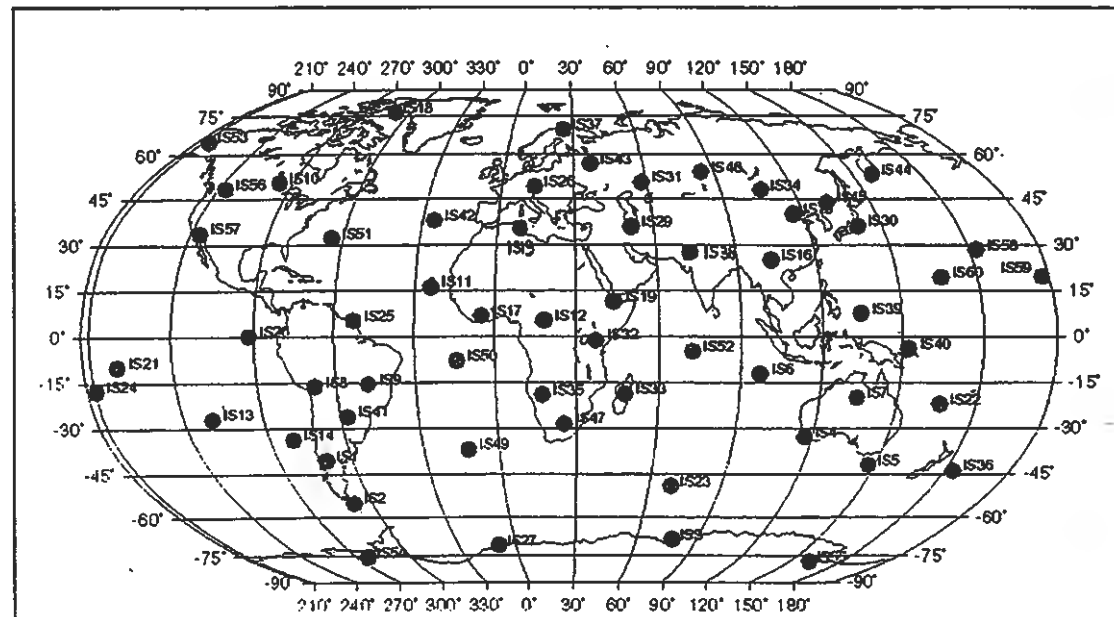


Figure 1 : The 60 stations Infrasound network

MONITORING TECHNOLOGY

The sensors used for the detection of the infrasound at the surface of the ground are microbarographs. The sensitive part is a barometric aneroid below submitted to deformations under atmospheric pressure changes. The sensors design eliminates temperature induced drifts. Microbarographs generally provide the relative pressure. The possible measurement of the absolute pressure in parallel allows a direct calibration of the sensor.

The microbarographs used for the CTBT measure infrasound in the range 0.02 to 4 Hz. They are characterised by a good sensitivity (18 dB below the minimum acoustic noise), and by a large dynamic (80 dB) in order to detect both explosions at very close distances and explosions at distances up to several thousands of kilometres. The sensors are equipped with acoustic filtering systems (microporous hoses or pipes) to reduce the noise produced by the surface winds.

The infrasound stations are composed of at least 4 sensors located in a triangle with a basis of 1 to 3 km with a central point. This allows to determine the explosion azimuth by triangulation, to remove false signals, not coherent at the scale of the array, and to increase the station reliability.

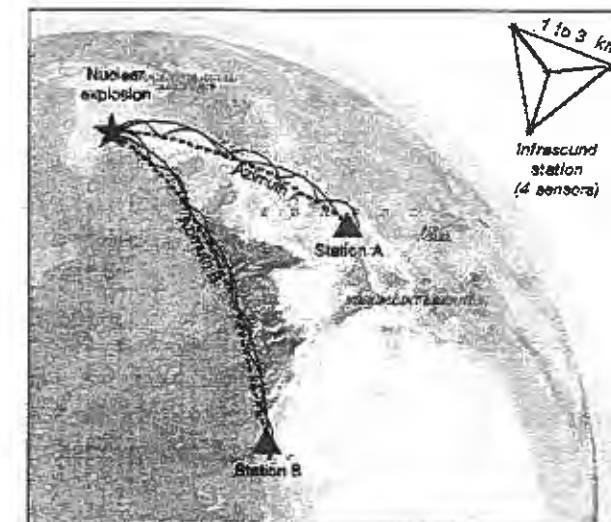


Figure 2: Infrasound station. The stations detect and give the azimuth of the nuclear explosions. The location is given by the intersection of different azimuths

INFRASOUND SIGNALS FROM ATMOSPHERIC EXPLOSIONS

Pressure waves are an important component of the source signal produced by a nuclear explosion, consisting essentially of sound waves in the infrasonic frequency domain (periods of about one second to several minutes or more for large explosion yields).

Infrasound is not audible, its frequency is higher than that of sound waves. It propagates at the sound speed in the atmospheric sound channel formed by the atmospheric temperature gradients under the effects of the high altitude winds (Figure 3).

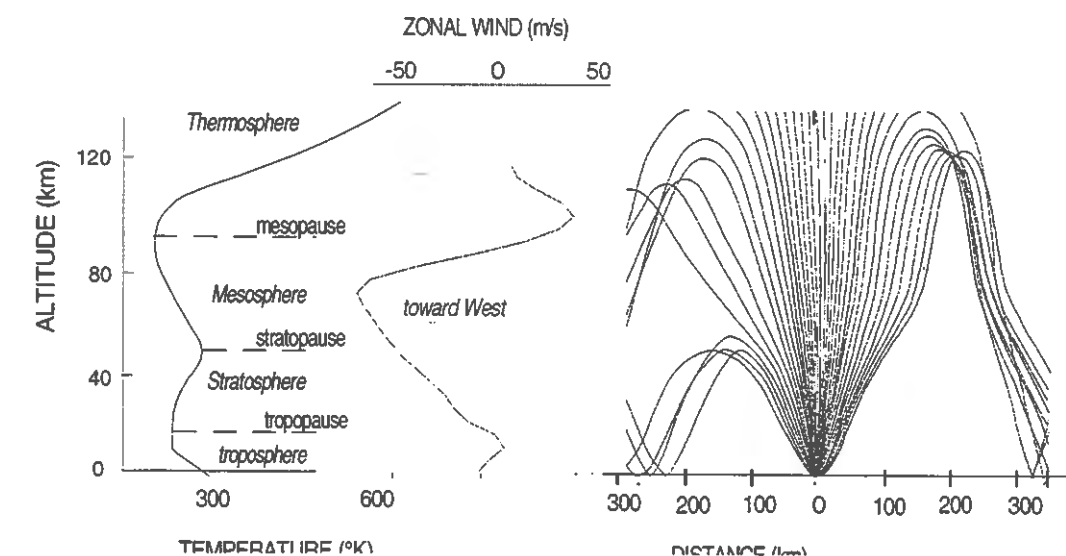


Figure 3: Ray tracing showing the different possible infrasound paths (right). Typical wind and temperature profiles are shown in the centre and left part of the figure.

The rays are reflected at the level of the temperature increases. High altitude winds produce an anisotropy in the propagation.

Because of the propagation effects, signals recorded at few hundreds of kilometres from the explosion may be formed of several wave trains corresponding to different paths in the atmosphere.

Figures 4 shows two examples of signals recorded during a nuclear test of a few kilotons, at distances of 440 and 450 km from the explosion to the north-west and east, respectively. The signal recorded in the east corresponds to a propagation in the direction of the high altitude winds while the signal in the north-west correspond to a propagation with contrary winds.

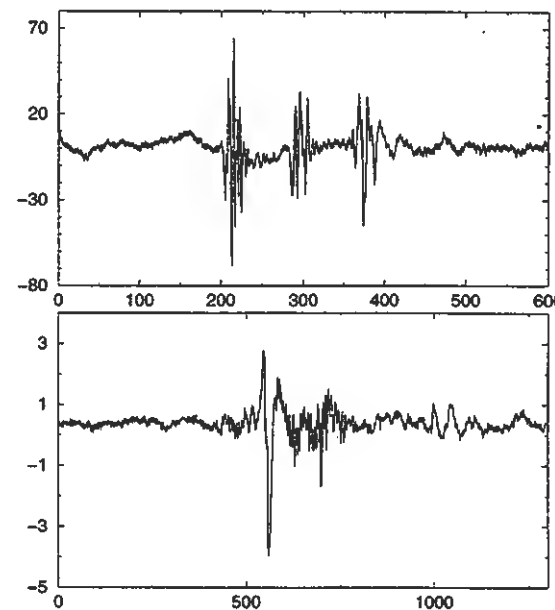


Figure 4 : Example of infrasound produced by an atmospheric nuclear explosion.

The explosion signal recorded at the East is composed of three different signals of 40 seconds, each separated by about 30 seconds. Their amplitudes range from about ± 130 Pa (1st arrival) to ± 70 Pa (3rd arrival). The signals obtained at the north west are weaker and longer and only two arrivals are recorded. The duration of the first signal is about 350 seconds, the amplitude is ± 6 Pa, while the second signal lasts about 100 seconds with an amplitude of ± 1 Pa.

The decrease of infrasound amplitude as a function of distance has been established empirically from the French nuclear explosion database. The first dominant effect is related to the high altitude winds. In some cases, they allow explosions of about 10 kt to be detected at distances of up to 7000 km windward from the explosion location, but they can make detection difficult at distances of about 1000 km in the opposite direction. The most significant impact comes from high altitude stratospheric winds, with velocities ranging from 60-90 m/s at altitudes of about 30-70 km (figure 3). These winds are

Atmospheric models based on world-wide measurements provide wind profiles as a function of time of year and latitude.

Figure 5 shows the amplitude (peak-to-peak), DP, of the pressure waves measured for tests of less than 400 kt for distances D ranging from 150 to 7000 km. The plotted amplitude is that of a 1-kt test, assuming a $W^{1/2}$ variation, where W is the explosion yield. The high altitude wind effect, determined by using the CIRA atmospheric model, has been taken into account. The propagation law giving the amplitude DP (in Pa) as a function of distance D (in km) and projection of stratospheric winds Vp (in m/s) on the propagation direction is of the form $\Delta P = 10^{5.31+0.0116V_p} D^{-1.76}$.

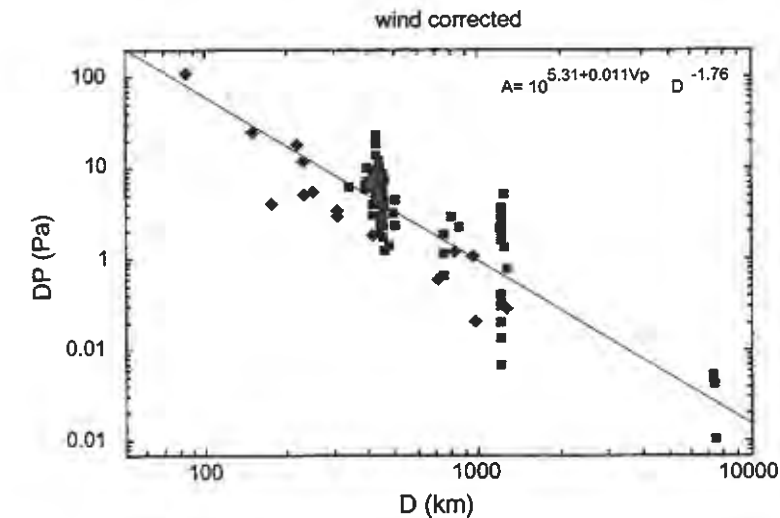


Figure 5 : Attenuation law of the infrasound deduced from the French nuclear tests versus the detection distance and versus high altitude winds.

INFRASOUND NOISE

The infrasound noise is produced by pressure turbulence induced by the winds at the ground surface. An empirical law (Figure 6) has been determined by using meteorological data performed at the infrasound stations for an open sensor and for different system of acoustic filtering (circular or linear hoses). The noise varies by a factor of 100 between quiet and disturbed conditions of wind. The noise can be reduced by a factor of ten or more by well adapted filtering systems.

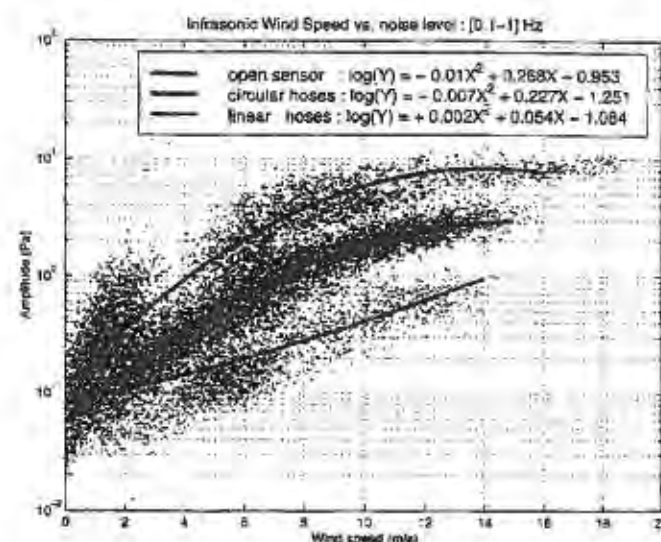


Figure 6 : Empirical law of infrasonic noise versus wind speed at the ground surface

DETECTION AND LOCATION CAPABILITY OF THE NETWORK

The network detection and location capabilities have been determined by modelling. The amplitude of the infrasound from nuclear explosions is given by the empirical propagation laws obtained from nuclear explosion data (Figure 5), the high altitude winds being determined by the CIRA atmospheric model. The infrasound noise is determined by the empirical law (figure 6) and a recent atmospheric model of the wind at the ground surface. The map which gives the network detection capability as a function of yield W is represented in figure 7.

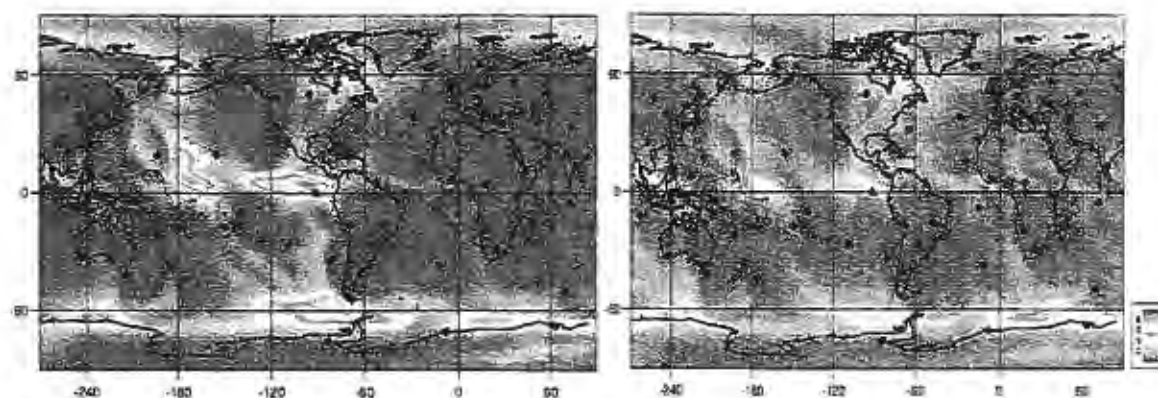


Figure 7 : Detection capability by two stations of the infrasound network in January at 00 UT (left) and 12 UT (right).

The detection capability varies significantly as a function of the time of the day because of the variation of the infrasound noise under the effect of the winds at the surface of the ground. The map shows that, in the Pacific ocean, the detection could be more difficult in conditions of high winds at the ground, specially during daytime. This appears in the Pacific ocean because the density of the station is lower than in the other

parts of the world. In these areas the number of station sensors will be increased in order to improve the detection capability. The network will then detect 1-kt everywhere in the world. In addition, the new development of more efficient acoustic filtering systems such as the STAR system improve the noise reduction and then the detection efficiency.

The location precision depends on the dimensions of the network: the most extended the network, the better the precision. The location capability of the network has been computed assuming an angle precision of 0.7° for a 3 km station array. The location precision is estimated within a circle of about 100 km or less everywhere in the world.

INFRASOUND EVENTS

An experimental prototype station developed by the CEA has been set up at Flers (Normandy) in France. This station is a four-sensors array whose characteristics correspond to the requirements of the CTBT monitoring network.

The PMCC (Progressive Multiple Cross Correlation) method permits the analysis of the data in a permanent way. Infrasound bulletins are edited every day, showing typical infrasound events detected at the station. For each event, the infrasound velocity and the azimuth are automatically determined.

Wave systems, sometimes highly complex in nature, are propagated through the atmosphere. Infrasound is produced by specific phenomena such as meteorological storms, earthquakes, volcanic eruptions, winds over the mountains, the ocean swell (microbaroms) or boreal aurora.

Well identified signals produced by chemical explosions, supersonic aircrafts, thunderstorms or microbaroms are used to test the data processing method and the detection and location efficiency of the station.

Figure 8 shows examples of signals obtained by the CEA several thousands of km from the volcanic eruption of Mt. St. Helens and Pinatubo. They are compared to a one-megaton explosion. Volcanic eruptions are powerful sources capable of producing low-frequency waves that a one-megaton nuclear burst could not generate.

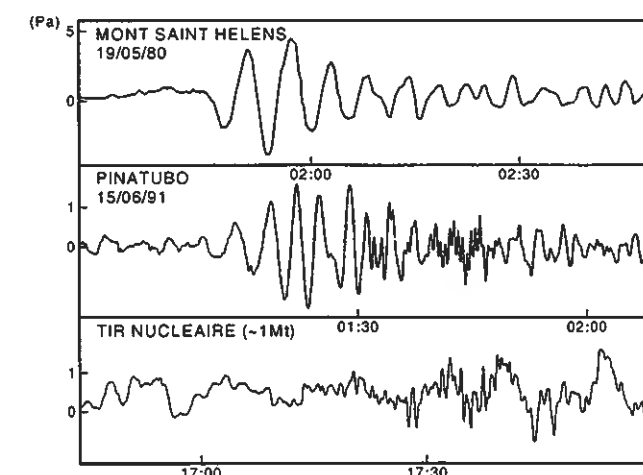


Figure 8 : Comparison between signals of volcanic eruptions and a 1 Mt nuclear explosion

Table 1 summarises the main types of infrasound events detected at the station Flers. The characteristics of these events have been determined and discrimination methods can be defined for the event identification.

Type	characteristics	complementary data
quarry explosions specific explosions	generally <1kt the signal frequency range depends on the source energy	explosion characteristics
supersonic airplanes	several daily flights several signal phases generally observed	trajectory details
volcano	few large explosive eruptions (St Helens, Pinatubo) local events possible	seismic data
microbaroms from ocean swell	extended source regions very frequently observed	meteorological data, satellites
thunderstorms	lightning, convective motions	meteorological data
infrasound from auroras	source available in high latitude regions	camera pictures
meteorites	High altitude sources	satellite data

Table 1 : Different infrasound signals of man-made or natural origin

CONCLUSION

Infrasound measurements are well adapted for detecting and locating atmospheric explosions. The explosion shock waves are characteristic, their low-frequency components are able to propagate at long ranges and can be detected by microbarographs. Previous measurements during nuclear and chemical explosions have provided a database for estimating the detection and location capability of the CTBT infrasound network. Experimental stations, such as the prototype station Flers in France, are very useful in the study of noise and natural disturbances. PMCC method is used to establish the daily infrasound bulletin and several well identified infrasound sources such as quarry blasts, ocean swell, supersonic aircraft or thunderstorms are permanently used to control the detection and location efficiency.

HYDROACOUSTIC MONITORING OF THE CTBT

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INTRODUCTION

It has been known for a long time that low frequency sound can travel for very large distances in the sea¹. This is usually due to the existence of a sound channel, the SOFAR channel, which effectively restricts the sound to depths where the sound travels without any interaction with either the sea surface or the sea floor. Without any interaction there is no loss of energy due to scattering or refraction into the seabed and the only losses are the cylindrical spreading loss and the very small absorption loss.

Explosions, chemical or nuclear, are powerful sources of broadband sound and small (0.8 kgm) charges of TNT have been readily detected for many decades over transoceanic propagation paths from the low frequency sound they produce. Such a source recently produced a 20 dB signal to noise ratio on a single hydrophone after a 10,000 km propagation path². Nuclear explosions, releasing many orders of magnitude more energy, are even more easily detected, the only qualifications being that there be no substantial land mass or extensive tract of shallow water between the explosion and the detector. Nor need the explosion take place in the sea: nuclear explosions within small islands have been detected by hydrophones thousands of kilometres distant.

Hydrophones are the most sensitive devices for picking up sounds in the sea but they are expensive to put in place, and their maintenance can be costly. An alternative to a hydrophone is a high frequency (0.5 to 20 Hz) seismometer near a steeply shelving coast. Such a seismometer responds to T phase, a compressional seismic wave generated by conversion of the incident sound at the boundary to the land. Such sensors are not as sensitive as hydrophones but they have been routinely used to detect submarine volcanoes and earthquakes from the underwater sounds these produce³. They are much cheaper to install and maintain than hydrophones.

Discrimination between transients due to man made explosions and those due to natural events can be relatively straightforward. Earthquake T phase has less energy at the higher frequencies and a more gradual build up and decay over a longer total duration. If the explosion does not vent at the sea surface it may be possible to measure a modulation to the frequency spectrum corresponding to a bubble pulse frequency. Explosive submarine volcanism can generate very high-level transients but the duration of this activity is a good discriminator.

THE CTBT

In Article 1 of the Comprehensive Test Ban Treaty each State Party undertakes not to carry out any nuclear weapon test explosion or any other nuclear explosion, and to prohibit and prevent any such nuclear explosion at any place under its jurisdiction or control. Article IV of the Treaty sets out a regime to verify compliance with this and the other basic obligation of the treaty.

Over 70% of the earth's surface is covered in water so it is fortunate that a sparse network stations using either hydrophones or T phase seismometers has the potential for monitoring clandestine nuclear explosions in the sea. As part of the International Monitoring System a network of 11 hydroacoustic stations was defined, 6 hydrophone and 5 T phase, whose locations are shown in the accompanying figure⁴. These stations were proposed at a Hydroacoustics Workshop in Paris in October 1995 and again at the

Hydroacoustics Experts Meeting in Geneva in December of that year and adopted by the negotiators in the Conference on Disarmament and are reflected in the hydroacoustics network in the treaty text. Two of the hydrophone stations (Wake and Ascension) and one of the T phase stations (Queen Charlotte) were in existence before the Treaty, but require upgrading to IMS specifications in the future. Work is progressing on the remaining stations and it is presently planned to have all stations contributing to the International Data Centre in Vienna within four years. Wake Island, already contributing to the IDC with existing hydrophones, is not expected to be fully upgraded until 2005.

CURRENT CAPABILITIES

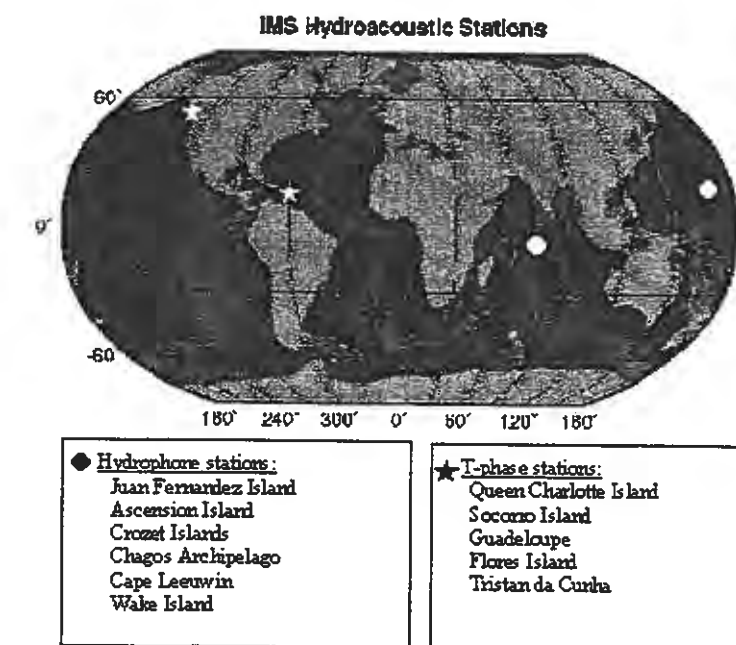


Figure 1 Map showing the planned IMS hydroacoustic network,

Stations which are contributing data to the IDC at the time of writing are shown on the map in white. None of these stations have been certified as defined in the proposed Operational Manual for Hydroacoustic Monitoring and the data must be regarded as interim, although in practise the effect of certification may be small. With this distribution of stations there is the capability for detecting nuclear explosions in the oceans in which they are placed or which they border, and a minimal capability for localising such explosions using hydroacoustic data only. Where these stations do have value is their ability to help discriminate between small natural earthquakes with sub sea foci and man made explosions in the sea. There are substantial ocean areas, the largest in the South Pacific, where the existing hydroacoustic stations provide no coverage at all.

FUTURE CAPABILITIES

The situation will be considerably better when all 11 hydroacoustic stations are contributing data. At the December 1995 meeting mentioned earlier it was predicted that an explosion of a well coupled 200 ton underwater explosion (equivalent to a $m_b=4$ earthquake) would be detected by a minimum of 3 stations in most oceans except the North Atlantic, the Arctic and within the Indonesian Archipelago. The resulting

predicted distribution of location errors is shown in Figure 2⁵, together with the predicted errors from the Primary, the combined Primary and Auxiliary IMS seismic networks, and then using all available data. The benefit of using all three networks is obvious. It has been noted at least two scientific meetings that the location accuracy of the hydroacoustic network can be improved if T phase from selected auxiliary seismic stations is also used, particularly for locations in the South Pacific.

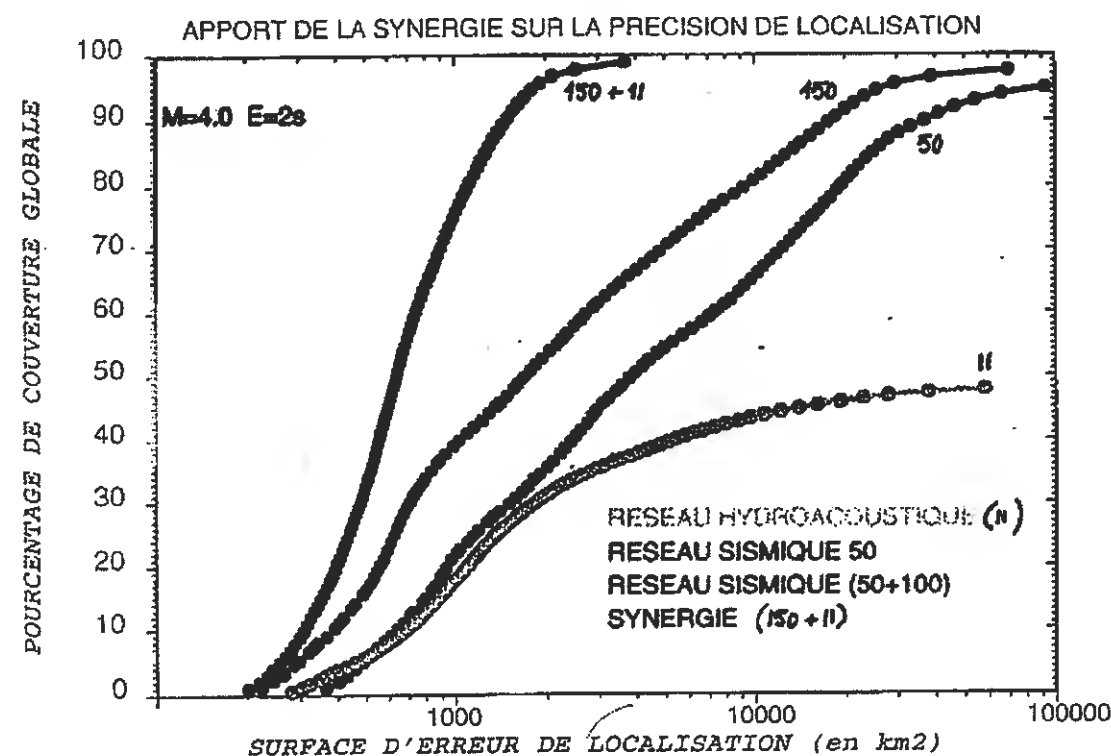


Figure 2: The synergy between seismic and hydroacoustic networks

The equivalent source level of a well-coupled 200 ton underwater explosions is so large that it is accepted that provided there is no bathymetric blockage, such an explosion will be detectable by at least one hydroacoustic station. It is usually assumed that a shallow or even near surface atmospheric test over water will also be readily detectable. This is not immediately obvious, for hydrophones in the SOFAR channel are not particularly noisy with the din of the hundreds of ships that are at sea every day. This is because ship noise does not couple well into the SOFAR channel and requires a favourably sloping bottom before it is trapped⁶. The best empirical evidence for coupling into the duct by a source outside the duct is provided by the undoubted existence of abyssally generated T Phase from earthquakes under the deep ocean⁷. At the time of the atmospheric nuclear tests at Mururoa data from hydrophones off New Zealand were examined for signs of an explosion but none was found.

THE PERFORMANCE LIMITS OF THE HYDROACOUSTIC NETWORK

The minimum detectable explosion in the sea is a complex issue which will depend on the individual station and the propagation path between it and the explosion, and is not one which can be approached other than in generalities. A key factor is the background noise against which the detection must be made, and this will only be accurately known when the stations are on line. Four of the hydroacoustic stations are in regions where there has been recent volcanic activity. Of more concern is explosive submarine activity,

particularly in the Pacific. In 1987-8 the MacDonald Seamount (28.99S, 140.26W) was active for weeks at a time. Another important factor is the propagation loss when not all the sound propagation is via the SOFAR channel. This depends critically on the nature of the seabed and the sound velocity profiles along the propagation path, and may be best estimated after propagation loss experiments have been conducted to 'fine tune' the acoustic models.

Source location is presently done by triangulation using travel times to the various detecting stations. For hydrophone sensors care is needed selecting the appropriate arrival time: in the North Atlantic an explosion on the SOFAR axis builds to gradual climax and abruptly drops away, whereas in the South Pacific the onset is abrupt and there is a gradual fall off in level⁸. The travel time for an axis-travelling ray is therefore best determined by the end of the sequence in the one case and the beginning in the other. Source localisation may be improved by timing the reflections from known bathymetric features. In this regard recently active volcanoes were found to be better reflectors of explosions from the Mururoa test site than were other islands, presumably because they have less sediment cover. Timing of explosions at T phase stations will be subject to difficulties because of the uncertain location of the point where the underwater sound is converted to the terminal island P phase. Calibration of the stations over a range of azimuths would seem necessary.

On a more positive note, computer processing power and hard drive capacity continue to grow at an amazing rate. Compared to voice recognition systems, the task of processing hydroacoustic data to discriminate between explosions from naturally occurring transients is relatively straightforward. The very high signal to noise ratio expected for any nuclear explosion raises the possibility of using the computer intensive techniques of matched field processing to determine source location.

REFERENCES AND NOTES

1. Urick, R.J. Principles of underwater sound / 3rd edition. McGraw-Hill Book Co., 1983. Section 6.2. pp 159 - 164.
2. Bannister, R.W. et al. ATOC---New Zealand receiver site survey and acoustic test. ASA 125th Meeting Ottawa May 1993
3. Talandier, J. Submarine volcanic activity. Detection, monitoring and interpretation. Eos Vol. 70, No. 18, 1989. pp 561, 568 - 569
4. This figure copied from Lawrence, M. et al. The hydroacoustic network, International Monitoring System: status and plans. CTBT Seismic Research Symposium, New Orleans September 2000.
5. This figure copied from Hydroacoustic/seismic working paper 'Possible Benefits of Comprehensive Synergy between Hydroacoustics and Seismics' presented by the French Delegation to the Ad Hoc Committee on a Nuclear Test Ban. December 5 1995.
6. Dashen, R. and Munk, W. Three Models of global ocean noise. J. Acoust. Soc. Am. Vol. 76, (2) pp 540-554.
7. Johnson, R.H. et al. Abyssally generated T phases. Geophysical Monograph No.12. The Crust and Upper Mantle of the Pacific Area. Edited by Knopoff et al. American Geophysical Union. 1968.
8. Guthrie, K.M. Wave Theory of SOFAR signal shape. J Acoustic. Soc. Am., Vol. 56, pp 827-836

OSI MAIN ELEMENTS AND EXPECTATIONS

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REFERENCES

I. INTRODUCTION

A. VERIFICATION

Verification encompasses the gathering of information and the use of that information to make judgments about the compliance of parties with the terms of an agreement¹. The concept of verification, therefore, includes the processes used to gather information and those persons or bodies charged with making compliance judgments. The process of gathering information about a particular activity, by local or remote means is called monitoring. The information is obtained by persons in the field or by technical means, or from the parties to the agreement.

It should be appreciated that the CTBT is different from other treaties foremost by having a unique, permanently installed, monitoring system with a worldwide coverage around the clock. This International Monitoring System (IMS) is a network of stations, which is attempting to be specifically targeted at detecting a particular type of activity, nuclear explosions. It is designed to detect, locate, and identify events that may be nuclear explosions. Due to cost consideration and technological shortcomings the IMS is deficient in some way in each of these goals: it is unable to detect events below a certain magnitude, it cannot locate the detected events to a defined small area with high accuracy, and last but not least it is unable to make reliable distinction between natural events, chemical explosions and nuclear explosions. Some of these shortcomings are technically inherent as a result of irregularity and complexity of the environment through which the signals travel from the source to the detecting station. This may be a result of climatic and weather changes affecting infrasound or radioactive debris distribution, or changing geophysical structures affecting seismological waves. As a result, the information gathered by the International Monitoring System may be inconclusive in many cases, and may not be clear enough for the decision making bodies of the organization to conclude that a State Party is guilty of non compliance.

B. CTBT VERIFICATION REGIME

To compensate for the shortcomings of the IMS, and in order to help the Executive Council (EC) which is the decision making organ, the CTB Treaty has three more elements in its verification regime in addition to the IMS: Consultation and Clarification (C&C), On-Site Inspection (OSI), and Confidence Building Measures (CBM)². In contrast to the IMS, which is a continuously-functioning system, these additional three elements are sporadic in nature and call, among other, for active initiatives and involvement from the States Parties.

CBMs are independent of the entry into force (EIF) of the Treaty. They can be performed voluntarily by States Parties, and actually some have already been performed. In addition to their political aspects CBMs have a technical value, as in the case of calibration experiments (such as the Dead Sea experiment⁴), which are aimed at the improvement of regional calibration in order to enhance the accuracy and reliability of the monitoring system. Information provided through such measures could be used for the consideration of an OSI and during its conduct, but the process itself is an independent one.

C&C is a process that could be initiated only after EIF of the Treaty. In case of concern about possible non-compliance with the basic obligations of the Treaty, States Parties are

urged first to make every effort to clarify and resolve the concern through C&C, among themselves or with or through the Organization.³ Information provided through such a process could be used for the consideration of an OSI and during its conduct (actually, there is a Treaty provision obligating a State requesting an OSI to include the results of C&C in its request), but the process itself is alien to OSI.

OSI could be launched to clarify whether a suspicious event detected by monitoring means was a nuclear explosion. This element of the verification regime enables an on-the-spot survey for the actual event that raised a concern.

OSI is a unique feature of the CTBT, which is fundamentally different from other treaties' elements of verification. One main difference is that the decision of carrying out an OSI lies with the EC, and not with the executive organs of the organization (as it is in the NPT) or with any individual State Party (as is practically in the CWC). Another difference is the perception of OSI as rare, which is reflected by the fact that there is no permanent inspectorate in the organization, and the inspectors are generally not employees of the organization. Another characteristic which makes OSI different is the nature of the inspection, which mainly covers broad areas, and not facilities or plants.

By its character, OSI is the most intrusive element of the verification regime and should therefore be considered carefully, in order to avoid abuse or use for non-Treaty purposes, but still keeping it as a capable tool. OSI is envisioned as being used only after other measures of the Treaty, such as Consultation and Clarification, have been exhausted.

Like the other components of the verification regime, OSI has to be implemented and ready for operation at EIF.² For these reasons, even though OSIs are envisioned to be rarely used, a major effort has to be performed before EIF to set up the OSI regime, which can only be implemented after EIF. Therefore, in parallel to setting up the IMS, the PrepCom is also laying the groundwork for on-site inspections as is described below.

C. OSI IN THE CTBT VERIFICATION REGIME

The Treaty, especially the Protocol, undertake the OSI as consequential as the IMS if we consider the detail and length of text devoted to it. This of course stems from the reasons mentioned above, and from the fact that OSI is an intrusive procedure and may touch on sensitive national issues, which are unrelated to the CTBT purpose. This is the reason that OSI issues, and most of all the Operational Manual for OSI (OpMan), are taken so seriously by WGB. The intrusiveness aspect of OSI is the reason for the OSI OpMan being developed by the states signatories and not by the Provisional Technical Secretariat (PTS). WGB is also developing the IMS/IDC OpMans, which unlike the OSI OpMan, are mostly technical in nature, and have no intrusiveness aspects. These manuals deal with the technical operation of stations, which is done by the host state parties, and with the IDC operations in Vienna.

D. OSI AS A DETERRENT

OSI is different from the other elements of the CTBT verification regime in that it is present in the background as a possibility in case of a suspected violation, unlike the IMS/IDC, which are a continuous monitoring system, collecting and analyzing data all

the time. A well-prepared OSI regime should therefore serve first of all as a deterrent, discouraging a potential violator because of the high probability it creates for exposure.

Being a rare event, an OSI that ends without contributing to clarification of an ambiguous event that raised the concern, or an abusive OSI, may seriously undermine the value of the CTBT verification regime. Like any other deterrent, it has to be capable of achieving its intended outcome in case of a suspected violation of the Treaty. Hence, it is important to develop the OSI regime to be the best possible in order that it will have a deterrence value. In order that it will be grasped as an effective tool that has to be taken seriously by any potential evader, it should not be allowed to become a sloppy and ill-defined regime, and therefore the needed guidance should be well established for efficient and successful performance.

II. OSI's MAIN PURPOSE AND PROVISIONS

A. THE PURPOSE

The sole purpose of an OSI is to clarify whether or not a nuclear explosion has been carried out in violation of the Treaty. The mission of the Inspection Team (IT), as derived from this purpose, is a monitoring task with the goal of providing plausible technical findings, enabling the EC to make the decision whether the event that caused the concern was a nuclear explosion or not. The OSI team will have to furnish direct technical results indicating that the event that caused the concern was a nuclear explosion, or that it was not a nuclear explosion (i.e. a natural event or a non-nuclear man-made event), or that there is no way to prove either one of the two.

Unlike a police operation or the UNSCOM mission, OSI is a process based on balances defined in the Treaty, including agreed measures that preserve the rights and obligations of both the IT and the Inspected State Party (ISP). The OSI should be, according to the Treaty, a sharp but constrained tool to be used with minimum intrusiveness, high efficiency, transparency, under specified timelines and using only the techniques and equipment provided by the Treaty.

The avoidance of intrusiveness is first of all directed to protect national security interests and to prevent disclosure of confidential information not related to the purpose of the inspection. This principle pertains to the gathering of data, where the Treaty maintains that only relevant data is to be gathered by the IT. A clear example of what is meant by relevant data is illustrated by the instructions in the Treaty for measuring only those parts of the gamma spectrum which are relevant to nuclear explosions⁶, which has been already elaborated by WGB and resulted in defining "information barrier", or "blinding" of radiation measuring devices to be used during OSI. This "blinded" device will reveal to the user only those parts of the data that may be relevant to a nuclear explosion, but not related to other activities such as nuclear reactor operation. The tight timelines and other constraints dictated by the Treaty should be regarded as a compromise that takes into account the needs to clarify the situation and to reduce intrusiveness caused by the disruption of normal life in the ISP.

B. OSI PROCESS - REQUEST TO DEPLOYMENT

When a State Party to the CTBT is concerned that a nuclear explosion was carried out in non-compliance with the Treaty on the basis of an event detected by the IMS, or on the

basis of its National Technical Means, that State may request an On Site Inspection. A concerned State Party is solicited to carry out Consultation and Clarification with the suspected State Party before requesting an OSI, a process during which these States may take any agreed steps they deem necessary in order to clarify the event that raised the concern of non-compliance. If the concerned State is not satisfied with the outcome of this C&C process, it may request the EC to launch an OSI to clarify whether the event of concern was a nuclear explosion.

For an OSI to proceed, after a request has been filed by a State Party, it has to be approved by the Executive Council by an affirmative vote of at least 30 of the 51 EC members. The OSI will be carried out on the basis of a mandate issued by the Director-General (DG) based on the EC decision. This is the only process leading to an OSI according to the Treaty. The state party sought to be inspected is obliged to permit the OSI, and not to impede the ability of the inspection team to perform its activities within the inspection area as decided by the DG and included in the inspection mandate.

An OSI may be conducted within limitations provided by the Treaty. An inspection team (IT) of no more than 40 members is permitted to inspect an area no larger than 1000 square kilometers (a continuous area with no linear distance greater than 50 kilometers in any direction). The Treaty permits the inspected state party (ISP) to restrict or manage access of the IT to sensitive locations within the inspection area (IA).

The timelines of OSI as dictated by the Treaty are different from those of the CWC challenge inspection for an obvious reason: unlike the CWC where the phenomena causing the concern of non-compliance may be removed (a process stopped or materials shipped away), the phenomena associated with a nuclear explosion, especially an underground explosion, are not likely to move away; the underground cavity stays in place, and the radioactivity is there for a long time. It may even be more evident after many days when the radioactive isotopes seep out to the surface. This radioactivity is the "smoking gun" of a nuclear explosion, and some of the radioactive debris will stay there for weeks, month, and even years. The IT is therefore required to start the inspection within some 9 days after the submission of the OSI request. The default duration of the inspection is up to day 60 after the EC approval, but it could be extended, if needed, up to day 130. It could also be shortened, if the IT so recommends.

C. ACTIVITIES AND TECHNOLOGIES

After arriving in the IA the IT will have to explore it, looking for any possible signs of a recent event compatible with the event that triggered the request for the OSI. The 15 activities and techniques (and only these) allowed to be used by the IT in (and only in) the IA are enumerated in Part II, Paragraph 69 of the Protocol.⁷

The Treaty provides for different techniques to be used during successive periods of the inspection⁷ in accordance with IT activities. In the initial period (up to day 25 after the EC approval of the OSI), equipment is provided for general area search, aimed at narrowing the search area; this includes position finding, radioactivity measurements and passive seismic techniques. During this period the IT will try to locate sites or limited sections of the IA in which signs are found that may possibly point to the event that triggered the request. In the rest of the inspection periods (up to day 130), the IT inspection activities may be focused on these sub-areas. During this period various geophysical techniques⁷, such as active seismology, are provided to enable the detection

of localized anomalies and artifacts that may be characteristic of the triggering event being a nuclear explosion. Most of these geophysical techniques are time consuming and are relevant for deployment in a small area of no more than a few square kilometers; therefore the narrowing process of the initial period is of utmost importance. The final step of an OSI may be the use of specialized drilling equipment, to obtain radioactive samples, which are the "smoking gun" of a nuclear explosion. Moving to the second period of the inspection, as well as drilling, require the approval of the EC.

Although most of the equipment for the techniques defined in paragraph 69 may be available off the shelf, these are not all directly applicable to OSI in light of the special needs for detection of nuclear explosion signatures and the non-intrusiveness dictated for the OSI regime. The development of the required modifications for existing equipment, although time consuming, can be overcome by existing engineering practices (e.g. "blinded" radiation measurements), but even then some inherent shortcomings of the techniques may not be overcome.

In view of the lengthy duration of the inspection (up to a maximum of 130 days) the IT will need significant in-country support from the ISP. Substantial amounts of portable equipment will be needed, including geophysical and radionuclide equipment, drilling equipment, communications equipment and the means to conduct over-flights.

III. STATUS AND PROBLEMS OF PREPARATIONS FOR THE FUTURE OSI REGIME

A. THE ELEMENTS OF THE OSI REGIME

In order for the verification regime to be capable of meeting the verification requirements of the Treaty, it (and the resolution on the establishment of the PrepCom) prescribe to the PrepCom to prepare before EIF three main components of the OSI regime: The list of equipment based on the technologies dictated by the Treaty for use during OSI, including purchase and application of these equipment; The OpMan for OSI which includes guidelines for all the persons and organs who are involved on behalf of the CTBTO in the OSI process; The training and exercise program for inspectors.

The process of preparing the instruments of the OSI regime is taking place in Vienna these days by State Signatories. The preparations include workshops attended by experts in the different fields which are the basis of the OSI, technical discussions in the OSI task group of WGB, and deliberations about political aspects related to OSI. International experts are also assisting in identifying elements required for an OSI infrastructure, including an Operations Support Centre, data bank and an equipment storage and maintenance facility. Initial drafts of the required documents are shaping up, based on these discussions and written contributions by State Signatories and the PTS. This is a lengthy process that cannot be advanced too rapidly because of its multilateral aspects, but it is anticipated to culminate eventually in consensus based on agreed solutions and compromises by the participants.

Of the three elements of preparation for OSI – Operational Manual (OpMan), equipment, and training – the last two present fewer difficulties than the first one. Although slowing the process, these two have less political implications and can be overcome by existing engineering and planning practices.

B. STATUS OF PREPARATIONS

1. EQUIPMENT

An initial list of equipment for testing and training purposes has been drawn up and future OSI equipment has been divided into seven categories: Seismic Aftershock Monitoring System; Gamma Search and Identification Tools; High Resolution Gamma Spectrometer; Xenon Sampling, Separation and Measurement Tool; Visual Equipment; Communications Equipment; and Auxiliary Equipment.

The procurement of equipment for the first period of the inspection is more or less under way; Procurement has begun of the radionuclide search and identification equipment, of seismic equipment for passive and resonance seismology, for visual inspection activities, and auxiliary equipment. Equipment for the other techniques are still to be discussed in view of the tailoring of these techniques to the OSI needs and for the detection of nuclear explosion signatures. These are labor consuming, but generally not a politically disputed area.

2. TRAINING

In order to have a wide base of potential inspectors from which 40 could be summoned on short notice for an OSI, an intensive training program has to be planned and executed. This training has to prepare prospective inspectors, inspection assistants, and inspection team leaders who are experts in their fields, for the special application of techniques for the OSI requirements, for the special environment of operation under the Treaty provisions, and for the synergy to be practiced in the team work. A major consideration in preparing the training program is the fact that experience and expertise in nuclear explosion phenomena will be decreasing with time, and the training program must compensate for that.

Training planning is underway, and several introductory courses have already been carried out, creating an initial list of some 150 inspectors (and inspector assistants) candidates. The first experimental advanced course is under preparation and will be carried out soon.

A general outline of the long term training process to be deployed after EIF has been discussed and accepted by WGB. The planning of this process is now being done by the OSI division of the PTS, with the help of expert sub-contractors. The main element missing for the finalization of a more advanced training process is the OSI Operational Manual.

It has also to be remembered that as OSI will be a rare event, and as years without accumulated nuclear testing experience pass by, no experience will be gathered beyond training and exercises. The training program and the OpMan (see below) should take this into account by providing a well-prepared framework of training and guidelines for the prospective inspectors, who will acquire their expert education and experience in a world hopefully devoid of nuclear explosions.

3. OPERATIONAL MANUAL

The OSI Operational Manual (OpMan) is assembled from texts of sections and chapters contributed by States Signatories and the PTS. The different contributions are merged into one edited text by the Program Coordinator for OSI, with the help of a few expert Friends nominated by him. This process, including the layout of the OpMan, has been approved by the PrepCom. As a first step, a basic document - the Initial Draft Rolling Text (IDRT) of the OSI OpMan - is under development to allow serious and effective elaboration on the Manual, including the politically sensitive aspects. The majority of the IDRT parts will most probably be ready for the elaboration process at the end of March 2001, but the process of completing the work on this manual is expected to be long, probably a few years.

The main difficulties in the preparation for the OSI regime are encountered in the development of the OpMan. The Treaty only outlines the general rules for OSI, without going into details of many, and totally neglecting some, of the issues related to OSI leaving these to be prepared by the PrepCom before EIF. The major predicaments this process is facing are the disparity in views of State Signatories on the scope and level of detail of the documents to be developed, and the definition of the equipment to be used under the technologies dictated in the Treaty. The emerging picture in the discussions of WGB is that the timelines defined by the Treaty for the OSI are very tight and call for very careful and detailed preparations. This is possible only if the procedures are based on good guidelines, taking into account as many foreseeable situations as possible, in order to avoid friction and loss of time during an OSI. Such methodical guidelines can only be developed in the unstressed atmosphere available in the discussions of WGB experts, but will not be possible during the execution of an OSI under the stress of an operation within a tight schedule.

The difficulties mentioned above are mostly concerned with the level of intrusiveness, the balance between the rights of the ISP and those of the IT, and the level of detail of guidelines to be included in the OM. Some of the main issues are:

- The definition of the IT mission. One approach would allow the IT to search throughout the inspection area for every possible violation of the Treaty regardless of the triggering event. Another approach wishes the IT to search for the event that triggered the concern of the requesting state party as reflected in the OSI request. This main element cuts through the implementation of most OSI techniques and is reflected in many parts of the OSI OM.
- Types of data that the IT should be collecting. The Treaty refers to the collection of "relevant" data; however, this idea is not fully agreed.
- The balance of the Treaty provisions between the inspection's needs on one hand and the ISP rights to protect information not related to the purpose of the inspection is another issue not fully agreed. This mainly relates to issues not fully covered by the Treaty, such as the general information (e.g. maps) about the inspection area, and information that is not specific to the event that triggered the OSI request.
- To what extent the OSI procedures have to take into consideration the possibility that the right to request OSI was abused. One approach wishes to keep this issue in

the hands of the EC; another approach wishes the IT to consider this possibility throughout the inspection.

- A definition of a cautious confidentiality policy for handling ISP sensitive information by the IT.

Putting all these disputes aside, the major challenge is to develop an OpMan that will justify the status of OSI in the CTBT verification regime. To fulfill this it has to be guaranteed that the OSI process will provide at its end a better knowledge about the concern reflected in the OSI request than was available prior to its launch. It has also to be guaranteed that it will act as a deterrent and not become an incentive for abusive requests.

The solutions will be in any case based on political compromise between the States involved. The deliberations underway in WGB in Vienna, which, assuming that they will proceed with determination and patience while emphasizing the substance over any other issue, are anticipated to lead eventually to consensus which will provide for effective guidelines, well-trained team members, appropriate equipment and proper administrative provisions.

IV. CAPABILITIES AND LIMITS OF THE OSI REGIME AFTER EIF

A. FOCUSING THE MISSION

When deployed, the OSI team will have to come up with concrete technical findings demonstrating one of the following about the event that caused the concern of non-compliance: that it was a nuclear explosion, that it was a natural event or a non-nuclear man-made event, or that there is no way to prove either one of the two. Focusing the scope of the mission to the necessary purpose, and including well defined guidelines, will help the IT to progress with the mission, and in the same time to avoid getting side-tracked or stuck in a situation that can be foreseen and avoided. Despite the inherent constraints on the IT mission, it will have high prospect of success if it will be defined as clarifying the concern that was raised in the request (i.e. the event that triggered the request), and tailored to activities relevant to this purpose. Such focusing of the mission, except for being incorporated into the OpMan, will depend on the guidelines in the mandate issued by the DG, and on its successful execution by the IT leader.

B. INTRUSIVENESS REVISITED

Limiting intrusiveness is a significant issue stressed in the Treaty more than once. Intrusiveness can be caused by "aggressive" inspectors, who are officially present only to monitor and observe defined types of information and phenomena, but are actually able to take in a lot of other information, inadvertently or otherwise, that may include sensitive data. The Treaty therefore reiterates the obligation of the IT to gather only relevant data (e.g., when discussing gamma radiation measurements.)⁶

Intrusiveness may also be a result of the application of certain technologies, meant to search for nuclear explosion-related anomalies, whose use may expose sensitive and non-

relevant information as a result of intrinsic similarity of some man-made phenomena to nuclear explosion phenomena (e.g., cavities *vs.* underground bunkers). This issue suggests that when technological options are being considered in monitoring and verification there is a need to have some provisions to demonstrate to those being monitored that the technologies being used are only being used for the purposes specified.¹ The installation of "information barriers" for relevant technologies and equipment to be used in OSI is one way of taking care of such intrusiveness in advance (e.g. the "blinding" of gamma radiation measurements equipment.)

C. DETERRENCE REVISITED

It is true that OSIs are envisioned to be rarely used, but in order to be of any value as a deterrent against violations of the Treaty, the state parties (and the policy makers) should be convinced of its effectiveness. This can happen only if all those involved are confident that the OSI regime is correctly developed.

Except for routine monitoring using the IMS and analysis by the IDC, the technical secretariat (after entry into force) will be conducting OSI training and exercises. These activities have two reasons: one is to keep the inspectors up-to-date and to gain experience in OSI; the other is to demonstrate that the OSI regime is functioning and effective. An unsuccessful and inconclusive OSI, especially the first one, will have a detrimental effect on the credence of OSI and on the verification regime as a whole.

D. TECHNICAL PROBLEMS

As already mentioned above, the geophysical techniques to be used in the later periods of OSI as they currently exist are not tailored to OSI needs, and have some inherent shortcomings when applied to the search for nuclear explosion signatures. The main problem is the lack of resolution, if a cavity of a nuclear explosion is being looked for in non-homogeneous geophysical environments. This problem may be solved in the future through R&D, but until then the IT will have to do with the existing resolution. The problem may be partially overcome by the utilization of synergy between the different available technologies.

Baseline information is another important factor for the effective performance of the verification regime. In the seismological IMS monitoring network this means the geophysical databases of travel times of seismological waves that enable best calculations of location. This can be improved by voluntary regional calibration and CBM.

In the OSI this concept relates to the geophysical techniques whose accuracy or threshold, that determine the detection possibility of anomalies related to nuclear explosions, are strongly dependent on baseline information, which in general is lacking. This is a difficult problem because of the local (small scale) nature of such information that is needed for the application of techniques such as gravitational field mapping and the different active seismology methods. In view of the unpredictable location of an OSI, the lack of applicable databases in this case may be intrinsic, because of the impossibility to cover the globe in advance with a dense set of measurements.

Because OSIs are ad hoc operations and start from scratch each time, information bases must be established anew each time an OSI begins, without the benefit of information collection in advance. The efficiency of these operations could be improved if the CTBTO was able to collect and analyze information about potential mission locations on

an ongoing basis. This is an unlikely development, however, as member states (to any treaty) have an inherent resistance to allowing an international organization to undertake anything that might be even remotely considered to be independent intelligence gathering.¹ Nonetheless, once the OSI is approved and is up and running the IT will establish, out of necessity, its own information gathering functions.

This can be partially amended by States Parties volunteering databases about regions they envision of having high probability as being challenged. A voluntary database may be established where States Parties interested in enhancing the verification regime will deposit data and information about their territory. This will be compounded with the information the TS has, such as standing arrangements with each SP, list of inspectors verified by this SP etc., to be used by the IT when needed.

E. THE (NON EXISTING) INSPECTORATE

The CTBTO will not have a standing OSI inspectorate, unlike other verification regimes. For each OSI, depending on the parameters known at the moment a request is filed for OSI, inspectors will be chosen from a pool of trained inspectors nominated by member states and the TS. This pool needs to be large enough (and geographically dispersed) to supply a team of up to 40 inspectors and inspection assistants having the required expertise for the specific OSI. This process of choosing the inspectors and assembling them has to be achieved within six days. Inspectors will require a diverse range of skills and the ability to work in harsh climates or terrain. Almost 150 potential candidates from 39 signatory states have participated in introductory courses conducted by the PTS until today, and this is still a meager start. The potential inspectors and inspection assistants will have to go through advanced courses and cross training in order to make them familiar with the other expertise in the team.

The coordination of the inspectors and inspection assistants base is definitely one of the major problems the CTBTO will face in coming years. An intensive program will have to be installed to track the training and availability of inspectors.

F. THE TIMELINE PROBLEM

Once a request for OSI is filed by a state party, the OSI clock starts to tick. The Operating Support Center, which is planned to be the administrative and logistical center of the operation, has to help the DG and the newly appointed Inspection Team Leader (ITL) to bring together the equipment and IT members to the point of entry in the inspected state within 6 days. During the first 4 days, until a decision is taken by the EC, the DG has to seek clarifications about the event that triggered the request from the state sought to be inspected in order to clarify and resolve the concern raised in the request. This is particularly important if a C&C (voluntary though recommended) has not been carried out.

Once the decision has been made by the EC to carry out the OSI following the request, the IT has up to 25 days for the first phase. At the end of this time (or earlier) a recommendation has to be formulated by the ITL whether to continue the OSI or stop it for either strong evidence on the one hand or no evidence on the other hand, and the IT findings up to that time have to be presented. This is a short time, taking into account the organization of the base of operation and planning of activities to be done, and the size of the area (up to 1000 sq km) to be covered. If the decision was made to continue

the inspection beyond the initial 25 days, the IT may deploy the continuation period geophysical techniques that are time consuming and demanding and may slow down the process.

Starting at the point of entry, the ITL will have to be careful to avoid stalled situations when agreement is needed with the inspected state. Such situations may expend time that cannot be gained back because of the deadlines set by the Treaty on different stages.

G. ITL QUALITIES AND STATUS

Because of the tight timelines adopted by the Treaty, an efficient and successful OSI will depend, among other things, on the personality and qualifications of the team leader, and on the guidelines and arrangements with which he will be equipped. There is no question that the result of an OSI depends heavily on the resourcefulness and leadership of the team leader. His ability and authority to make and apply decision at turning points of the inspection is of utmost importance. His diplomatic skills will have an important effect on the conduct of the OSI by avoiding unnecessary conflicts with the ISP, which may lead to inefficient use of the allotted time. The task of the ITL will be more controllable if he or she will be equipped with the best tools and guidelines possible.

In order to achieve optimal results from an OSI, the team leader will need experienced experts equipped with the right equipment and a good basis for planning the specific OSI including guidelines for different situations. This means a good and detailed Operations Manual, well-adjusted equipment, experienced and well-trained team members, and practical standing arrangements with the inspected state.

The unpredictable initiation of an OSI will create a situation which is unlikely to be covered by the regular financial regulation of the organisation, which have a system of controls that make it slow-reacting compared to the fast pace of the OSI. Special funding and expenditure regulations will have to be devised for this situation. These regulations will have to depend heavily on the authority of the team leader. Being directly under the DG, the team leader for all purposes should be given the appropriate status, e.g. a deputy DG, as he/she will need the authority and means to use funds with minimum bureaucratic delays.

One of the most difficult situations that a team leader may face is that in which there is no conclusive information found during the initial period or the continuation period that would point to a possible site related to the event that triggered the request. Based on his/her and the team's best expert judgment he/she may conclude that termination of the inspection is justified. This will pose a dilemma: political pressure may push for continuing the inspection throughout the 130 allowed days, while, according to his/her judgment, there is a high chance of obtaining only inconclusive findings. The latter may be regarded as his/her fault and incompatibility.

H. ENVIRONMENT - ISP AND CLIMATE

Any OSI mission will be confronted by unforeseen limitations originating from two sources: The inspected state party and the environment.

The inspected state party, unidentified until a few days before the inspection, may pose an unpredictable level of cooperation. For its own national reasons or because of

intrinsic inability, the inspected state may be uncooperative, and possibly even opposed to the OSI to the point of being disruptive. Whilst in the focus of an international crisis, the IT has to accomplish its mission with the least friction with the inspected state; at the same time the IT is dependent upon that state which is suspected of non-compliance and which may present restrictions and prohibitions.

The other factor to be revealed only after the request has been filed is the type of environment in which the requested inspection area resides. Diverse possible environments have to be accounted for in the preparations for OSI, taking into account almost any possible climate on the globe. This means that arrangements have to be made for availability of equipment and clothing for any such climate on a short notice, and the proper training and guidelines should be implemented in advance.

These unknown circumstances may hamper the conduct of the IT mission and cause, in extreme cases, partial fulfillment or failure of the mission. Thoughtful and flexible planning in the design of OSI infrastructure and guidelines are necessary to minimize such disruption of the mission.

V. CONCLUSION

What can an OSI be expected to achieve? The answer to this question depends heavily on the outcome of the preparations for the OSI regime that are in progress in Vienna. The OpMan development is the main issue in this process, and will have the strongest effect on the future OSI regime. The working assumption can be that an OpMan may be agreed sooner or later, or prepared somehow, but it cannot be presupposed what its content will be. It will have to be judged at the end of the process. Until then we can only work towards the most appropriate OpMan to be developed. "Appropriate" here means one that will best contribute to the CTBT verification regime while preserving the internal Treaty balances. We cannot assume, however, that the OpMan will eventually cover every possibility of the OSI regime. But, it is clear that an inadequate OSI manual will undermine the deterrence value of the verification regime.

A successful OSI is expected to provide significantly better knowledge than was known prior to the OSI about the event that triggered the OSI request. Assuming that the OSI regime is well prepared, this is a plausible, although difficult mission, considering the intrinsic problems and difficulties facing the IT as described above. These intrinsic problems cannot be solved by an OpMan, but the inclusion of good guidelines and the right arrangements may lessen their effect on the outcome of an OSI. Such arrangements will also strengthen the significance of the OSI in the Treaty verification regime.

Being a rare event, the TS may find it difficult to maintain tension and to avoid slipping into relaxed behavior. Another impairing factor will be the diminishing expertise in nuclear explosion phenomena as a result of the cessation of nuclear testing. Combined, these two processes may bring about a significant decrease in the effectiveness and deterrence of the OSI regime. This may be one of the most difficult challenges of the technical secretariat in future years. To avoid such a possibility the TS will have to be vigilant, resourceful and diligent in keeping the training and exercise program active, in all its aspects, against all trends.

REFERENCES

¹ Jane Boulden, The Verification and Monitoring of Peace Accords, Wilton Park Conference on the Monitoring and Verification of Peace Agreements, 24 March 2000, Cosponsored by the Verification Research, Training and Information Centre (VERTIC).

² Article IV, Paragraph 1 of the Treaty: "1. In order to verify compliance with this Treaty, a verification regime shall be established consisting of the following elements:

- (a) An International Monitoring System;
- (b) Consultation and clarification;
- (c) On-site inspections; and
- (d) Confidence-building measures.

At entry into force of this Treaty, the verification regime shall be capable of meeting the verification requirements of this Treaty."

³ Article IV, Paragraph 29 of the Treaty: "29. Without prejudice to the right of any State Party to request an on-site inspection, States Parties should, whenever possible, first make every effort to clarify and resolve, among themselves or with or through the Organization, any matter which may cause concern about possible non-compliance with the basic obligations of this Treaty."

⁴ In support of the calibration initiative, three controlled underwater chemical explosions, announced in advance to the international CTBT community, were detonated in the Dead Sea between November 8 to 11, 1999. The three explosions were detonated by the Geophysical Institute of Israel, contractor to the U.S. Department of Defense, Defense Threat Reduction Agency, in cooperation with the Israel Atomic Energy Commission, the National Data Center of Israel. The explosions were carried out with the objective of calibrating seismic travel times across the Middle East and Eastern Mediterranean region to improve location estimates by the IMS.

⁵ Article IV, Paragraph 35 of the Treaty: "35. The sole Purpose of an on-site inspection shall be to clarify whether a nuclear weapon test explosion or any other nuclear explosion has been carried out in violation of Article I and, to the extent possible, to gather any fact which might assist in identifying any possible violator."

⁶ Part II, paragraph 89(b) of the Protocol: "89. ...the inspected State Party shall have the right... *inter alia*...: (b) Restricting measurements of radionuclide activity and nuclear radiation to determining the presence or absence of those types and energies of radiation relevant to the purpose of the inspection;"

⁷ OSI techniques according to Part II, Paragraph 69 of the Protocol.

Group 1: Position finding; Visual observation; Video and still photography; Multi-spectral imaging; Gamma radiation monitoring; Gamma energy resolution analysis; Environmental sampling; Passive seismological monitoring;

Group 2: Resonance seismometry; Active seismic surveys; Magnetic field mapping; Gravitational field mapping; Ground penetrating radar; Electrical conductivity;

Group 3: Drilling;

The use of these is restricted for different periods of the OSI: Up to 25th day - group 1 techniques.

From 26th to 60th days (continuation period) - groups 1 and 2 techniques.

From 61st to 130th days (extension period) - groups 1 and 2 techniques, according to IT indication in the extension request.

On special approval - group 3.

**THE CONTRIBUTION OF NATIONAL TECHNICAL MEANS
TO CTBT VERIFIABILITY**

**SLIDE
PRESENTATION**

Professor Terry Wallace

**Department of Geosciences, University of Arizona
USA**

- The IMS monitoring system will not detect signals smaller than magnitude 3.4
- Magnitude 3.4 could mean that a 1 kt decoupled explosion goes undetected
- Using a decoupling factor of 70, this means that explosions larger than 50 kt could be evasively tested



Discrimination

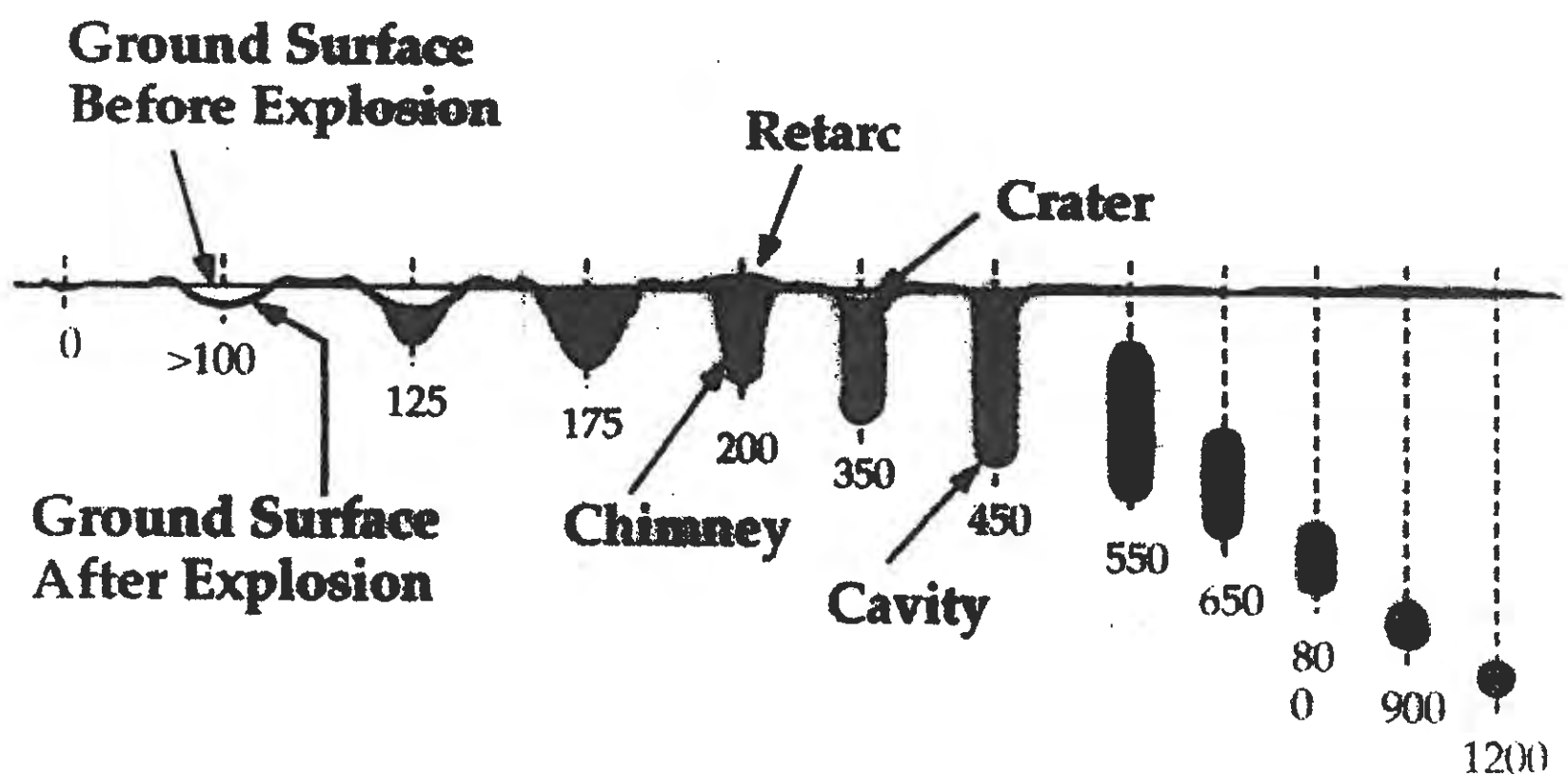
■ Small Magnitudes

- As source dimensions decrease the spectral differences decrease
- Evasion
- Noise

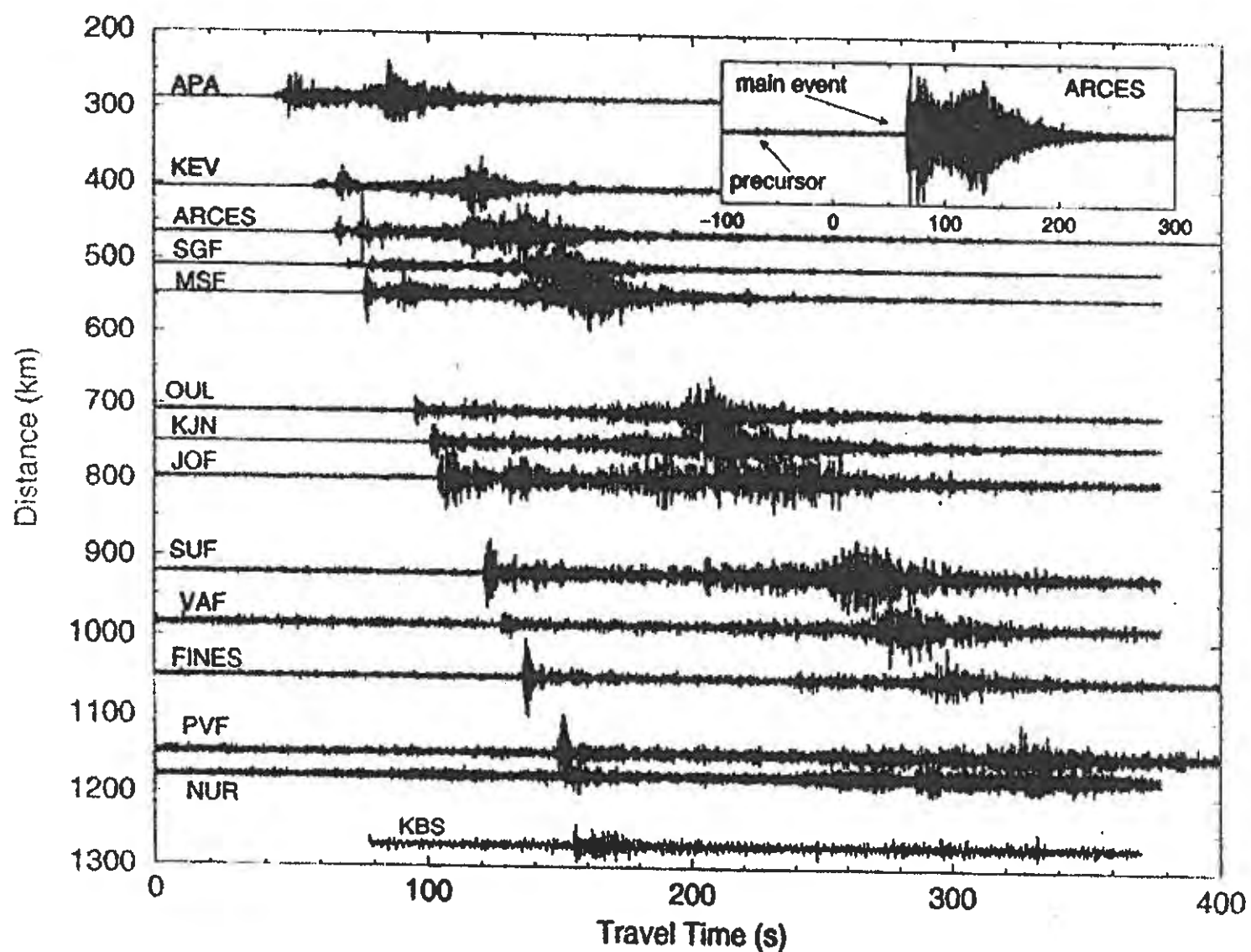
■ Solutions?

- Calibration!

Crater Formation As A Function Of Depth Of Burial



Kursk Record Section



- 5 years: 2,300 broadband stations
- 5 years: 18,000 short period stations
- 5 years: 700 stations available via the internet or GCI
- 10 years: 4,000 broadband stations
- 10 years: 3,000 available via internet or GCI

Detection and Location

■ Station Distribution

- IMS
- NTM
- Open Seismic Stations

■ Global Detection Capability

- $\text{IMS} + \text{NTM} + \text{Open} = 2.75$ for 85% continents

■ Problems? How to Get Open Data

CTBT Verification

■ Event Detection

- Seismometer distribution, noise and processing

■ Event Location

- Phase id, earth models, calibration

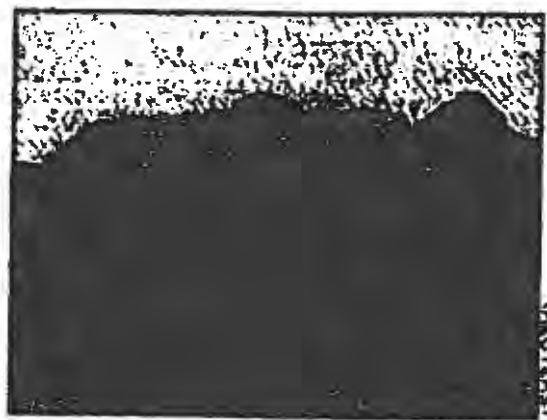
■ Event Discrimination

- Source models, calibration

■ Event Attribution

National Technical Means

- * Seismic Stations
- * Satellite
X-Ray
Gamma
Imagery
- * Other environmental Sensors

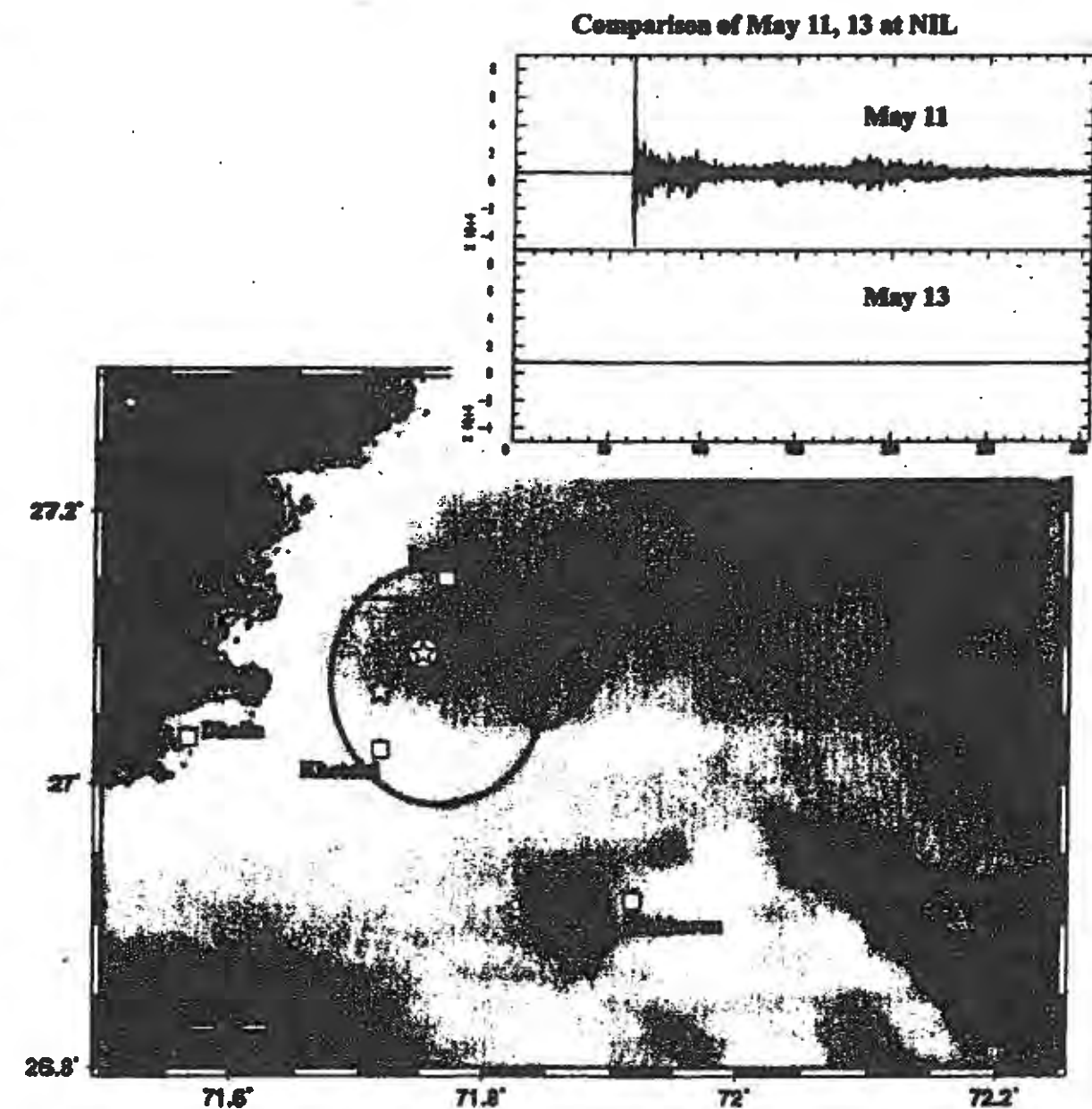


Omega Three
July 29, 2000

Yield = 100 tons

Open Seismic Stations, National Technical Means, and non-offical monitoring facilities and the CTBT

Terry C. Wallace



**CONTRIBUTION OF REMOTE SENSING SATELLITES TO CTBT
VERIFIABILITY**

Professor Bhupendra Jasani

**Department of War Studies, King's College London
UK**

DRAFT

After 42 years since the first international proposal for a complete ban on testing nuclear weapons was made in April 1954 by India, the Comprehensive Nuclear Test Ban Treaty (CTBT) was finally opened for signature on 24 September 1996. In its Preamble, it is recognised "that the cessation of all nuclear weapons test explosions and all other nuclear explosions,...constitutes an effective measure of nuclear disarmament and non-proliferation in all its aspects,...". Thus, the State Parties committed themselves not to carry out nuclear tests. It was also accepted that "the most effective way to achieve an end to nuclear testing is through the conclusion of a universal and internationally and effectively verifiable comprehensive nuclear test-ban treaty,...". With this in mind, several verification methods have been recognised in the Treaty, all of which depend on the detection of a nuclear explosion after it occurs. However, from the point of view of non-proliferation of nuclear weapons, this would be too late and would not fulfil the above aim of "non-proliferation in all its aspects...". Ideally, in order to achieve truly the non-proliferation goals of the CTBT, it would be useful to have a method that could detect a potential nuclear test so that the State involved could be persuaded not to carry it out. It is suggested here that, to some extent, the use of commercial remote sensing satellites can satisfy such a requirement.

HISTORICAL PRECEDENTS

Photographic reconnaissance satellites belonging to the former Soviet Union detected the preparations by South Africa of its planned nuclear test in 1977.¹ However, South Africa was persuaded not to carry out its test. In 1981, it was reported that India had begun preparations for a test in the Rajasthan desert.² These observations were carried out until 1984. On 15 December 1995, news was leaked that US military observation satellites had detected considerable activities at India's nuclear test site.³ It was assumed to be related to continued nuclear test preparations. After considerable diplomatic flurries supported by satellite imagery⁴, India was apparently persuaded not to go through with its plans.

It has been argued that satellites failed to observe the Indian nuclear test preparations in 1998. It is hard to believe that satellites observed preparations in 1981 through 1984 and again in 1995 but suddenly stopped looking at the Rajasthan Desert in 1998. In fact, it was reported that satellite imagery indicated that a test was imminent in May 1998. The information, however, came too late to the decision makers.⁵ It should be realised that it is always difficult to predict the exact time of such an event unless communications are also monitored closely. If a State wishes to hide a nuclear test, it will either encrypt all communications or remain silent before a test. The above indicates that optical reconnaissance satellites have been used for monitoring preparations of nuclear tests. In fact satellites are an important element of the national technical means (NTM) of verification. The NTM consists of methods of collecting information using technical equipment not dependent on any co-operation by other countries.

Vast amount of energy are released from a nuclear explosion. This energy is emitted in the form of thermal and light radiation, blast and shock waves and nuclear radiation consisting of gamma rays, X-rays, neutrons and charged particles as well as fission and fusion products.

Beside optical cameras, various types of nuclear radiation detectors such as for example gamma ray, X-ray and neutron detectors, and optical instruments are deployed on board spacecraft.⁶ In the US, satellites carrying such devices were called Vela satellites. Subsequently, such sensors have also been carried on board the US Defence Support Program (DSP) satellites⁷ and on global positioning system (GPS)⁸ satellites. However, all of these types of satellites were primarily developed and deployed for defence purposes, and as such, data from them are not generally available to the international community, particularly those generated from the Vela, DSP and GPS satellites. While the data generated by such satellites are not commercially available, they are shared only with a few very close allies. Even these may not get all the information they require. Thus, for multilateral treaties more open verification methods need to be explored. Commercial remote sensing satellites now have this potential.

WHY COMMERCIAL SATELLITES?

The CTBT does not exclude the possibility of using satellites in its verification procedures. While this technique is not one of the several verification methods listed in the Treaty, States Parties to the Treaty are urged to look at this technique. Article IV.11 of the CTBT for example states that

"Each State Party undertakes to cooperate with the Organization and with other States Parties in the improvement of the verification regime, and in the examination of the verification potential of additional monitoring technologies such as...satellite monitoring..."

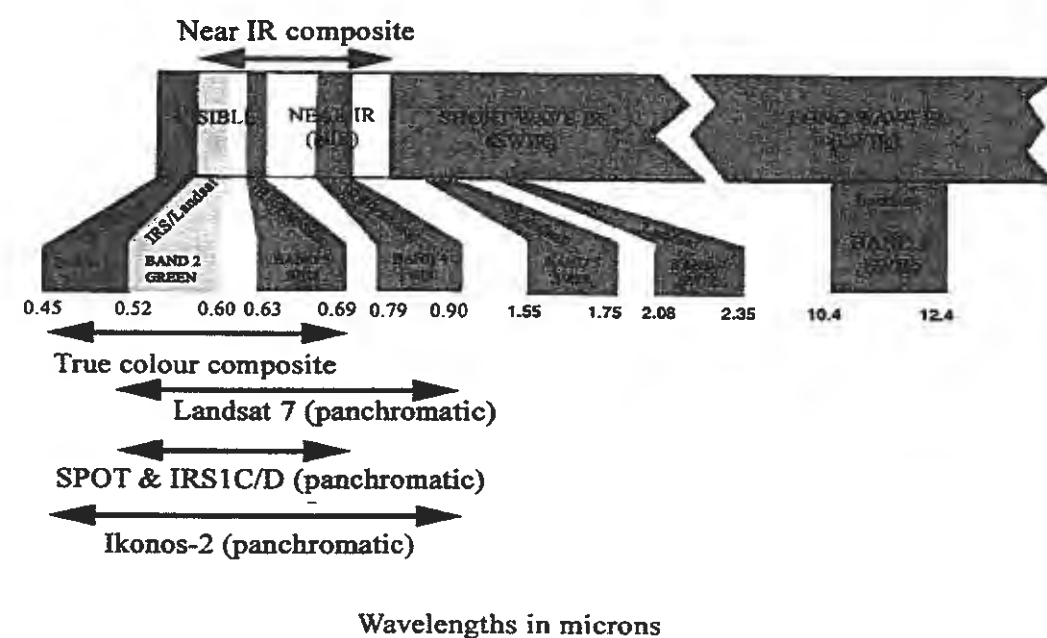
Satellites offer the possibility of monitoring a large area of the Earth quickly and repeatedly. Not only this, but they could provide an improved factor of at least 7 in terms of area coverage compared with that obtained from aerial surveillance by aircraft. For example, a modern aircraft, such as the US SR71, flying at an altitude of some 25km at a speed of 1km/sec, is capable of filming slightly more than 250,000km² of the earth's surface in an hour.⁹ A satellite, such as the French satellite SPOT (resolution¹⁰ 10m), or the Indian IRS-1C or -1D (resolution 5.8m), travelling at some 7km/sec at an altitude of 800km, could observe about 1,750,000km² of the earth's surface in an hour. A satellite carrying a sensor with a resolution of 1m, such as the US Ikonos-2, could cover about 277,000 km² in an hour, nearly the same area as that covered by an aircraft. Unlike for over-flights by aircraft, no permission would be required from States over which satellites pass. Furthermore, since a satellite orbits at an altitude of at least 150km, well beyond national airspace, and since it is unmanned, humans are not exposed to retaliation from an adversary, unlike reconnaissance aircraft pilots. Moreover, the quality of data from commercial observation satellites has improved some 100 fold since 1972 (see Table 1) when the first such spacecraft was launched by the US. Finally, data from commercial observation satellites could be purchased by anyone. Considerations like these must give much impetus to the development of multilateral technical means of verification (MTM).

Electromagnetic (EM) radiation reaching a sensor on board a satellite can be recorded on film or electronically in digital form. The latter, recorded over specific spectral regions of the EM radiation, are assigned brightness values. Thus, such data are not in colour. In the case of the Landsat-5 satellite, there are seven bands (see Figure 1). Colour images are then

obtained when selected bands are channelled through red, green and blue colour guns in a computer display monitor. If bands 1, 2 and 3 are assigned colours blue, green and red respectively, the resulting colour image will be very close to an image formed by human eyes. Such an image is known as a true colour composite. Spatial resolutions of such multi-spectral sensors range from 4m to 120m. While a panchromatic band spans over a wide range of wavelengths (see Figure 1), the spatial resolution is much better (see Table 1). For example, the latest US commercial satellite Ikonos-2, launched in 1999, has a resolution between 0.8 and 1m. Thus, in a multi-spectral satellite image (for example, a combination of bands 2, 3 and 4 of a Landsat), after a nuclear explosion, a localised spectral change can be detected owing to the change in surface structure. Surface fracturing or a crater can be detected by high-resolution panchromatic image.

Therefore, with the development of commercial remote sensing satellites, even the participation by the international community in the verification process of a treaty such as the CTBT is now possible. Satellites are non-intrusive and information acquired by them is openly available. Moreover, a number of States are launching and operating their own commercial remote sensing satellites with high-resolution sensors on board. Thus, authentication of data becomes possible. There is a considerable potential for detecting changes in a scene owing to nuclear tests both by eye and with the use of mathematical techniques using computers. The latter are most useful for detecting spectral changes in a scene. It has often been argued that optical sensors are very limited because clouds frequently cover the earth's surface. Civil radar satellites that have day and night and all weather capabilities now overcome this obstacle and can be used to detect changes, by interferometric methods, before and after a test.

Figure 1. This shows spectral sensitivity of the French, the Indian and the US satellites. Number of bands in each case is also indicated.



Satellites cannot always detect the nuclear test preparations. For example, India conducted its first nuclear test in 1974 at a site at Pokharan test range in the Rajasthan desert. This test came as a surprise since apparently satellites did not detect the preparations.¹¹ However, subsequently in the same region satellites did detect test-related activities in 1981.¹² It should also be emphasised that satellites are not the only method used for verification of treaties. Information derived from many sources is usually required and used. Data from satellites could act as an additional very important source of information. This data can also be used to trigger on-site inspections.

COST OF SATELLITE DERIVED DATA

It is often argued that the cost of satellite imagery will be so high that their use for verification becomes prohibitive. For monitoring a CTBT, generally some specific known sites are to be monitored so that large area scanning of the earth's surface is not necessary. At present there are six known nuclear test sites. These are: (1) the US Nevada site (the Yucca Flats and Frenchman's Flats); (2) the Russian Novaya Zemlya; (3) the French site in the Pacific at Moruroa and Fangataufa; (4) the Chinese site near Lop Nor; (5) the Indian Pokharan site in the Rajasthan desert; and (6) the Pakistani site at Ras Koh in the Chagai Hills region. In addition, only a few States listed in the CTBT with significant nuclear activities are likely to develop nuclear weapon programme. Thus, the area to be monitored may not be so large. Also, once a site has been identified and recorded initially, it does not have to be monitored continuously. Only the test locations need to be monitored periodically. Thus, images of smaller sizes could be acquired. This will have a considerable impact on the cost of imagery.

The cost of images is not always simple to estimate because the cost of an individual scene can be very different when bought singly or as one of a larger order. Moreover, scenes that are archived and are older than a certain date may be cheaper by as much as 40 percent. On the other hand, if a satellite is specifically targeted to acquire a scene, then the image will cost considerably more. The retail prices of data from various remote-sensing satellites are shown in Table 2. The cost can be reduced if extracts of full scenes are purchased. However, in this case the exact location of the site needs to be known so that only a small scene needs to be purchased. Initially the sites could be identified using, for example, the SPOT or the Indian IRS-1C satellites since they cover larger areas. Once the site of interest is identified, then a high-resolution image could be acquired. Table 2 gives some estimates of the cost of various types of imagery products. It should be remembered that as more and more countries launch their own satellites and enter the market, the cost is bound to decrease.

SOME CONCLUSIONS

As a result of considerable improvement in the capabilities of commercial remote sensing satellites, their use could significantly enhance the verification of the CTBT. Not only can the location of a test be determined accurately but its preparations can also be detected possibly in time to avert the test. This is important as the ideals of non-proliferation are then truly fulfilled. Moreover, it would be difficult to hide from satellite observations a nuclear

test in a seismic event because, on a multi-spectral image, an explosion would record very localised spectral and surface structural changes that would not be the case in an earthquake. Perhaps there are two most important aspects of monitoring from space; it is non-intrusive and it could be used by anyone because satellite imageries can be acquired commercially.

It is reasonable to assume that countries without any significant nuclear research and/or nuclear power programme and any national security concerns are less likely to embark upon nuclear weapons testing. This would reduce the number of countries to be monitored. Furthermore, as more and more countries launch and operate their own satellites, not only the cost of imageries will be reduced but also it would be possible to authenticate information from various sources.

It is, therefore, suggested that such satellites should be a part of the CTBT verification regime. The Treaty, while at present does not include verification by satellites, it does suggest that the use of satellites could be investigated at some future date. The CTBTO together with States Parties should begin to look at satellites now and if it concludes that the technique can "enhance the efficient and cost-effective verification of this Treaty..." it "be incorporated in existing provisions in this Treaty, the Protocol or as additional sections of the Protocol, in accordance with Article VII., or, if appropriate, be reflected in the operational manuals in accordance with Article II, paragraph 44." It is suggested here that this technique should now be explored in collaboration with the CTBTO.

TABLE 1. CURRENT AND SOME FUTURE COMMERCIAL REMOTE SENSING SATELLITES BELONGING TO VARIOUS COUNTRIES.

Country Satellite	Date of launch of first satellite	Resolution in pixel size (m)		
		Panchromatic	Multi-spectral	Thermal/IR
OPTICAL				
<i>Brazil/China</i> Zi Yuan CBERS I & II	1999-2001	20		
CBERS III & IV		5	10	40-80
<i>France</i> SPOT-4 SPOT-5	1998 2002	10 2.5	10	
<i>India</i> IRS-1C,-1D IRS-P5	1995, 1997 1999-2000	5.8 2.5	25	
<i>Israel</i> Eros-A	1999	1		
<i>Japan</i> ALOS	2003	2.5	10	
<i>Russia</i> Resurs-F series	1989-98	2		
<i>USA</i> KH-1 to 4 KH-4A KH-4B Landsat-5 Landsat-7 Ikonos-1 did not achieve orbit, -2 Quickbird-1,-2 Orbview-3 Orbview-4 Earlybird-1 ASTER	June1959-Dec63 Aug1963-Oct69 Sept1967-May72 1984 15 April99 1999 1999 2000 1997 18 December99	7.6 2.7 1.8 15 0.8-1 0.8 1-2 1-2 3	 30 (bands 1-5,7) 30 (bands 1-5, 7) 3-5 4 4 4 & hyperspectral 8 15 15 (bands1-3), 30m (bands 4-9)	 120 (band 6) 60 (band 6) 90 (bands 10-14)
RADAR				
<i>ESA</i> 1, & -2	ERS- 1991 & 1995	25		
<i>Japan</i> JERS-1	1992	18		
<i>Canada</i> Radarsat	1995	9-100		
<i>Russia</i> Almaz-1B	1998	4-15		
<i>USA</i> SIR-C	1994	8-30		

TABLE 2. COST OF DATA FROM SOME OF SATELLITES.

Satellite	Area (km ²)	Data format	Cost US\$ (cost/ km ²)
<i>Photographic</i>			
Russian KVR-1000	1,600	Film positive Film negative	3,300/(2.10) 3,520/(2.20)
<i>Digital</i>			
Russian KVR-1000	16 160 1,000 1,600	Panchromatic	1.100/(68.75) 1,760/(11.00) 2,750/(2.75) 4,400/(2.75)
French SPOT	3,6000	Multispectral level 1B (3 bands) Panchromatic level 1B Multispectral level 1A/1B (3 bands) Panchromatic level 1A/1B Multispectral level 2A (3 bands) Panchromatic level 2A	~ 1,200/(0.33) ~ 1,600/(0.44) ~ 2,000/(0.56) ~ 2,800/(0.78) ~ 2,800/(0.78) ~ 3,400/(0.94)
Indian IRS-1C	4,900	Panchromatic Multispectral (4 bands)	2,500/(0.51) 2,800/(0.57)
US Ikonos		Panchromatic Multispectral (4 bands)	Min. 1,000 or (12-17) - US; 2,000 or (29-44) - Int.
Landsat	22,500	Multispectral (7 bands)	~ 4,400/(0.18)
<i>Radar (digital)</i>			
European ERS-1, -2	6,400	Synthetic aperture radar (SAR)	~ 1,200/(0.19)
Canadian Radarsat	2,500	SAR	~ 2,500/(1.00)

NOTES AND REFERENCES

¹ Jasani, B., "Military Satellites," World Armaments and Disarmament, SIPRI Yearbook 1978, (Almqvist & Wiksell and Stockholm International Peace Research Institute, Stockholm, 1978), pp.69-103.

² Senator Alan Cranston, "Nuclear Arms Race in South Asia Endangers US Security Interests," Congressional Record, US Senate, April 27, 1981, pp.7375-7377.

³ Weiner, "India Suspected of Preparing for A-bomb Test", The New York Times, 15 December 1995, p.A6.

⁴ Richelson, J., "Examining US intelligence failure", Jane's Intelligence Review, vol. 12, no., 7, September 2000, pp.41-44.

⁵ *Ibid*, Richelson, p.43.

⁶ "Satellite Instruments for Monitoring the Limited Test Ban Treaty", Verification Technology, Sandia Technology, Sandia National Laboratories, Albuquerque, New Mexico, November 1984, pp.8-11.

⁷ Whelm, C. R., Guide to Military Space Programs, Arlington, VA: Pasha Publications Inc., 1994, p.81.

⁸ "GPS to Test Nuclear Detection Sensor", Aviation Week & Space Technology, vol. 111, no. 9, 27 August 1979, p.51.

⁹ Leopold, G., "Verification technology grows in tandem with pressure to obey SALT II", Defense News, vol. 1, no. 50, 1986, p.11.

¹⁰ Resolution may be defined as the smallest distance between two identical objects at which they can be resolved by a sensor as two objects. Such a definition is applied to a photographic image. In the case of a modern digital device, this resolution may be defined as the area on the ground represented by each sensor cell or a pixel. Thus, smaller the pixel, smaller the area and thus, finer the resolution.

¹¹ Jasani, B., "Reconnaissance satellites", World Armaments and Disarmament, SIPRI Yearbook 1975, (Almqvist & Wiksell and Stockholm International Peace Research Institute, Stockholm, 1975), pp.381-384.

¹² *Ibid*, Cranston, p.46

**THE CONTRIBUTION OF SCIENTIFIC NETWORKS TO CTBT
VERIFIABILITY**

**SLIDE
PRESENTATION**

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US**

Washington Post

THURSDAY, OCTOBER 14, 1999

Inside The Weekly, Please
Today's Contents on Page A1

25¢

Senate Rejects Test Ban Treaty

Nuclear Pact Falls 51 to 48 as GOP Deals Clinton Major Defeat

By HELEN DEWAR
Washington Post Staff Writer

The GOP-controlled Senate emphatically rejected the Comprehensive Test Ban Treaty yesterday, dealing a devastating blow to a pact that has been at the center of global efforts to curb the spread of nuclear weapons.

Senate Republicans said it would be impossible to ensure that other nations were abiding by the treaty, and they argued that the pact would make it difficult for the United States to ensure the viability of its own nuclear stockpile. They rejected Democratic complaints that they were sending a dangerous message to other nations interested in joining the nuclear club.

Indeed, the 51 to 48 vote against the pact fell largely along party lines, with only four Republicans joining 44 Democrats in supporting the treaty—far short of the two-thirds necessary for ratification.

The vote was President Clinton's biggest foreign policy defeat on Capitol Hill and represented another collapse of bipartisanship in a Congress characterized by a high degree of style and paralysis. It also could have far-reaching international repercussions. Many U.S. allies including Britain, Germany and France have warned that rejection of the test ban treaty would raise serious doubts about America's commitment to reducing the nuclear arms threat.

Declaring that "the fight is far from over," Clinton last night denounced the treaty's rejection as "reckless" and "partisan."

"For now the Senate has said no, but I am sending a different message. We want to limit the nuclear threat. We want to bring the test ban treaty into force," Clinton said on the White House lawn.

"When all is said and done, the



Majority Leader Trent Lott (center) leaves the Senate floor with staff members yesterday after he and fellow Republicans defeated the Comprehensive Test Ban Treaty, which President Clinton had called one of his highest foreign policy priorities.

Analysis

For U.S., Fallout Will Be Fading Influence

By STEVEN MURSON

istration has been waging since the tor of Disarmament Diplomacy and

Senate Statements



“...a 70-kiloton test can be made to look like a 1-kiloton test, which the CTBT monitoring system will not be able to detect.”

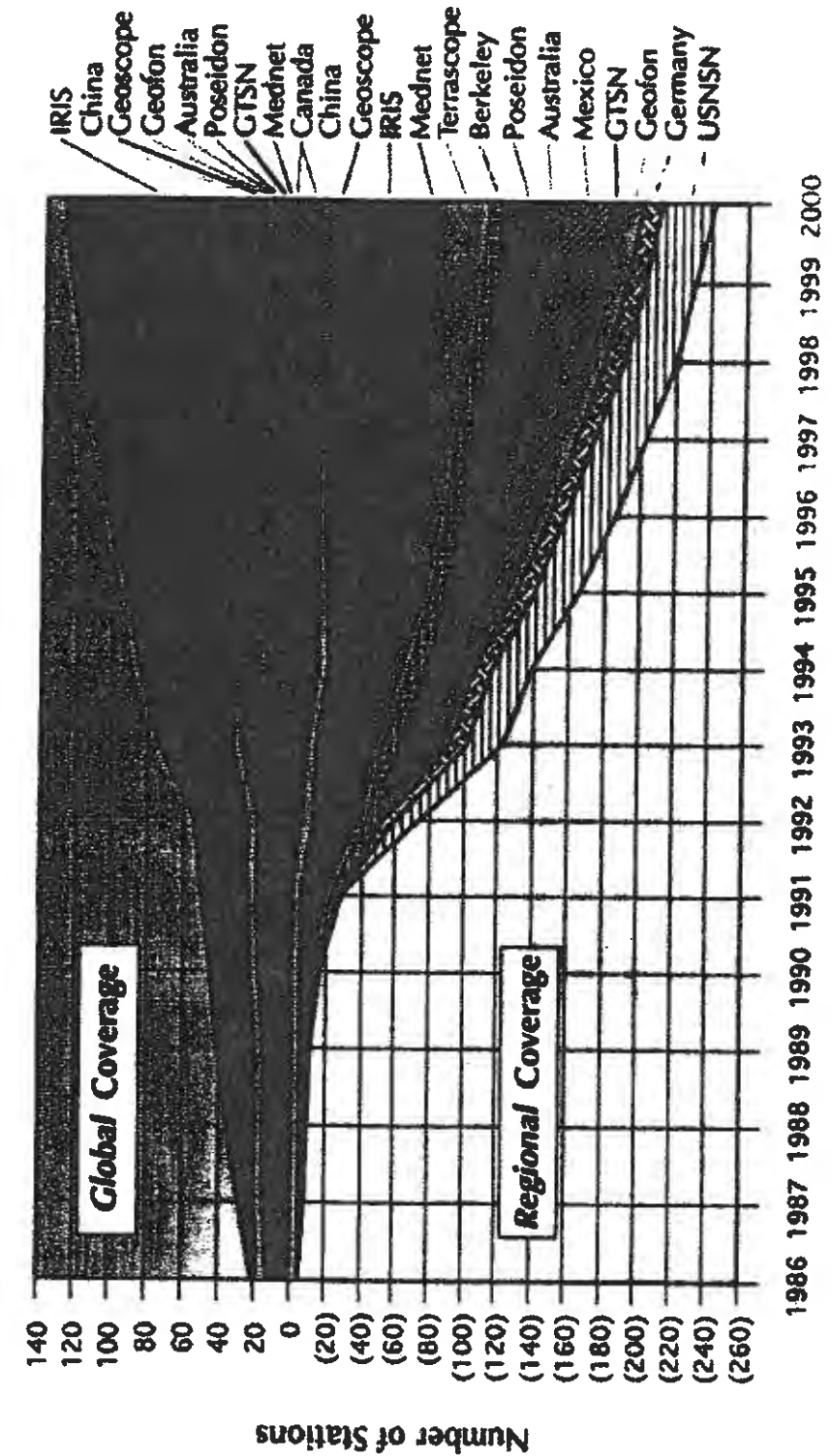
- Senate Majority Leader Trent Lott, 10/8/99.

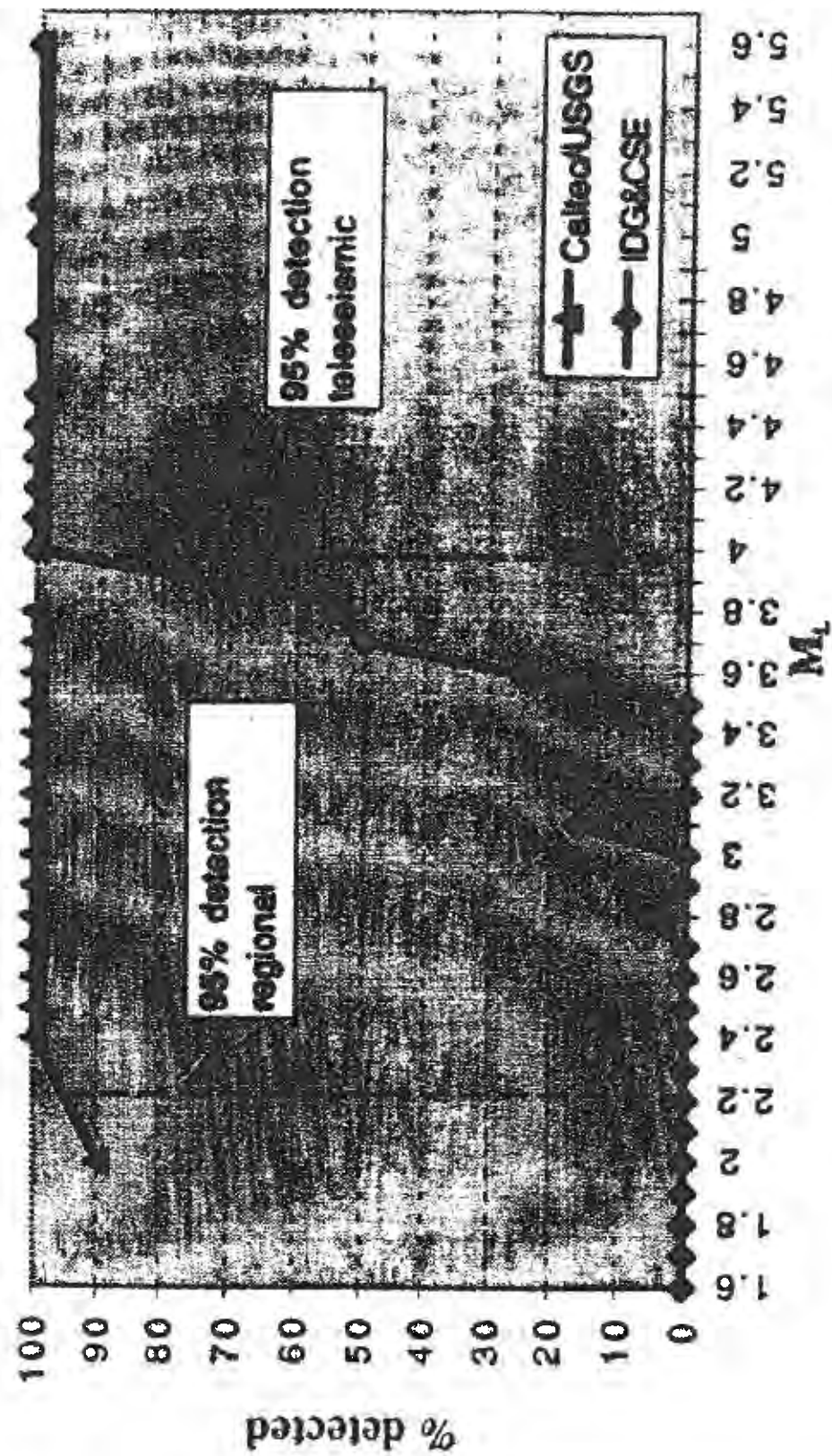
“...countries can conduct tests up to 60 kilotons without being detected by the IMS.”

- Chairman of the Senate Committee on Foreign Relations, Jesse Helms, 10/12/99.



Seismic Network Growth



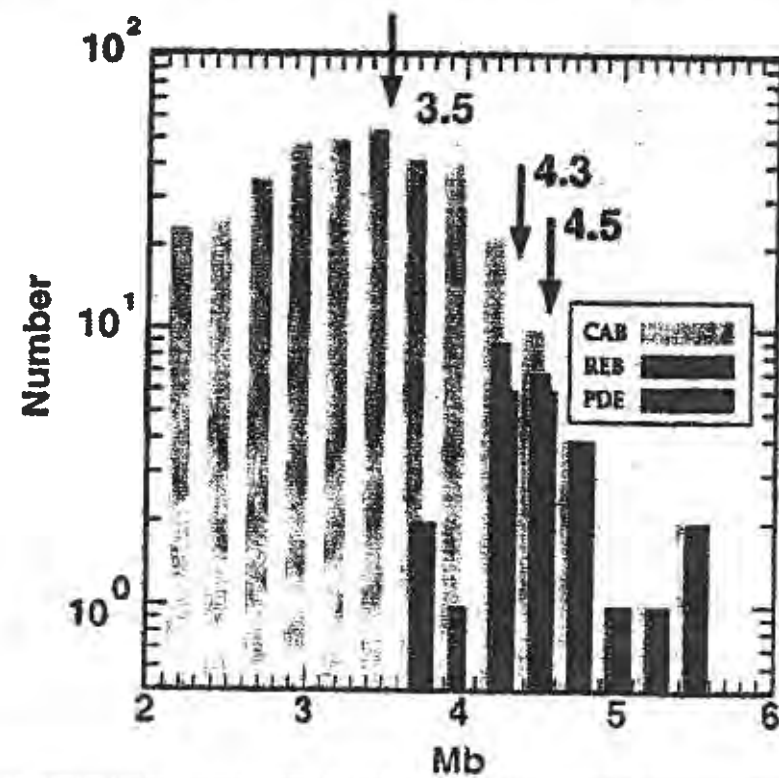
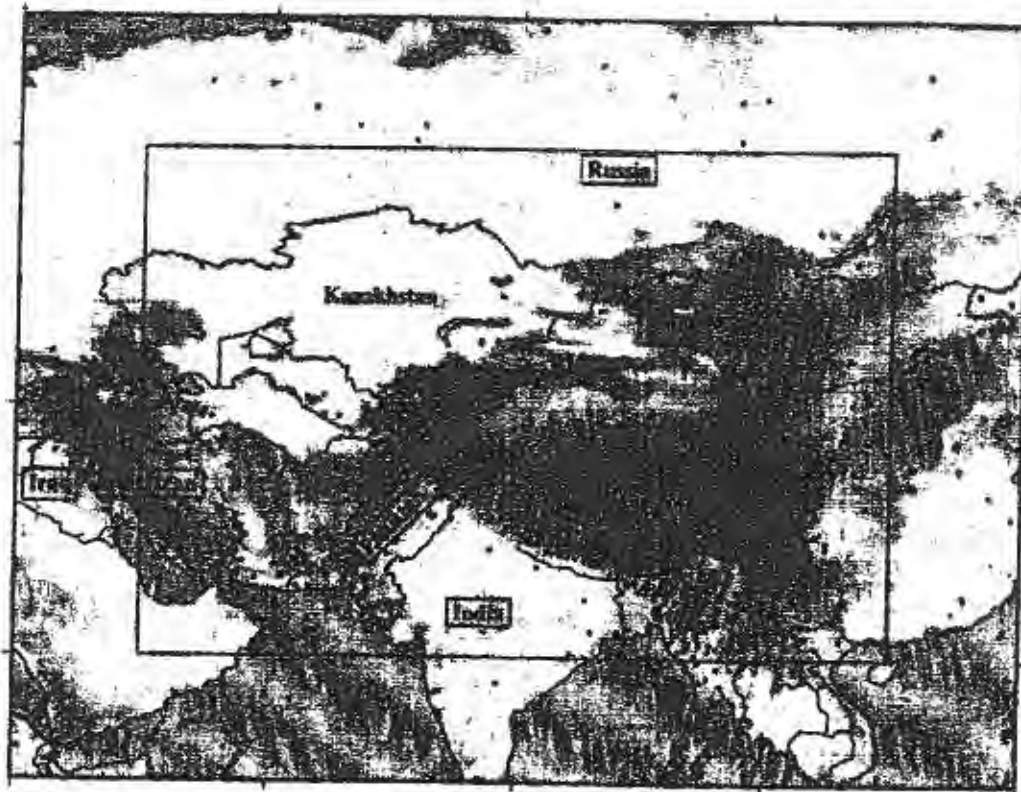


3) Different Boundary Conditions

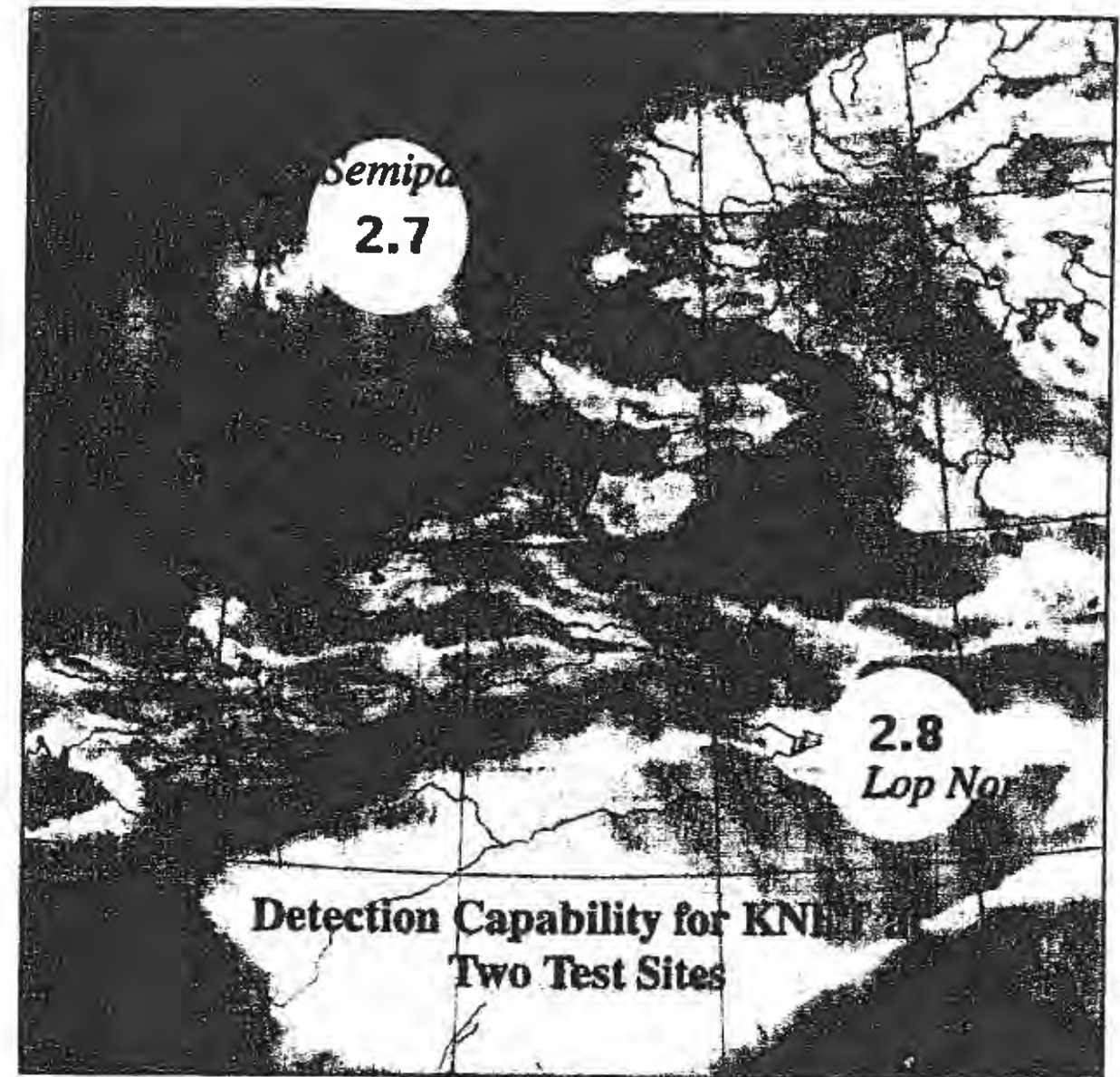
not just IMS ...

- US Capability = Σ IMS, AEDS, NTM, Open Sources
- Capability will only improve

Central Asia



KNET and Monitoring in Central Asia



***American Geophysical Union and Seismological Society
of America Joint Position Statement
Capability to Monitor the Comprehensive Test Ban
Treaty
(Adopted September, 1999)***

In September 1996, the United States was the first of 152 nations to sign the Comprehensive Test Ban Treaty (CTBT), an international agreement to ban all nuclear test explosions. The treaty is intended to impede the development of nuclear weapons as part of the international nonproliferation regime. The treaty has not yet been ratified by the U.S. As a result, many of its verification provisions have not yet been fully implemented. When implemented, the American Geophysical Union (AGU) and the Seismological Society of America (SSA) are confident that the combined worldwide monitoring resources will meet the verification goals of the CTBT.

The CTBT will be monitored by: 1) the national intelligence means of various countries, 2) the International Monitoring System (IMS) negotiated under the CTBT that consists of seismic, hydroacoustic, radionuclide, and infrasound networks, along with on-site inspections, and 3) the efforts of numerous independent scientists and institutions worldwide. It is this combination of resources that gives confidence in the ability to uncover CTBT violations. AGU and SSA believe that this overall monitoring capability will continue to strengthen as more data are collected, more research is performed, and as global communication networks expand.

The seismic component of the International Monitoring System is to consist of 170 seismic stations. This network is expected to detect all seismic events of about magnitude 4 or larger and locate these events within 1000 square kilometers (a circle with a diameter of approximately 35 km). This is the maximum area permitted by the treaty for an on-site inspection. A seismic magnitude of 4 corresponds to an explosive yield of approximately 1 kiloton (the explosive yield of 1,000 tons of TNT). AGU and SSA believe that the verification system, if built as planned, can be relied upon to meet that goal.

One of the biggest challenges to monitoring the CTBT is the possibility that testing could be successfully hidden by conducting nuclear explosions in an evasive manner. The concern is partly based on U.S. and Russian experiments which have demonstrated that seismic signals can be muffled, or decoupled, for a nuclear explosion detonated in a large underground cavity. The decoupling scenario, however, as well as other evasion scenarios, demand extraordinary technical expertise and the likelihood of detection is high. AGU and SSA believe that such technical scenarios are credible only for nations with extensive practical testing experience and only for yields of at most a few kilotons. Furthermore, no nation could rely upon successfully concealing a program of nuclear testing, even at low yields.

Data from the treaty's monitoring system will also contribute to our scientific understanding of the Earth and efforts to mitigate earthquake hazards. Article IV.A.10 of the treaty states "The provisions of this treaty shall not be interpreted as restricting the international exchange of data for scientific purposes". AGU and SSA support a broad interpretation of this article and strongly urge that all data from the International Monitoring System be made openly available without any restriction or delay.

1. Monitoring Capability
 - 1) IMS
 - 2) NTM (e.g. AEDS)
 - 3) Open Resources
2. Capability Will Continue to Improve
 - More Sensors
 - More Research
 - Expanding Global Communications
3. Encourage with Open Data
 - Makes System Sustainable
 - Ensures Access
 - Confidence Building

CHALLENGES

- Integrate Evolving Data Sources

ADVANTAGES

- Evolving/Improving
- Sustainable
- Most Likely to Provide Evidence of Violation

**SYNERGY AND THE INTERNATIONAL MONITORING
SYSTEM**

Peter D. Marshall

**UK Atomic Weapons Establishment at Aldermaston (AWE)
UK**

The International Monitoring System (IMS) was designed by the Group of Scientific Experts (GSE) during the CTBT negotiations in Geneva. During the negotiations the experts were instructed to take full account of the potential synergy of the technologies to be deployed to monitor compliance with the provisions of the treaty in order to maximise the cost-effectiveness of the IMS. The Experts' proposals and design were accepted by the diplomatic representatives of the states negotiating the treaty.

Of the four approved technologies deployed in the IMS only the detection by the radionuclide system of specific radionuclides can uniquely identify a source as a nuclear explosion. Data from the three waveform technologies: seismic, hydroacoustic and infrasound sensors are used to detect, locate and identify explosions in the atmosphere, underground and underwater but it is not possible using data from these systems to determine whether an explosion source is nuclear or not. In the absence of diagnostic radionuclide evidence a state party may wish to request an on-site-inspection (OSI). The synergy of the techniques deployed for the detection of nuclear explosions was taken into account when the Expert Group considered what technologies should be employed during an OSI.

To consider the synergy within the IMS it is convenient to consider the role of each technology in monitoring a particular environment. However, it should be noted that the synergy between the various technologies deployed within the IMS remains the same whether the IMS is complete or not. Furthermore, any additional monitoring system operated as a national facility or by independent non-governmental bodies will operate synergistically with the IMS.

UNDERGROUND NUCLEAR EXPLOSIONS

To detect and locate underground nuclear explosions, the seismic network of primary and auxiliary stations is fundamental. However, for source identification purposes, seismology is only a complementary, not a definitive technique. It is not possible through seismological means to identify a source as being a nuclear or conventional explosion; for this task the detection of radionuclides is essential. Radionuclides from an underground nuclear explosion may leak to the surface through fissures or fractures surrounding the cavity created by the explosion.

Detection of specific radionuclides during an OSI is vital evidence of a breach of the provisions of the treaty. Detection may be achieved by using drilling techniques to obtain samples from debris in or around the explosion cavity, which may have been located using geophysical, and in particular seismic, methods.

The hydroacoustic system may detect signals from underground explosions, particularly from those detonated on small islands in oceanic basins. The technique is itself only complementary to the seismic and radionuclide networks for detection, location and source identification. However, it has a significant role in the identification of earthquakes which occur in the sub-oceanic crust or upper mantle, thus ruling out the possibility that such phenomena are explosions. The detection and analysis of hydroacoustic T-phase signals will prove of significant value to the event-screening process required by the treaty, which is being developed for use by the International Data Centre (IDC) in Vienna. The detection of a T-phase signal in the hydroacoustic system data can also be used to improve source location when used in conjunction with the seismic system.

Infrasound is of minor value for the detection and location of fully contained underground explosions and has no value for source identification. However, an underground explosion which breaks the surface may be detected by the infrasound system, and if the source is nuclear, radionuclides may be detected by the radionuclide system.

It is important that the IMS and IDC provide high quality and timely data to enable states parties to discriminate between natural phenomena and nuclear explosions. However, at low magnitudes (below m_4 equivalent to a fully contained nuclear explosion of about 1 kt) many conventional explosions used for mining and quarrying purposes will be detected by elements of the IMS. A synergy exists between the various detection technologies which is of value in identifying such events as non-nuclear. The ability to correctly identify such explosions builds confidence in adherence to the treaty by states in which large mining explosions are routinely conducted for economic purposes.

Summary:

1.1. Underground Nuclear Explosions			
Technology	Detection	Location	Identification
Radionuclides	Complementary	Little value	Fundamental (if detected)
Seismic	Fundamental	Fundamental	Complementary
Hydroacoustic	Complementary	Complementary	Complementary
Infrasound	Little value	Little value	-
1.2. Earthquakes			
Radionuclides	-	-	-
Seismic	Fundamental	Fundamental	Fundamental
Hydroacoustic	Complementary	Complementary	Complementary
Infrasound	-	-	-
1.3. Conventional Mining and Quarrying Explosions ¹			
Radionuclides	-	-	Fundamental ²
Seismic	Fundamental	Fundamental	Fundamental
Hydroacoustic	-	-	-
Infrasound	Fundamental	Complementary	Fundamental

1. In areas of extensive mining, national co-operating facilities may be installed by a state party to demonstrate its compliance with the treaty. This table indicates the synergy that exists between the technologies to monitor mining explosions which are not contained, in which the surface above the shot point is severely fractured, thus releasing shock wave energy into the atmosphere.

2. The absence of radionuclides from an explosion that has clearly vented to the atmosphere and has been detected by the infrasound system would indicate that the explosion is non-nuclear and hence not a treaty violation.

UNDERWATER NUCLEAR EXPLOSIONS

Explosions detonated underwater or on small islands in oceanic basins may be detected by the hydroacoustic network. If the explosion is not contained, radionuclides may be deposited into the atmosphere and carried by the prevailing winds to radionuclide detectors. Submarine volcanoes and geophysical surveys may also generate hydroacoustic signals and it is important that such events are not misidentified as possible nuclear explosions.

The presence of a bubble-pulse oscillation in, and the high-frequency content of, a hydroacoustic signal is clear evidence of an underwater explosion. But again only the detection of specific radionuclides can identify the source as nuclear. The detection of an infrasound signal will depend on whether or not the explosion was fully contained within the water.

Summary:

2.1. Underwater Nuclear Explosions

Technology	Detection	Location	Identification
Radionuclides	-	-	Fundamental (if detected)
Seismic	Complementary	Complementary	Complementary
Hydroacoustic	Fundamental	Fundamental	Fundamental (Identification of explosion)
Infrasound	Little value ⁽¹⁾	Little value ⁽¹⁾	Little value ⁽¹⁾
2.2. Underwater Volcanoes and Conventional Explosions			
Radionuclide	-	-	Fundamental ⁽¹⁾
Seismic	Complementary	Complementary	Complementary
Hydroacoustic	Fundamental	Fundamental	Fundamental
Infrasound	Little value ⁽¹⁾	Little value ⁽¹⁾	Little value ⁽¹⁾

1. Only if venting to the air occurs.

ATMOSPHERIC NUCLEAR EXPLOSIONS

DETONATED OVER LAND

The principal methods deployed to detect nuclear explosions detonated in the atmosphere are radionuclide and infrasound techniques and a synergy between these two systems is of significant value for treaty monitoring purposes. Again the unique identifier of a nuclear explosion is the presence of specific radionuclides. However the back-tracking technique used to locate the epicentre of the radionuclide release is not very accurate, making it very difficult to identify the state responsible in areas such as Europe, where numerous states are located in a relatively small area. To improve the location capacity of the IMS for atmospheric explosions, the infrasound system is deployed, illustrating the significant synergy between the radionuclide and infrasound systems. The seismic network and the hydroacoustic system may detect an atmospheric explosion if large enough, but will contribute little to verification. The major source of signals detected by the infrasound system is from explosive volcanic eruptions, the passage of weather fronts, sonic booms and signals from venting quarrying explosions. The contribution that the IMS data can make in identifying natural or man-made non-nuclear phenomena are summarised following the discussion on atmospheric explosions detonated over water.

Summary:

3.1. Atmospheric Nuclear Explosions Over Land

Technology	Detection	Location	Identification
Radionuclides	Fundamental	Complementary	Fundamental
Seismic	Little value	Little value	Little value
Hydroacoustic	-	-	-
Infrasound	Fundamental	Fundamental	Complementary

DETONATED OVER OCEANIC BASINS

The major difference between the detection of explosions over land and over water is the contribution that the hydroacoustic network can make. This is illustrated by a comparison of the Summary below (Table 3.2.1) with that given in 3.1.

A nuclear explosion detonated over an oceanic basin in which the shock wave strikes the water may be detected by any of the four technologies within the IMS. As can be seen in Table 3.2.1 below, the synergy between the infrasound and hydroacoustic system can be used together with the seismic system to provide a very accurate estimate of the location of the explosion. Heavy rain or cooling vaporised water resulting from the explosion may cause the radionuclide particulates to be 'washed-out' in the immediate area of the epicentre, with the result that particulate radionuclides may not propagate to the particulate detectors so that the essential evidence to uniquely identify the source as a nuclear explosion will not be gathered. However, an accurate location would make it

possible to go to the area and collect water samples for subsequent analysis to identify the source as a nuclear explosion.

The deployment of noble gas detectors as part of the IMS could be vital for the detection of radioactive noble gases, which are not 'washed-out' and are distributed by the prevailing winds to the radionuclide detectors. Thus the synergy between the four technologies is maintained and contributes significantly to the overall cost-effectiveness of the IMS.

Summary:

<i>3.2.1. Atmospheric Nuclear Explosions Over Water</i>			
Technology	Detection	Location	Identification
Radionuclides	Fundamental	Complementary	Fundamental
Seismic	Little value	Little value	Little value
Hydroacoustic	Complementary	Complementary	Some value
Infrasound	Fundamental	Fundamental	Complementary
<i>3.2.2 Non-nuclear Atmospheric Sources, e.g. Volcanoes</i>			
Radionuclides	-	-	-
Seismic	Complementary	Complementary	Some value
Hydroacoustic	-	-	-
Infrasound	Fundamental	Fundamental	Fundamental

ON-SITE-INSPECTION: POST-EXPLOSION ACTIVITIES

The IMS may provide data which indicates that a detected and located event may have been a nuclear explosion and such data, together with non-IMS data may be used to request an on-site-inspection. Of the four IMS technologies, only two have a role in OSI: (a) seismic to detect post-shot tectonic seismicity and seismic activity associated with the decay of the explosion-generated cavity and the redistribution of stress within the hypocentre region and (b) the detection of radionuclides in or around the hypocentre to produce the evidence that the event was indeed nuclear. The location of the cavity and the presence of specific radionuclides will only be detected by seismic and radionuclide detectors taken into the search area by an OSI team. A synergy exists between the deployment of seismic and radionuclide technologies to make an OSI an effective verification tool, as well as being a possible deterrent to a potential violator.

CONCLUSION

To prove that a source detected by the IMS is indeed a nuclear explosion and as such is a violation of the provisions of the treaty it is essential to detect and identify specific radionuclides either as particulates or as noble gases. Thus the radionuclide network is a vital element of the IMS. To provide maximum cost-effectiveness and to ensure adherence to the provisions of the CTBT down to a very low level, it is imperative that the radionuclide network works in synergy with the three waveform technologies to provide data to ensure detection (and hence deterrence), location and identification of nuclear explosions conducted in the atmosphere, underwater or underground.

The numbers of stations within the IMS was determined by the Group of Scientific Experts in Geneva working within the consensus guidelines provided by the negotiating delegations in Geneva. To improve the verification regimes of the IMS, IDC and OSI, states parties were encouraged to deploy national facilities. Such systems will operate in a synergistic way with the IMS to improve treaty monitoring in areas where additional technical systems are deployed to demonstrate adherence to the provisions of the treaty.

SUMMARY TABLE OF THE SYNERGY OF THE IMS FOR DETECTION OF NUCLEAR EXPLOSIONS

Technology	Detection	Location	Identification	OSI
Radionuclides ⁽¹⁾	Fundamental	Complementary	Fundamental	Fundamental
Seismic	Fundamental	Fundamental	Complementary	Fundamental
Hydroacoustic	Fundamental	Fundamental	Complementary	No value
Infrasound	Fundamental	Fundamental	Complementary	No value

⁽¹⁾ Particulates and noble gases.

**CREDIBLE SCENARIOS TO EVADE DETECTION OF
NUCLEAR EXPLOSIONS BY THE CTBT's VERIFICATION
SYSTEM**

Dr Yuriy Khokhlov

**Research Institute for Pulse Technique, MINATOM
Russia**

The CTBT verification system known as the International Monitoring System (IMS) is designed to detect non-evasively conducted nuclear explosions down to at least 1 kt detonated in the atmosphere, underwater or underground.

Any attempts to conduct a clandestine nuclear test in the atmosphere or underwater are likely to be detected by one or more elements of the IMS, e.g. the radionuclide or hydroacoustic system. The detection of any signals, whether they are anomalous or not, could lead to a request for an on-site-inspection (OSI). For a number of reasons the best environment in which to attempt a clandestine test is underground. Any seismic signals generated by such an explosion may be buried in the background noise and hence not detected or obscured by one of the many thousands of earthquakes which occur each year.

A number of possible methods of conducting a clandestine test underground and evading detection have been proposed over the years and techniques have been developed to defeat them, e.g. multiple explosions to simulate earthquake-like characteristics. However, the most practical one is that known as decoupling in which an explosion is conducted underground in a cavity so that the seismic waves are effectively muffled and as a result may not be detected. What is required to achieve decoupling is a cavity filled with an energy-absorbing medium so that the pressure from the shock wave on the cavity wall is made equal to, or less than, the overburden pressure. The most effective energy-absorbing medium is air or a very porous material. Theoretical simulation studies have shown that the maximum decoupling of an air-filled cavity occurs when the radius of the cavity is equal to or greater than $30m/kt^{1/3}$ where m is in metres and kt is in kilotonnes. At low frequencies, say ~1 Hz a decoupled explosion conducted in a cavity excavated in salt will reduce the seismic waves generated by a factor of the order of 100. This means a 100 kt nuclear explosion would generate seismic waves equivalent to a 1 kt explosion. If the cavity size is reduced then the decoupling factor decreases and the explosion becomes partially decoupled.

The experimental evidence for decoupling of nuclear explosions is limited, it is however, convincing. Both the Soviet Union and the United States have proved that nuclear explosions detonated in salt cavities can be decoupled by factors of between 40 and 70 although there is evidence that at higher frequencies (around 15-20 Hz) the decoupling factor is significantly less but to detect such frequencies would require a seismic station quite close to the epicentre, say within 500 kms.

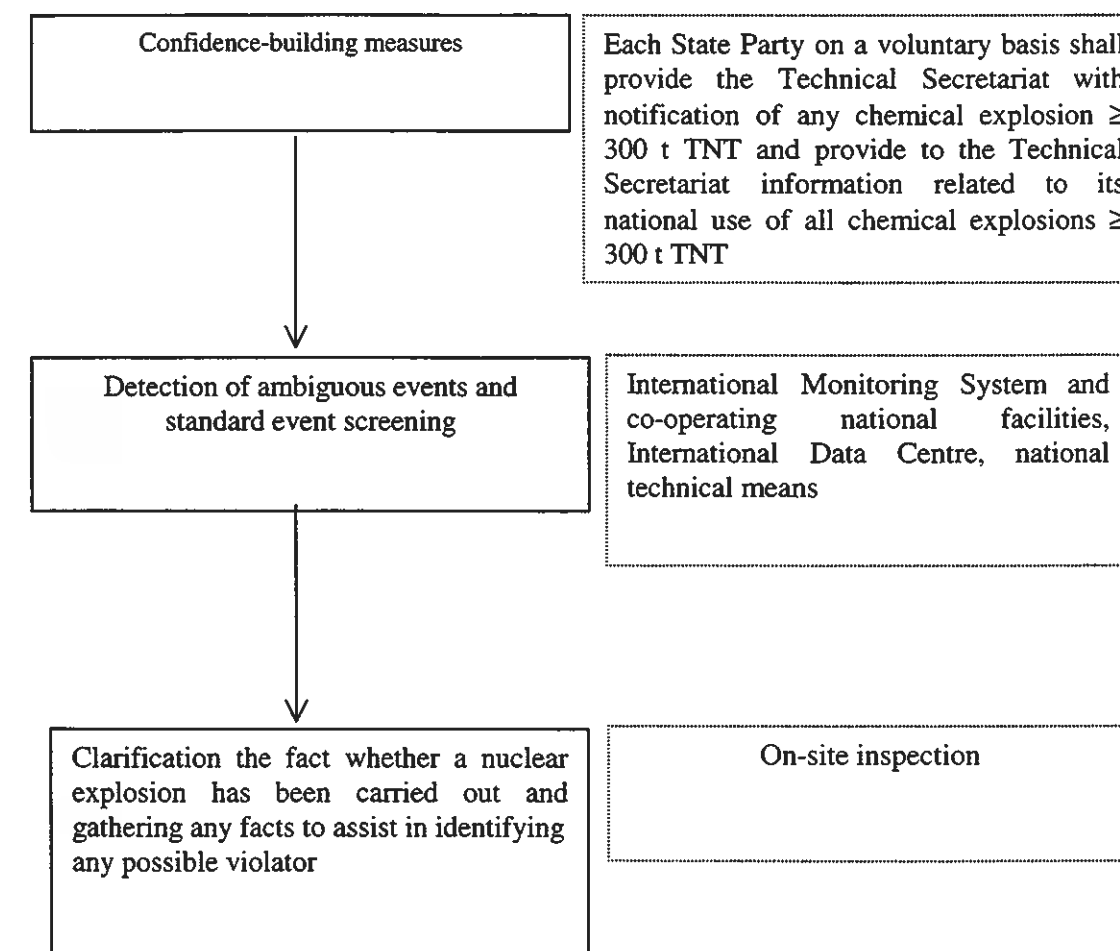
To conduct a decoupled explosion would entail considerable financial expense to construct a suitable cavity underground. To prevent any surface evidence of an underground explosion the nuclear device would need to be placed in a cavity at considerable depth, of the order of 1 km or more for even a 1 kt explosion. (To prevent any surface evidence the relationship between depth and explosion yield is of the order of: $Depth = 1000m W^{1/3}$ where W is the yield in kt). Even at these depths the natural fissures surrounding the cavity may allow radioactive noble permeate to leak to the surface and be detected by the IMS radionuclide system.

A potential evader must decide what yield he wishes to conduct evasively. Also what cavity volume is required for that yield and at what depth must the cavity be to achieve full decoupling. He must be sure that the cavity created will survive at that depth for long enough to emplace the device and conduct the test. In some rock-types the cavity may collapse or may fill with water. These are some of the problems the evader must address.

Furthermore could such activities be conducted without being detected by another nation's NTM? Clearly there are many uncertainties for a potential evader to consider. Such technical evidence, detected by NTM could be used to request the CTBTO Executive Council for an OSI.

Of course the evader could consider using an existing cavity created by a nuclear explosion conducted before the moratorium or the CTBT came into force. This is probably a riskier enterprise than constructing a new cavity. Most nuclear explosion generated cavities occur at shallow depths with extensive fracturing radiating out from the cavity many of which will be close to the surface increasing the risk of releasing noble-gases to the atmosphere.

Within the provisions of the Treaty there is a procedure for resolving ambiguous signals detected by the IMS and these are given in the Table below.





Independent Commission on the Verifiability of the CTBT

Commissioners

H.E. Ambassador Nobuyasu **Abe**

Peter **Basham**

Dr Elisabeth **Blanc**

Dr Ola **Dahlman**

(Chairman) Dr Trevor **Findlay**

Dr Lindsay H. **Hall**

Professor Herbert E. **Huppert**

Professor Bhupendra **Jasani**

Dr Yuriy **Khokhlov**

Peter **Marshall**

Dr Mordechai **Melamud**

Dr Joachim **Schulze**

Dr Gregory **van der Vink**

Professor Terry C. **Wallace**

(Secretary) Dr Oliver **Meier**

The Independent Commission on the Verifiability of the Comprehensive Nuclear Test Ban Treaty (CTBT) was established in August 2000. The CTBT, opened for signature in 1996, bans all nuclear test explosions in all environments. The Commission's mandate was to assess the CTBT's verifiability, both currently, in terms of the existing capabilities available to the international community, and in future, once the complete array of capabilities envisaged in the Treaty is fully functioning. In addition to considering the Treaty's International Monitoring System, the Commission was tasked with assessing the contribution to verifiability of on-site inspections, confidence-building measures, so-called national technical means, and the scientific communities. Finally, it was asked to evaluate the possibilities for evading the verification system and potential responses to such scenarios.

The Commission comprised 14 internationally eminent scientists and experts, representing a wide range of expertise and backgrounds, acting in their personal capacities. It convened in London on 26–27 October 2000 to complete the Final Report and to hear presentations by the Commissioners. Their papers are published here as an Annex to the Final Report. Further information is available on the Commission website at www.ctbtcommission.org.

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