CONFERENCE ON DISARMAMENT

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Ad Hoc Committee on a
Nuclear Test Ban

Working Group 1 - Verification

International Monitoring System
Expert Group Report
based on Technical Discussions held
from 6 February to 3 March 1995

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INTRODUCTION

In accordance with the mandate given in CD/NTB/WP.203, groups of technical experts held discussions on four technologies (seismic, hydroacoustic, radionuclide, and infrasound) during the period 6 February to 3 March 1995.

The mandate required, inter alia, the International Monitoring System (IMS) Expert Group to propose to the Verification Working Group of the Ad Hoc Committee on a Nuclear Test Ban the type(s) of station(s) to be used, the number of stations and other elements of the IMS network required to achieve global coverage, the geographic distribution of stations and other elements of the IMS network.

The experts were asked to take into account the results of expert work conducted in 1994, in particular the work reported in CD/NTB/WP.171, 172, 176, 177 and 181 as well as relevant contributions by CD delegations of the Conference on Disarmament.

The mandate required that meetings of the Expert Group be divided into sub-groups on the four technologies. During the period 6 to 17 February 1995 experts on radionuclide and infrasound met, initially as sub-groups and then as a single group to discuss the synergy of the two technologies. During the period of 20 February to 3 March 1995, experts on seismic and hydroacoustic monitoring met as sub-groups and then together to discuss the synergy of the two technologies.

In all, 29 States sent experts who attended one or more of the sub-group meetings. A total of 95 delegates attended the technical meetings, of whom over 80 were experts. The largest group of experts were concerned with seismic monitoring, the next largest with radionuclide monitoring. Infrasound and hydroacoustic monitoring attracted a smaller number of experts due to a lower level of activity in these technologies in most States. However, hardly any experts remained in Geneva for the full period of the expert meetings, which meant it was not possible to have a definitive discussion on the total synergy of the IMS technologies.

Each of the sub-groups was led by a Chairman and each sub-group organized a small drafting team to complete the report summarizing their discussions.

To provide some guidance to the expert sub-groups on the general views and concepts of how the CD viewed the IMS, the groups were provided with a summary of delegations' views expressed during the intersessional discussions held last year on the various elements of the IMS. As these summaries for each of the technologies seemed to indicate a monitoring capability of about 1 kt detonated underground, underwater and in the atmosphere, the groups considered various network options in terms of their capability to monitor a 1 kt test conducted without any attempt at evasion of detection or identification. This was done to provide a common baseline to evaluate a variety of technology network configurations and indicate possible options. However, the experts realise that no decision has been made by the CD on the precise specifications of a monitoring capability for any of the technologies under consideration.

It was not possible in the Expert Group to achieve consensus on a single IMS design as required under the mandate. However, the options presented in each sub-group's report are fewer and closer in agreement than was achieved in the expert meetings during 1994. Moreover, in the areas that are principally technical, substantial agreement was achieved among the experts on many aspects such as operating principles, equipment required, sensor specifications and characteristics and data handling. While the experts failed to achieve consensus on a single IMS network, there was consensus on the technical and scientific contents of the reports prepared by the drafting groups and approved by a full meeting of the sub-group of experts.

Each report contains, inter alia, an executive summary, a discussion on synergy as perceived by the experts, station types, network designs, data flow, costs and the experts' suggestions for possible future work. No significance should be given to the order in which the reports are presented.

PART I: INFRASOUND MONITORING

Executive Summary

Infrasound is a proven technique for detecting and locating atmospheric nuclear explosions. A properly designed system provides detection within a few hours, location accuracy of 100 km or better, and some indication of yield. These capabilities complement the unique event identification provided by radionuclide sampling, so that when operated in conjunction these two techniques provide a complete atmospheric monitoring capability. We provide performance specifications for the necessary equipment, which is commercially available, and a standard station configuration. We suggest a network designed to provide uniform global coverage with a high probability of detection for a 1 kt nuclear explosion, taking full advantage of synergy with other systems and with an option to allow balancing of costs versus coverage for remote ocean areas. Estimated costs are

Infrasound System Costs (Millions of US$):

Stations	Capital	Operating
60	10.8	3.6
70	12.6	4.2

Further technical work is required to fill in the specific technical details of various aspects of the system. We estimate the time for deployment to be three years from the commitment of funding to initial operation of the system, with another year of refinement in procedures to achieve optimal system performance.

Introduction

Many countries have expressed their view that infrasound monitoring is an essential component of the international monitoring system (IMS) for a Comprehensive Test Ban. The expert report presented to the Conference on Disarmament's Ad Hoc Committee on a Nuclear Test Ban in August 1994 presented several infrasound monitoring options, with varying capabilities, and gave initial estimates for system specifications, costs, and schedule. This report focuses on the monitoring option which appeared to be of the most interest and refines the network design and the various estimates.

The experts would like to restate the contributions of an infrasound network to the overall international monitoring system. Infrasound is a proven technique for detecting explosions in the atmosphere at altitudes ranging from sea level to around 100 km. The signal is detected promptly, providing detection within at most a few hours of the event. A properly designed network can locate the explosion to within about 100 km of a point on the earth's surface. The altitude resolution of the technique is not known at this time. Infrasound measurements can also give some indication of the explosion yield. The technique is capable of uniquely identifying infrasound signals generated by explosions from those due to other events, such as lightning, volcanic eruptions, or meteors, but the infrasound signature cannot by itself determine whether an explosion is nuclear or not. This deficiency can be made up by working in conjunction with a radionuclide detection system, which provides strong identification but has weak localization characteristics. It is important to keep in mind that in addition to timeliness, location capability, and an indication of yield, the very presence of the infrasound signal provides an independent confirmation that an event of interest has occurred, greatly increasing confidence in a detection by any other technique.

System Requirements

Based on the responses from a number of countries to the various IMS options presented at the end of the August 1994 CD session, it is clear that the desired infrasound network should be able to both detect and locate nuclear explosions of relatively small yield. The experts have attempted to design a cost-effective system which meets this goal as well as possible with nearly uniform coverage of the entire earth. Truly uniform coverage is not possible over all ocean areas because of geographical factors, but it is possible to approach this goal over land areas. Another strong consideration is synergy between various elements of the IMS, both in capabilities and operations. The coverage of the infrasound network is such that it can be used as a trigger for a radionuclide system should this be deemed desirable. Operational synergy considerations lead us to co-locate sites whenever possible. All of these considerations were taken into account in the network design presented in this paper.

Equipment

In the previous report the experts suggested a three-element array of wideband microbarographs at each site. Upon further consideration the experts recommend a four element array with three of the elements arranged in an equilateral triangle and the fourth element in the centre. The optimal spacing between the elements depends on the detection range and on the details of the signal processing algorithms chosen, and is a detail which will need to be resolved after further analysis. In any case, it should be between 1 and 3 kilometres. The geometry is shown in figure 1.

The addition of the fourth element ensures that the system can continue to function without a drastic reduction in capability using just three elements if any one of the elements fails for any reason. With the three element design the loss of a single detector would result in the complete loss of direction-finding capability for the station, a catastrophic reduction in capability. This would necessitate an immediate repair, which could be expensive for locations which operate unattended, and the station would not be functional until repairs were complete. The four element array can continue to function with one element missing, allowing repairs to be conducted when convenient and providing continuous coverage in the interim. In addition, going to a four element array improves the sensitivity of the system, flattens the response for explosions at a larger range of distances from the site or for a larger range of yields, reduces the sensitivity to local wind noise, and improves the accuracy of direction determination.

The specifications for the sensors are similar to those proposed in the previous report. The experts propose using microbarographs with a flat frequency response from 0.01 to 10 Hz, with a resolution of 0.01 Pa at 1 Hz and a dynamic range of at least 80 dB. An example of such an instrument is shown in figure 2. The instruments should initially be fitted with standard analog noise reduction equipment, either perforated pipes or porous hoses, to reduce wind noise. The site selected would require a level area of approximately 0.25 km^2 around each sensor for deployment of the noise reduction equipment. Advances in digital signal processing techniques may make it possible in the future to achieve equivalent performance without the analog noise reduction equipment. This is an area of active research at the present time. The microbarographs should incorporate a built-in calibration mode to ensure proper operation of the equipment.

Analog data from the sensor would be digitized with a 20-bit analog-to-digital converter. The digitized data should be sent to a central recording and processing unit using low-powered radio links or buried cables, either fibre optics or conventional copper. The central unit

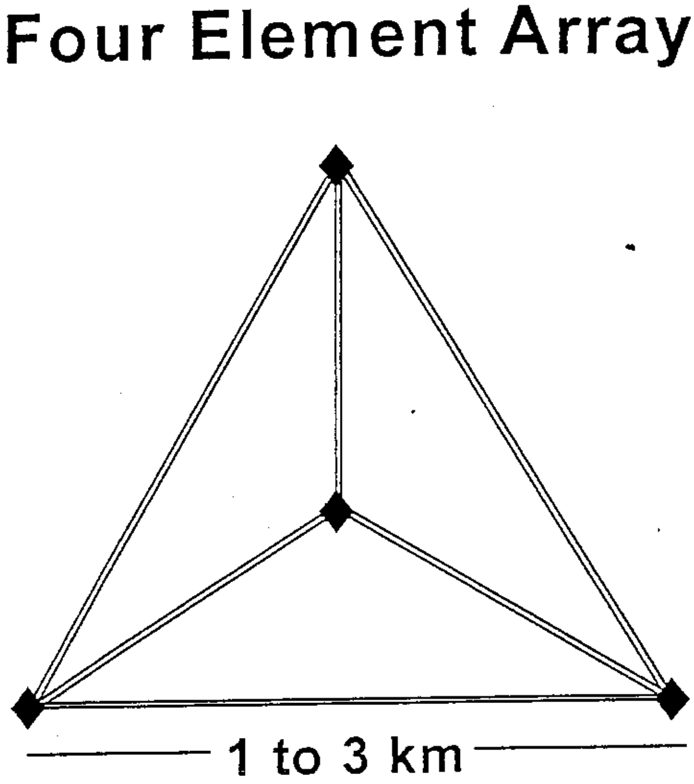


FIGURE 1 : 4 ELEMENT INFRASOUND ARRAY CONFIGURATION

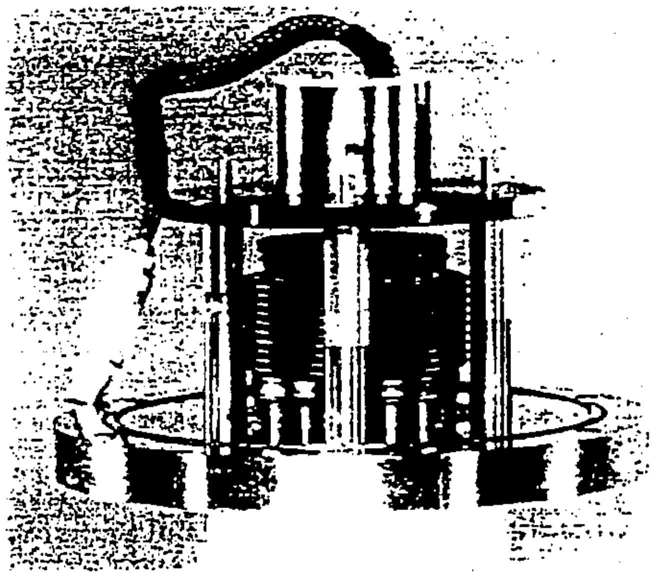


FIGURE 2 : WIDEBAND MICROBAROGRAPH

should analyse the data using standard beamforming and trigger algorithms to provide reliable detection and direction information. Data would then be written continuously to the temporary on-site storage, and triggered event data would be sent immediately to the International Data Centre (IDC).

Data handling requirements are also unchanged from the previous report. We recommend sending a reduced data stream continuously at a slow rate, about 1 bit per second. This both verifies that the system is functioning and makes it more difficult to tamper with the data flow, providing a measure of data surety. Other data authentification measures may be taken as required, including use of the proposed authentification equipment for seismic systems at those sites which are co-located. Full resolution infrasound data would be sent to the IDC when an event occurs which meets the infrasound trigger criteria. The data rate at full resolution is about 250 bytes/sec. Even when sending full resolution data, this is a low rate compared to seismic systems, so for sites co-located with seismic stations we can use the existing data link with no increase in bandwidth. For independent sites our data rate is low enough that we can use an ordinary telephone channel, with a connection either by cable or by satellite.

A full record of all of the data should be kept on site for a limited period, as recommended in the previous report, to be available upon request in case there is a detection of a possible event by other techniques. This data would also be of considerable interest to the scientific community, and it may be possible to arrange for it to be archived for scientific investigations at some appropriate facility.

The equipment normally functions without an operator present. Periodic maintenance is required, plus repairs as needed, but it is common for this type of equipment to function for a year or more completely unattended.

Network Design

The experts began their deliberations by considering the networks presented in the expert report from August 1994 and in proposals from states in the Conference on Disarmament. Complete network designs for an infrasound system have been presented to the Ad Hoc Committee by four countries: China, France, the Russian Federation, and the United States. These networks are described in working papers CD/NTB/WP.212, CD/NTB/WP.215, CD/NTB/WP.187, and CD/NTB/WP.184, respectively. The various networks presented are rather different, both in the number of stations and in site locations. All of these networks have certain strengths, but none of them fully meet the requirements set forth above. By combining the strengths of each proposal and after considerable discussion, the experts have come to a rough consensus on a preliminary network design which we believe meets the requirements stated above. It is important to keep in mind that this is only a preliminary design, and we have not benefited from an in-depth study taking account of global wind patterns in arriving at this design. The final configuration may therefore differ from this proposal in some details, but we expect that the broad outlines of it would be similar. We must retain the flexibility to refine the network as we gain experience with its operation.

Although the detection pattern from a given site varies with wind conditions, this effect roughly averages out over the course of a year, so uniform geographical distribution of stations gives uniform detection probability in an average sense. Experts from different countries have used somewhat different equipment in the past and therefore have a range of views on the precise detection range of the technique, but there is a broad consensus that a detection range of about 2000 to 2500 km is appropriate for monitoring 1 kt explosions under normal conditions. The principal network design issue is the degree of uniformity in detection and location capability which one wishes to achieve. There are certain remote parts of the earth which are difficult to monitor with this method, and putting in stations designed specifically to monitor these regions will increase the cost of the network. For this reason we present a basic network of 60 stations which provides a high probability of detecting and locating a 1 kt atmospheric nuclear explosion over all land masses and moderate to high probability over most ocean areas, and then show how this could be improved by the addition of another ten stations designed to fill gaps in the basic system, primarily in the ocean areas. Location accuracy of the networks is expected to be about 100 km in general, with a slightly higher number for very long range detections. It is a decision for the Working Group to determine whether the benefit of the additional coverage justifies the cost required to obtain it.

A list of the proposed site locations is given in table 1. Please keep in mind that this is a notional list and does not represent a commitment by any State at this time. Sites have been co-located with GSETT-3 seismic stations wherever possible, and half of the basic system sites are in fact co-located. These sites are indicated with an α or β in the table, depending on whether they are sited with α or β seismic stations. Figure 3 is a map showing the location of the stations. The stations in the basic system are indicated by asterisks, while the additional stations discussed above are shown by diamonds. In order to facilitate comparisons of the coverage provided by the various network options we considered, we have provided coverage maps in the appendix to this document. There are six maps showing the four national network proposals and our basic and enhanced networks. Each map shows the location of the monitoring stations and contour lines showing the regions of the world which are within 2,500 km of two stations, where detection and location capability is highest, and those regions which are more than 2,500 km from two stations. The areas more than 2,500 km from two stations are cross-hatched on the maps.

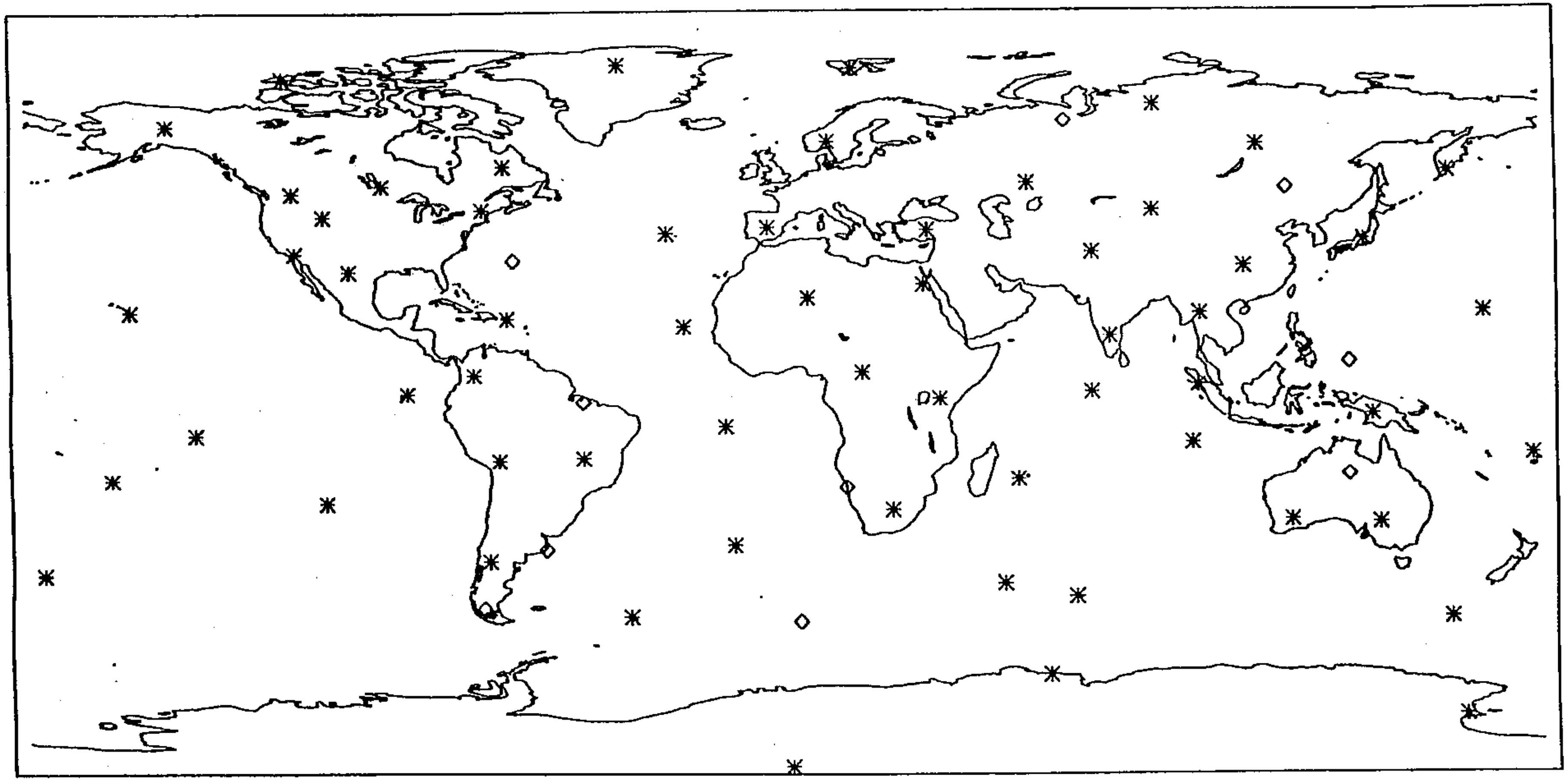
Comparison of the experts' recommended network options with the various national network proposals shows that we have achieved a system design with far more uniform coverage than before while keeping the number of stations as low as possible. The principal difference between the experts' proposals and the Chinese, French and United States networks is the presence of more sites in the southern oceans. Most of the sites in those proposals are located on continental land masses. This type of configuration leaves large areas of the oceans poorly covered, and the experts felt that this was a serious deficiency of the earlier network designs.

In the experts' design we have co-located with seismic sites wherever possible, but have included independent island sites where necessary. As will be explained below, there is considerable operational synergy with seismic sites, so co-location has significant financial advantages. In some cases where infrasound and radionuclide stations can be on the same island they could share some logistical support, but the synergy in this case is much less than when co-locating with seismic stations.

Synergy

We mentioned in the introduction that infrasound monitoring provides prompt detection and fairly accurate location information, but has problems with event identification. Radionuclide monitoring, on the other hand, has excellent event identification but poor location ability. Thus the capabilities of the two techniques complement each other almost ideally, and taken together they provide a complete monitoring capability for atmospheric nuclear explosions.

FIGURE 3: NOTIONAL INFRASOUND STATION LOCATIONS



Because the reporting time for infrasound is fairly rapid, it is possible in principle to use it as a trigger for radionuclide detection. There are several factors which must be taken into account in evaluating the practicality of this idea, including the probability of the infrasound system failing to detect an event, the frequency of false positive events reported, and the scale of the change in the operation of the radionuclide system when it is triggered. We discuss these points in order.

The experts believe the detection probability of the infrasound system is good, about 80-90% for a 1 kt explosion in most areas. Even though this is quite good it is not perfect. If the radionuclide system is strongly coupled to an infrasound trigger, as in the proposals to launch aircraft into areas which are otherwise not covered, evading detection by the infrasound system would also be very likely to evade detection by the radionuclide system, at least in the short term. This must be taken into account when evaluating the effectiveness of the radionuclide system.

Just as there will be some chance that the infrasound system will fail to detect a real event there will also inevitably be a certain number of false triggers. By this we mean signals which pass the infrasound trigger criteria and cannot be identified as known types of events such as volcanoes, etc. Although our experience is that this number is rather low, typically one to ten events per year at the sites the experts are familiar with, the proposed system would be more comprehensive than anything currently in existence and would operate in areas of the world in which we have no experience. The experts' estimates of the false trigger rate for the overall system cover a wide range, from one or two events per year to several per month. Resolution of this question will have to wait until the system has been operated for a while, at which time we can have a more precise idea of the overall false trigger rate.

The last point is the effect of triggering on the radionuclide system. For a system which uses an extensive network of fixed ground sites, the only change would be to alter the sample collection frequency at selected sites of the system. In this case the impact of triggering may be fairly small, and a false trigger rate of one or two events a month may be tolerable. If going to triggered radionuclide operations involves more extensive operational changes, particularly if this involves launching aircraft, the potential impact of high false trigger rates is much larger.

Costs

There was broad agreement on the cost of the system. We break the costs down into capital costs, for equipment and installation, and operating costs including personnel, maintenance, and communications. Equipment costs for a four-element station are approximately 100,000 $US for equipment presently available, including the sensors and the central data recording and processing unit but exclusive of communications equipment. It may be possible to reduce this cost somewhat by buying a large number of identical sensors. For those independent sites which cannot make use of existing data links, data transmission equipment must also be purchased. This would add 1,000 to 10,000 $US to the cost, depending on whether one uses existing telephone lines or a satellite connection. It is also possible to further reduce the costs for sites which are co-located with seismic stations if some of the data recording and processing equipment is shared, although this would require careful coordination of the systems involved.

The estimates for installation costs varied among the experts, primarily because of differences in the estimated cost of labour. Labour costs comparable to standard rates for skilled technical staff in Europe lead to an estimated installation cost of 70,000 $US per site for co-located stations and 120,000 $US for independent sites, including transportation of staff and equipment. We agreed on an average capital cost estimate of 180,000 $US per site.

Operating costs will vary from site to site depending on environmental conditions, and therefore the frequency with which maintenance must be performed, the difficulty in reaching the site, and whether communications use existing high-capacity seismic data lines or use a dedicated low-speed line. The experts are in broad agreement that the average operating cost per station for a mix of co-located and independent sites would be about 60,000 $US per year. The cost estimates are summarized in the table:

Infrasound System Costs (Millions of US$):

Stations	Capital	Operating
1	0.18	0.06
60	10.8	3.6
70	12.6	4.2

Directions for Further Work

The experts believe that with this report the major conceptual issues for this system have been adequately addressed. In order to make further progress it will be necessary to perform detailed technical work in some areas. In particular, these include:

* more detailed specification of the instrument parameters, including temperature variations, length of the noise reducing hoses, element spacing, and similar technical details.
* thorough analysis of the processing algorithms in use at present and a decision on a uniform data processing method for use in this application.
* development of an agreed model for predicting the system performance at any given time, incorporating global wind patterns.
* precise sites for the stations, based on co-location with seismic stations where possible, direction from the system model, and local conditions.
* characterization of local noise environments and other environmental factors for sites.

Work on several of these issues is already in progress by several countries. For example, Australia, France, the Netherlands, and the Russian Federation all currently operate equipment meeting the basic performance specifications given earlier in this report, and their combined experience could lead to a quick resolution of the first issue. France is actively engaged in algorithm development, and the United States is developing a global system model. It would be extremely useful to begin to deploy a small number of stations in the near future, so that we could begin to gain experience with deploying and operating this type of system. This could be done in parallel with the work outlined above, and in fact would help these efforts to an earlier conclusion.

Once the network is operational, either wholly or in part, the experts feel it would be extremely useful to conduct a small number of calibration explosions in order to verify that the network performs as expected. These would be kiloton-class chemical explosions conducted in a few selected locations so as to exercise as much of the network as possible at a reasonable cost. Careful site selection would make it possible for these same explosions to be used for calibrating seismic and hydroacoustic networks as well.

The experts feel strongly that work at this more technical level would best be done in the context of one or a few workshops where detailed technical presentations would be made by interested parties, followed by discussion as necessary. The initial presentations at such workshops would be organized along the lines of ordinary scientific meetings, without the formality which sometimes accompanies discussions in a diplomatic forum. The difference between the workshops and an ordinary scientific meeting would be that resolution of questions and a decision on the issues would be required. In our view, this means that such workshops would have to be conducted under the auspices of the United Nations or some other international body which would ultimately be responsible for the performance of the system.

As we have indicated above, some countries have already begun work on various issues with their own funding, and for their own purposes. While much of this work may be applicable to the IMS, there will undoubtedly be some work required which is specific to the IMS, which may in turn require specific funding. Moving from the conceptual level to a fully detailed, buildable system will require that the work be under the auspices of the United Nations or some other international body with the authority to make decisions and expend funds.

Time for Deployment

The time it will take to deploy an infrasound system will depend to some extent on the exact details of the system design, but we can give an estimate. As discussed above, there are a number of issues which need to be resolved to come up with a final system design. In order to move from a system concept, as described in this paper, to a fully operational system the following tasks must be accomplished:

* Detailed system design
* Acquisition of equipment
* Site preparation
* Installation of equipment and establishment of data links where necessary
* Testing, calibration, and evaluation of system

All of these tasks require financial resources to be identified and committed before work can begin.

Detailed system design could begin as soon as there is a decision on the basic system concept and financial and administrative arrangements have been made, and should be completed in one year.

Once the system design is complete, acquisition of equipment can begin. Allowing for the time required by the contracting process, delivery of initial hardware can be expected about six months after initiation of the process. Full delivery of all equipment will take perhaps another six months to a year.

Site preparation can begin at the same time as equipment acquisition. The time to complete this will vary considerably with site location. For sites which are co-located with seismic stations this preparation is minimal and may be completed in a few days. Independent sites, particularly in remote locations, may require extensive work which could take several months to complete.

Installation can begin as soon as the equipment starts being delivered, and can proceed to some extent in parallel with acquisition. Establishment of data links will be simple for co-located sites and may require some time for remote independent sites. We expect a total of about two years from the beginning of acquisition to completion of installation at all sites.

Once the equipment is in place, the system must be tested and evaluated. Initial tests can be performed quickly, in a few weeks. At this point the system will be usable but not optimized. It will probably require a year of operational experience to fully evaluate the network and configure it to operate to its highest potential. As mentioned above, a few calibration explosions in this period would be most helpful. We expect changes in the details of the operating procedures for the first year as we learn how to operate the system most effectively, after which time it should settle into a standard mode of operation.

INFRASOUND DEPLOYMENT TIMELINE

Funding Committed	Design Complete	Installation Complete	Standard Operation
1 year	2 years	1 year	
Start Design	Start Acquisition	Start Operations & Evaluation	

TABLE 1 : STATION LOCATIONS IN NOTIONAL INFRASOUND NETWORK

Basic Network:

Latitude	Longitude	Co-location	Name
22.79	5.53		Tamanrasset, Algeria
-67.60	62.87		Antarctica
-89.90	1.00		South Pole, Antarctica
-77.50	161.84	α	Vanda, Antarctica
-40.73	-70.55	α	Paso Flores, Argentina
-8.0	-14.3		Ascension Island
-31.18	120.62	α	Woolibar, Australia
-31.87	141.58	α	Stephens Creek, Australia
-54.3	158.6		Macquarie Island, Australia
-12.0	97.0		Cocos Island, Australia
38.30	-28.00		Azores
-16.28	-68.12	α	La Paz, Bolivia
-15.64	-48.00	α	Brasilia, Brazil
76.23	-119.35	α	Mould Bay, Canada
54.82	-66.78	α	Schefferville, Canada
16.0	-24.0		Cape Verde Islands
5.16	18.42	α	Bangui, Central African Rep.
4.58	-74.03	α	XSA, Columbia
-21.21	-159.77	β	Raratonga, Cook Islands
30.27	109.50		China
43.82	87.68		Urumqi, China
79.17	-39.37		Greenland, Denmark
-27.0	-109.2		Easter Island
26.00	33.00	α	LUXESS, Egypt
-15.0	178.0		Fiji
-21.0	55.4		Reunion
-46.0	52.0		Crozet Island
0.0	-90.0		Galapagos Islands
13.59	77.43	α	Gauribidanur, India
36.54	138.20	α	Matsushiro, Japan
-49.15	69.10		Kerguelen Island
-10.0	-140.0		Marquesas Islands
0.42	73.1		Maldive Islands
-1.27	36.80	α	Nairobi, Kenya
-44.0	-176.0		Chatham Islands, New Zealand
33.65	73.25	α	Pari, Pakistan
18.0	-66.0		Puerto Rico
60.50	10.50	α	NORSAR, Norway
78.17	16.37	α	Spitzbergen, Norway
-5.20	140.00	α	Papua New Guinea
51.13	58.35		Orsk, Russian Federation
59.67	112.70	α	Peleduy, Russian Federation
53.00	158.0		Petropavlovsk, Russian Fed.
53.94	84.81	α	Zalesovo, Russian Federation
-28.60	25.42	α	Boshof, South Africa
39.67	-3.95	α	Sonseca, Spain
-54.0	-37.0		South Georgia Island
2.10	98.45		Sumatra
19.00	99.00		Thailand
39.0	34.0	α	XTUR, Turkey
-37.0	-12.3		Tristan de Cunha
48.26	-117.12	β	Newport, United States
50.23	-95.87		U.S.
19.59	-155.28		Hawaii, U.S.
33.60	-116.45	α	Pinon Flats, U.S.
64.77	-146.88	α	North Pole, U.S.

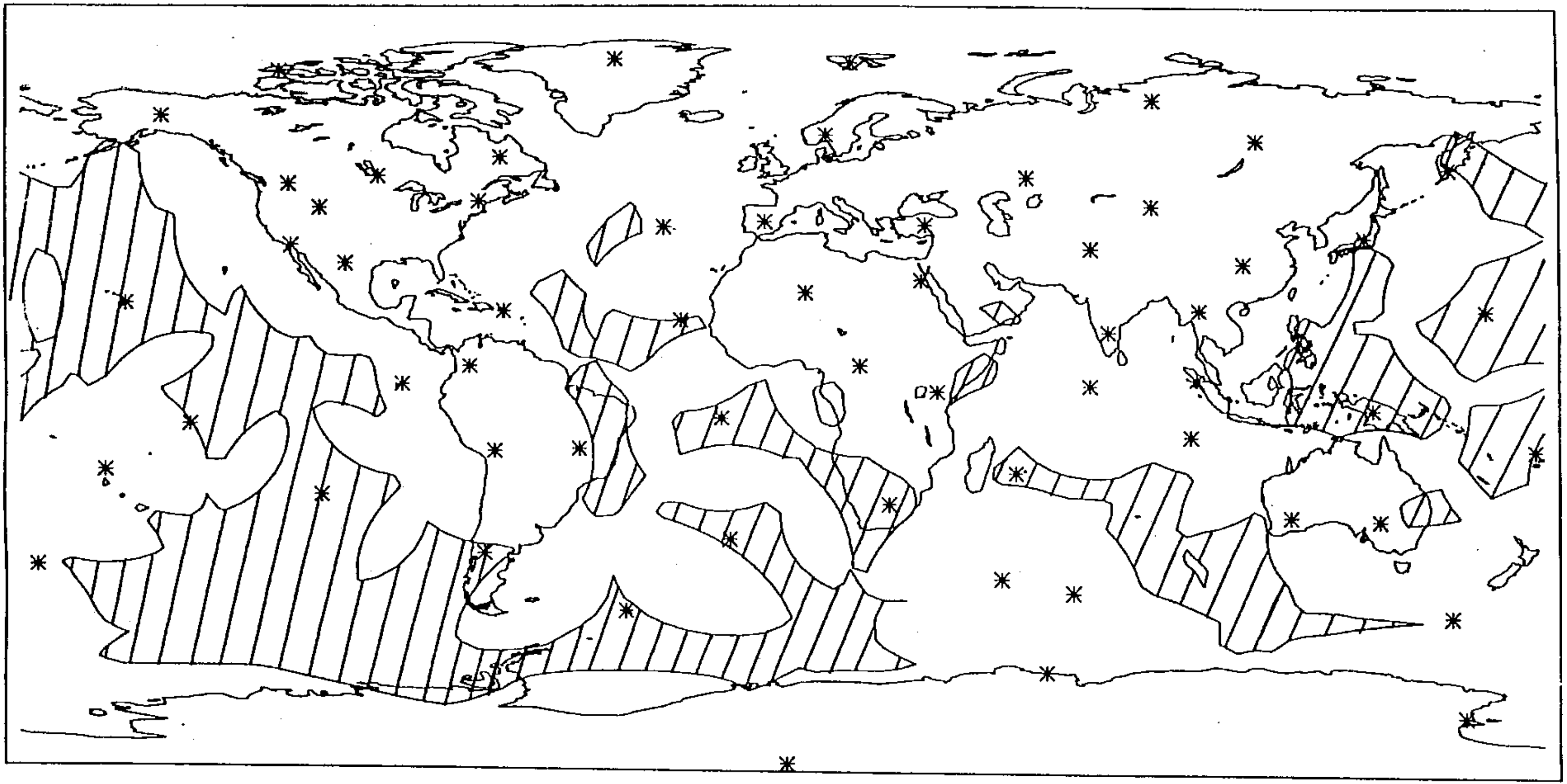
Additional Stations for Remote Area Coverage:

Latitude	Longitude	Co-location	Name
44.24	-71.93	α	Lisbon, U.S.
42.57	-109.72	α	Pinedale, U.S.
29.32	-103.67	α	Lajitas, U.S.
19.16	166.38		Wake Island
-38.0	-57.0		Mar del Plata, Argentina
-19.93	134.33	α	Warramunga, Australia
32.0	-64.5		Bermuda
-55.0	3.3		Bouvet Island
-2.0	-48.0		Belem, Brazil
7.5	134.5		Belau, Caroline Islands
-52.00	-72.00		Puerto Natales, Chile
49.3	119.7	α	Hai Lar, China
-23.0	14.5		Walvis Bay, Namibia
65.5	67.0		Salekhard, Russian Federation

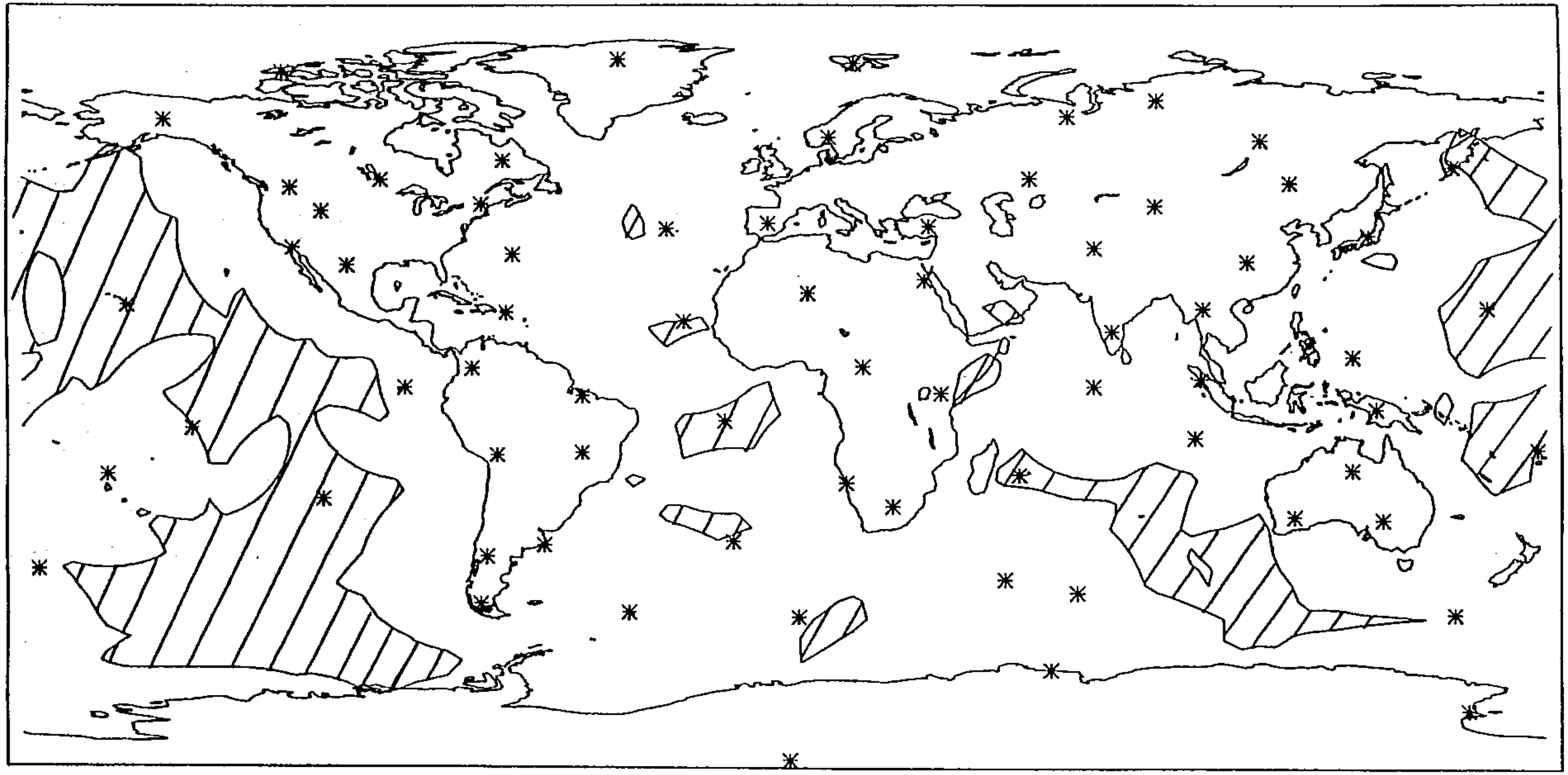
Appendix

Coverage maps for the experts' 60- and 70-station configurations and the proposals put forward by China, France, the Russian Federation and the United States

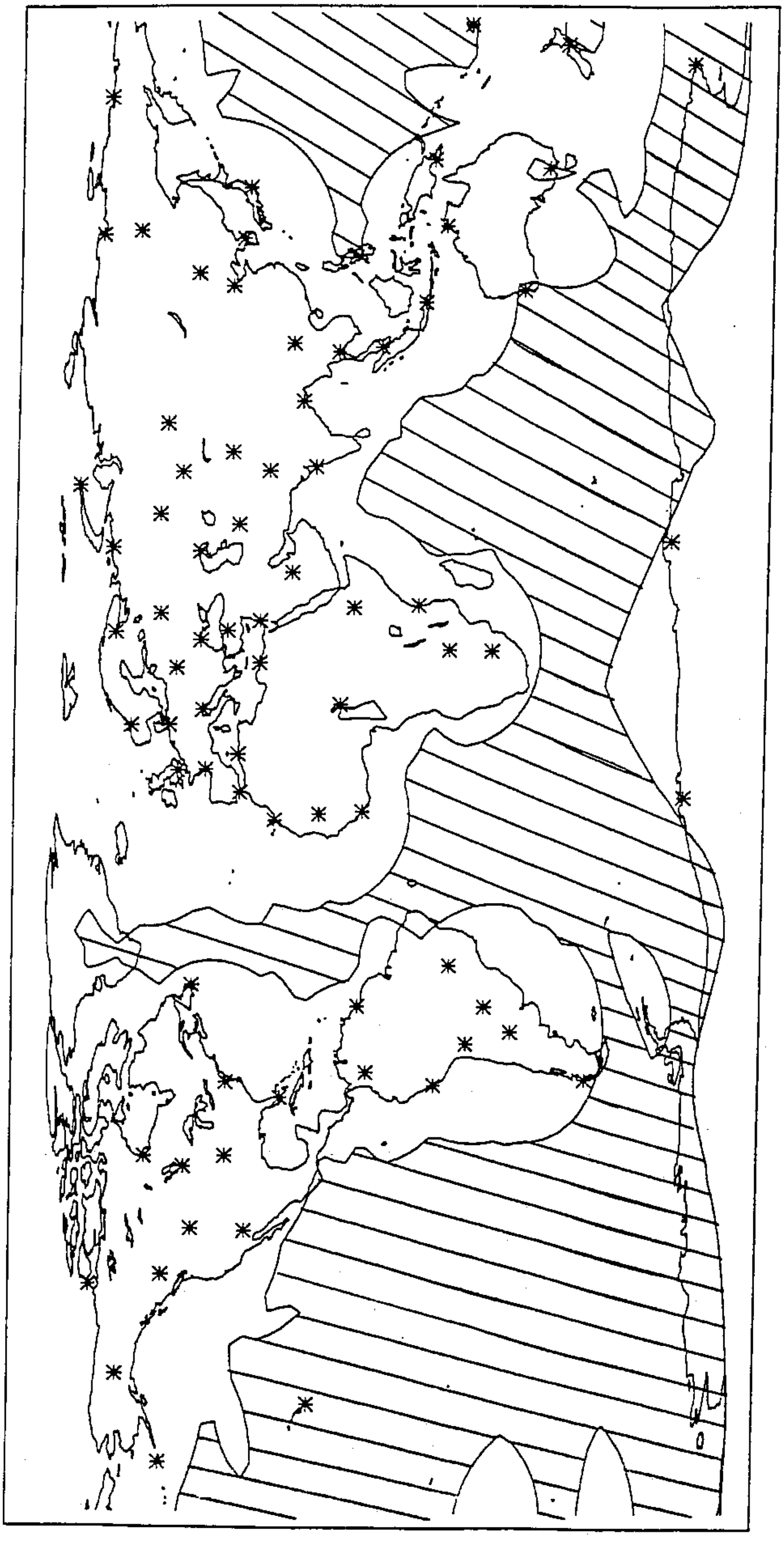
COVERAGE MAP: EXPERTS' 60 STATION NETWORK



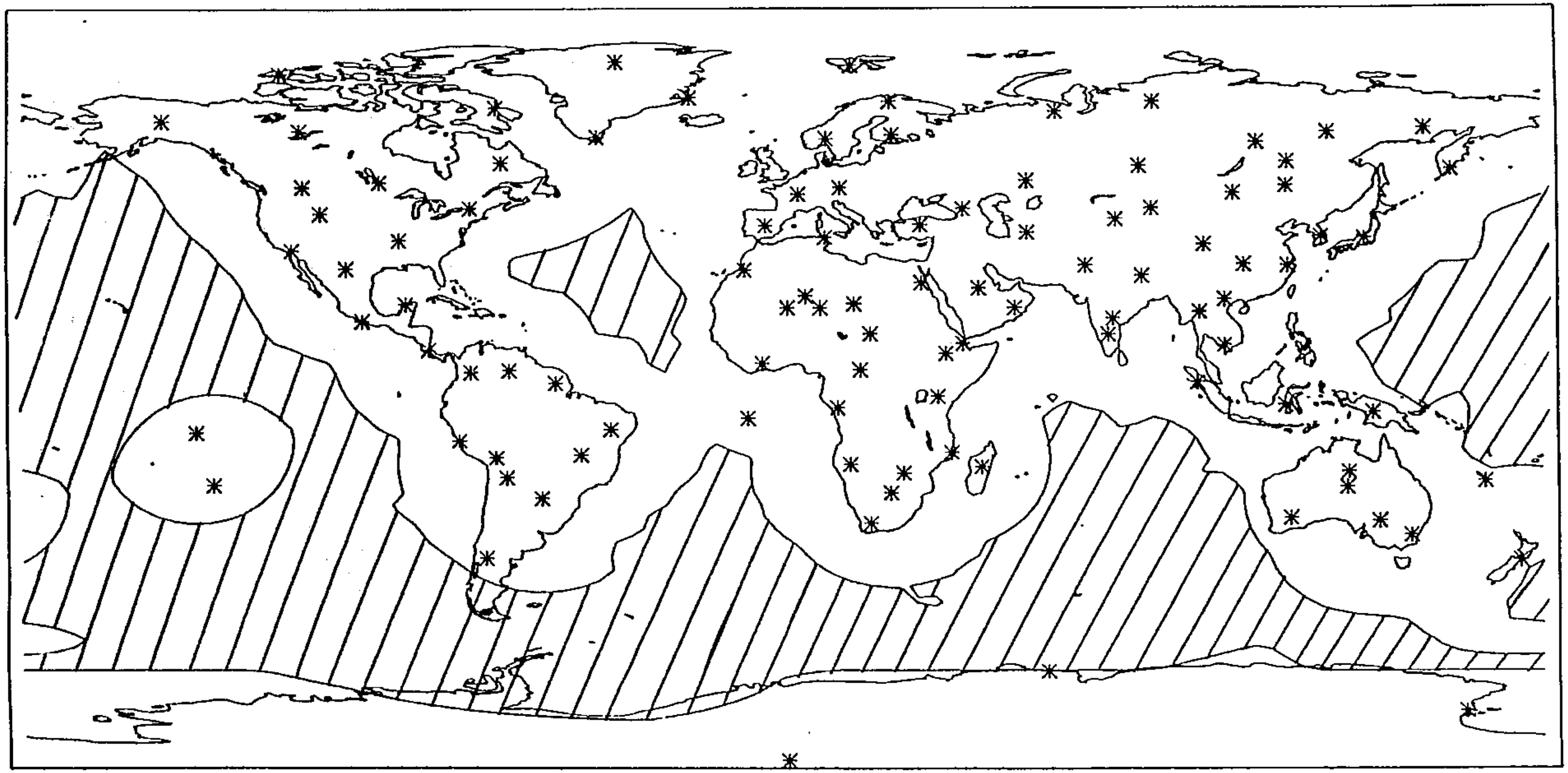
COVERAGE MAP: EXPERTS' 70 STATION NETWORK



COVERAGE MAP: CHINESE PROPOSAL

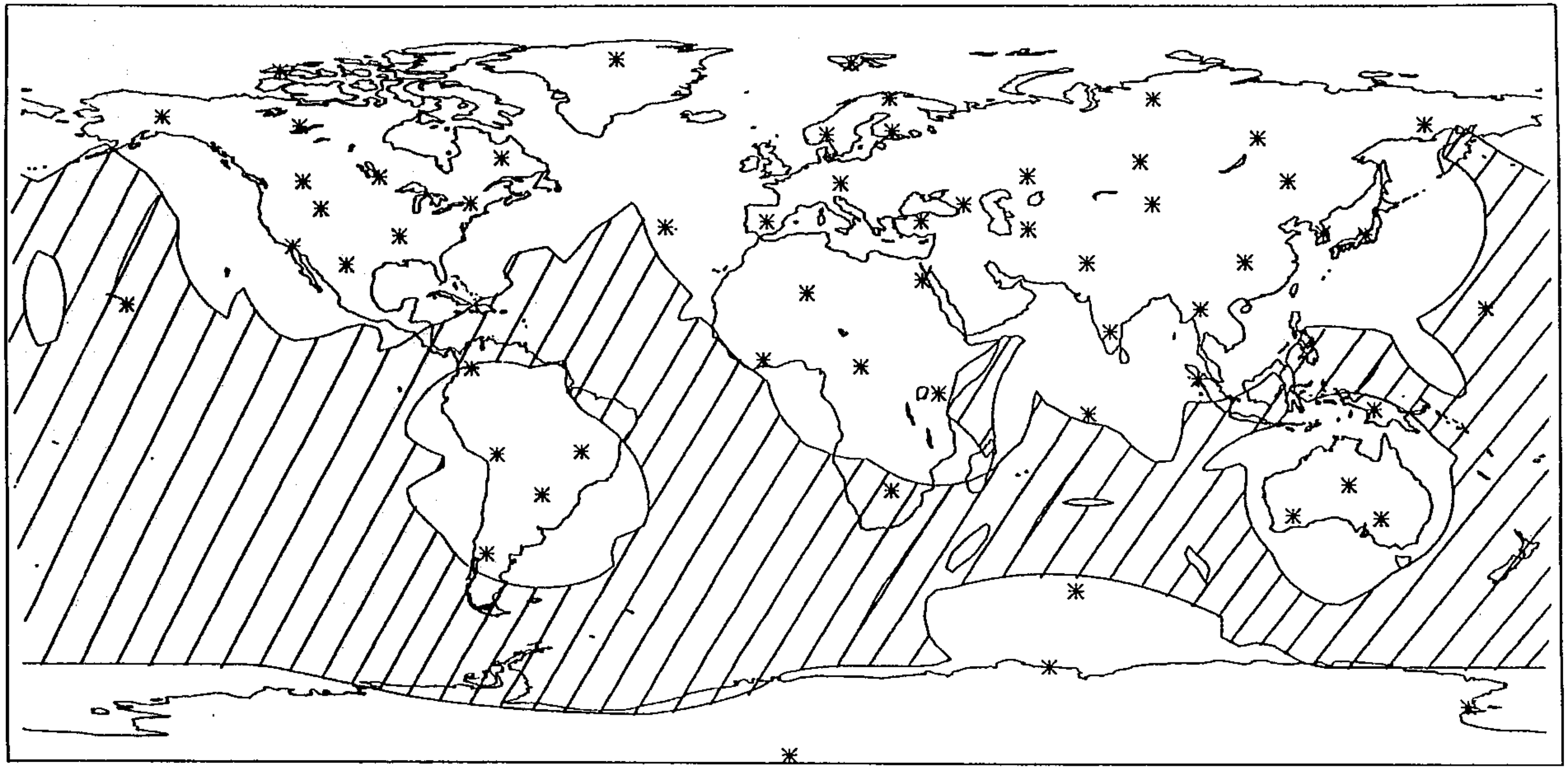


COVERAGE MAP: FRENCH PROPOSAL



COVERAGE MAP: RUSSIAN FEDERATION PROPOSAL

COVERAGE MAP: UNITED STATES PROPOSAL



PART II: RADIONUCLIDE MONITORING

Executive Summary

The experts on radioactivity took as their mandate the requirements set out in CD/NTB/WP.203. The experts considered four possible test scenarios, namely a 1 kt atmospheric test, with and without evasion, underwater and underground, each releasing different amounts of radionuclides into the atmosphere. For the non-evasive atmospheric test scenario the experts agreed that an IMS station should consist of a high volume sampler (air flow of about 500 m^3/h) and a high resolution gamma spectroscopy for analysis, with a sensitivity of 1-60 $\mu Bq/m^3$. Three days are considered adequate for sampling and reporting results.

The experts had the benefit of some preliminary computer model assessments of atmospheric transport of radionuclides to aid their deliberations. From these, three ground based networks of 50, 75 and 100 stations were considered further. In addition a network of 20 ground based stations with the use of 3 aircraft was also considered. The effect of a 100 station network is to provide fast detection in most parts of the world, the tropical regions being the longest; a reduction to 75 stations results in longer response times, and a further reduction to 50 stations increases this time in some parts of the world even more. Detection with a high probability is estimated to be within 3 to 10 days for 100 stations and in the range of 10 to 16 days for 50 stations. The 20 station/aircraft option results in all areas having detection times within 20 to 30 days.

The three ground based particle networks will cost in the range of $ 11-23 M for capital, with annual costs of $ 3-6 M. The option which includes aircraft (aerosols and noble gases) costs $ 8 M, with annual running costs of $ 4-13 M. Costs for both particulate and noble gas monitoring range from $ 19-38 M for capital, and $ 4-8 M for annual operation. At this stage it is not possible to estimate to what extent individual components of the equipment at the monitoring stations will need replacement due to aging, wear and tear, damage, etc. However, the experts considered that provision should be made on an annual basis after about 10 years of operation. This would lead to replacement costs in the range $ 1.5-4 M per annum at current costings.

In order for the experts to define more exactly a single radionuclide network for the IMS and its cost effectiveness a decision is required on

a) whether noble gas detection should be included to extend the capability of the network to provide significant deterrence to a potential evader;

b) the time interval between the suspicious event and the time to initiate agreed OSI procedures;

Some experts believe that it will be necessary to better define the procedures to deploy aircraft for monitoring purposes over ocean areas.

The experts consider that some further, more comprehensive evaluation studies, by a small group of experts, on designing the agreed network is necessary. Some arrangement should be made to provide funding, estimated to be about $ 2 M per annum for a year or two.

1. Introduction

In the report, CD/NTB/WP.171 of 19 August 1994, the experts on radioactivity detailed approximately 20 options for radionuclide networks of varying capabilities and costs, for the detection, identification and location of a nuclear explosion either in the atmosphere or in environments from which there may be a release of aerosols or gases into the atmosphere.

Subsequently, a further report from the Friend of the Chair (Non-seismic Verification), CD/NTB/WP.181 of 2 September 1994, and proposals by a number of other delegations have presented integrated International Monitoring Systems (IMS) which draw upon several of the options presented by both the radionuclide experts and by experts in other technologies.

To further refine a suitable radionuclide monitoring network for an IMS, a experts met during the period 6-17 February 1995. They took as their mandate the criteria given in the paper of the Chairman of the Verification Working Group, CD/NTB/WP.203 of 16 December 1994, which required further definition of the following:

a. the type of station required;
b. the number of stations required to achieve global coverage;
c. their geographical distribution;
d. an indication of the expected performance of the network in combination with other networks;
e. the data processing and flow requirements;
f. estimated costs;
g. further experimental or theoretical studies required to define more fully the stations and the network;
h. financial requirements before entry into force;
i. an indication of the earliest date at which a network can be established; and
j. the decisions required and practical steps needed to establish and operate the IMS.

In addition, the experts were requested to examine synergy with other technologies, especially infrasound.

It had been accepted previously that aerosol monitoring is an essential component of the radionuclide monitoring system for the detection and identification of atmospheric nuclear tests.

In the case of an underground explosion or in circumstances where local atmospheric conditions might lead to a significant reduction in airborne particulate, inclusion of noble gas monitoring in the network might provide additional deterrence. Of the noble gases likely to be released to the atmosphere following a nuclear explosion, xenon isotopes are the most suitable for monitoring purposes. Other noble gases produced during nuclear explosions, for example krypton-85 and argon-37, are not useful for monitoring purposes because of their low production in a nuclear explosion, high background concentrations from other sources, or technical difficulties in measurement.

2. Basic Design Criteria for the Radionuclide Network

The key to the design of any radionuclide monitoring network is the designation of scenarios in which the system must perform and the criteria for detection, identification, location, and responsiveness for OSI planning.

The first scenario in which a radionuclide system has an important monitoring role is the non-evasive 1 kt atmospheric test. In this scenario, which represents the simplest possible case, in excess of 90 per cent of the radionuclides produced are initially injected into the atmosphere. This results in an initial source term of approximately 2×10^{15} Bq of ^{140}Ba which is representative of several other key isotopes produced with similar activities. A system designed solely for this scenario would only provide a limited capability to monitor tests in which a determined evader has made an effort to reduce the amount of radionuclides transported "down range".

To accomplish a truly comprehensive monitoring system and to provide a more credible deterrent, other scenarios were considered in which some form of evasion technique could be used. These could include an atmospheric test of 1 kt in which in excess of 99 per cent of the particulate debris (aerosols) is washed out in the local area of the test (for example, a test conducted in a heavy rainstorm). For this scenario it is assumed that only gas signatures remain (> 90 percent of initial gas). The source term for this scenario is 1x10^{15} Bq of ^{133}Xe.

In addition, the capability of a radionuclide system to monitor underground and underwater tests is assessed. The underwater source term is identical to that of the evasive test in the atmosphere. However, a smaller source term was considered for the underground test. To represent an underground test of 1 kt, it was assumed that 10 per cent of the xenon created escapes into the atmosphere, and that the gases are emitted from the test site over a 12-hour period, as opposed to instantaneously in the other scenarios. The source term for this event is 1x10^{14} Bq of ^{133}Xe.

These scenarios are summarized below.

1.	Non-Evasive Atmospheric	~2 x 10^{15} Bq of ^{140}Ba (Instantaneous release, 50% local fallout, 1 micron average particle diameter)
2.	Evasive Atmospheric	~1 x 10^{15} Bq of ^{133}Xe (Instantaneous release, near 100% particulate debris fallout, <10% loss gaseous debris)
3.	Underwater	~1 x 10^{15} Bq of ^{133}Xe (Instantaneous release, near 100% particulate debris washout, <10% loss gaseous debris)
4.	Underground	~1 x 10^{14} Bq of ^{133}Xe (12 hour release, no particulate debris , 10% of gaseous debris released)

With the scenarios and source terms defined, it is appropriate to establish the criteria upon which the systems must be evaluated. In keeping with the criteria defined in the radioactivity experts' report in August 1994 (CD/NTB/WP.171), a radionuclide system should be rated in four areas: detection, identification, responsiveness for OSI and, to a lesser extent, for location.

The definitions of these criteria are:

1) Detection of fission product radionuclides and measurement of their activity. The probability of detection P_d for the scenarios is:

- P_d > 90 per cent within 10 or 20-30 days[1] of a 1 kt non-evasive atmospheric test.
- P_d > 50 per cent within 10 days of a 1 kt evasive atmospheric test or underwater test.
- P_d > 10 per cent within 10 days of a 1 kt underground test as defined above.

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[1] The range for the response time reflects the differences of opinion expressed in the group, for which no consensus could be achieved.

2) Identification of individual radionuclides and determination of their isotopic ratios. Probability of identification as fresh fission products $P_i > 95$ percent, with false alarm rate $P_{fa} < 5$ percent.

3) OSI Responsiveness in providing timely reporting of the raw data to the IDC. In order to minimise the reporting time, data should be reported within 72 hours after starting sample collection.

In addition, where possible, the system should be able to locate an event (by combining meteorological information with radionuclide and other sensor data) to within about 200 km over large land masses and to within about 500 km over oceans.

3. Proposed Network Design

From a technical point of view the key parameters of the network design are the number of ground-based stations, the sampling and reporting time, the sensitivity, the analysis system(s) and the system concept. The system concept describes the interaction between the permanent operation of the ground-based and the triggered airborne monitoring of free ocean areas as well as the different operating modes of the ground-based network, the site-selection criteria, the network reliability, the use of existing monitoring stations, and synergetic effects.

In addition to these technical aspects, the network design has to consider the complex nature of atmospheric transport and mixing and the numerous possibilities for the selection of test sites. Since the last meeting of experts in August 1994, a lot of valuable information has become available from system analyses studies based on three-dimensional atmospheric transport models. It has become clear from these studies that there is a well-defined relationship between the key parameters which defines the overall performance of the network, e.g., the number of ground-based stations and their sensitivity, and the capability to detect a nuclear event at any arbitrary point, identify it as a nuclear event and to locate it with accepted certainty. Due to the complex nature of atmospheric transport and mixing, it is necessary that the detection and identification capability of the networks described in this report be expressed in terms of detection and identification probabilities.

The variety of available options for the network design as outlined in CD/NTB/WP.171 has been reduced substantially. In this report, the experts describe the capabilities and the costs of three ground-based networks and a combined network also involving aircraft. The details are described below.

Finally, the network design has to consider synergy with other networks of the IMS, in particular the infrasound network. In this field, progress has been made since the last meeting of experts in August 1994. The results are presented below.

3.1 Ground-based monitoring

The experts agree that ground-based monitoring stations are an essential component of any monitoring network and that 50 to 100 such stations will be required to meet the objectives of the IMS as outlined in chapter 2. Monitoring networks with 50, 75, and 100 stations are described in this report. Appendix 1 provides a list of locations, most of which have been used for the model calculations and some of which could form the basis of the IMS radioactivity network.

The geographical distribution of the stations in the example networks requires further consideration on the basis of meteorological studies. The model results available so far indicate that this could influence the network's detection probability for suspicious events.

One of the key parameters to define the overall performance of the network is the network's capability to detect a nuclear event at any arbitrary point on the globe. The detection probability depends both on the sensitivity of the stations of the network and the accepted transport time. As the agreed sensitivity of the particulate monitoring is about a factor of 1,000 higher than that of noble gas monitoring (cf. section 4), the detection probabilities of the proposed aerosol and noble gas networks will be described separately.

The detection probability of an aerosol network with 50, 75, and 100 stations and a sensitivity as described in section 4 depends on the accepted time delay between an event and its detection by the network. Qualitatively it is evident that the detection probability will increase with an increasing number of stations for the same detection time. As there are practical and financial limits to this, a range of 50 to 100 stations has been chosen by the experts.

The expected performance of the three different networks considered by the experts is shown Figure 3-1. The US network of 100 "proposed" stations (CD/NTB/WP.184) is compared to smaller networks of 75 stations and 50 stations concentrated on the continents. The network of 75 stations is based on deleting 25 stations from the US network that are on the most remote islands or very near other stations. Similarly, the US proposed network was "reduced", or thinned, to only 50 stations for comparison.

The results assume each station is capable of detecting at least 1 microbecquerel of barium-140 per cubic meter of air sampled. Then, travel times, averaged over a range of meteorological conditions, are calculated for debris from hundreds of "theoretical" 1 kt nuclear explosions occurring anywhere in the atmosphere to each station in the networks (L. Roger Mason, "Comprehensive Design Analysis for an International Radionuclide Monitoring System", 1995). Detection probability at any time after the explosion is defined as the number of (theoretical) explosions detected by at least one station in a network divided by the total number of explosions modelled.

The proposed network of 100 stations is expected to detect about 90 per cent of these 1 kt events within about 10 days after an explosion. By comparison, the 75- and the 50-station networks can be expected to provide detection probabilities of only about 60 per cent, 10 days after such a nuclear explosion. These networks are not expected to provide a 90 per cent detection probability for more than two weeks (about 16 days) after such events.

The same atmospheric transport models are used to evaluate detection capabilities as a function of station sensitivities. Figure 3-2 illustrates how the network detection probability is expected to vary if detectors of higher or lower sensitivity are used at each monitoring station. For the proposed network of 100 stations, the detection probability is again determined for 1 kt nuclear explosions anywhere in the atmosphere. If each station were to use only inexpensive "environmental monitoring" detectors, like simple dose-rate meters, the detection probability for these events is not expected to ever exceed about 15 to 20 per cent. Very sensitive sodium iodide (NaI) detectors may achieve a detection probability of between 60 and 75 per cent after 10 days. However, only the performance of high-purity germanium detectors is expected to provide the performance needed for the network to be an effective deterrent. This analysis also shows that increasing detector sensitivity beyond that specified does little to improve the overall network detection capability; more stations would be required for significant improvements.

It can also be shown that the less sensitive detectors cannot adequately support radionuclide identification or the quantitative characterization required to aid in locating events of interest.

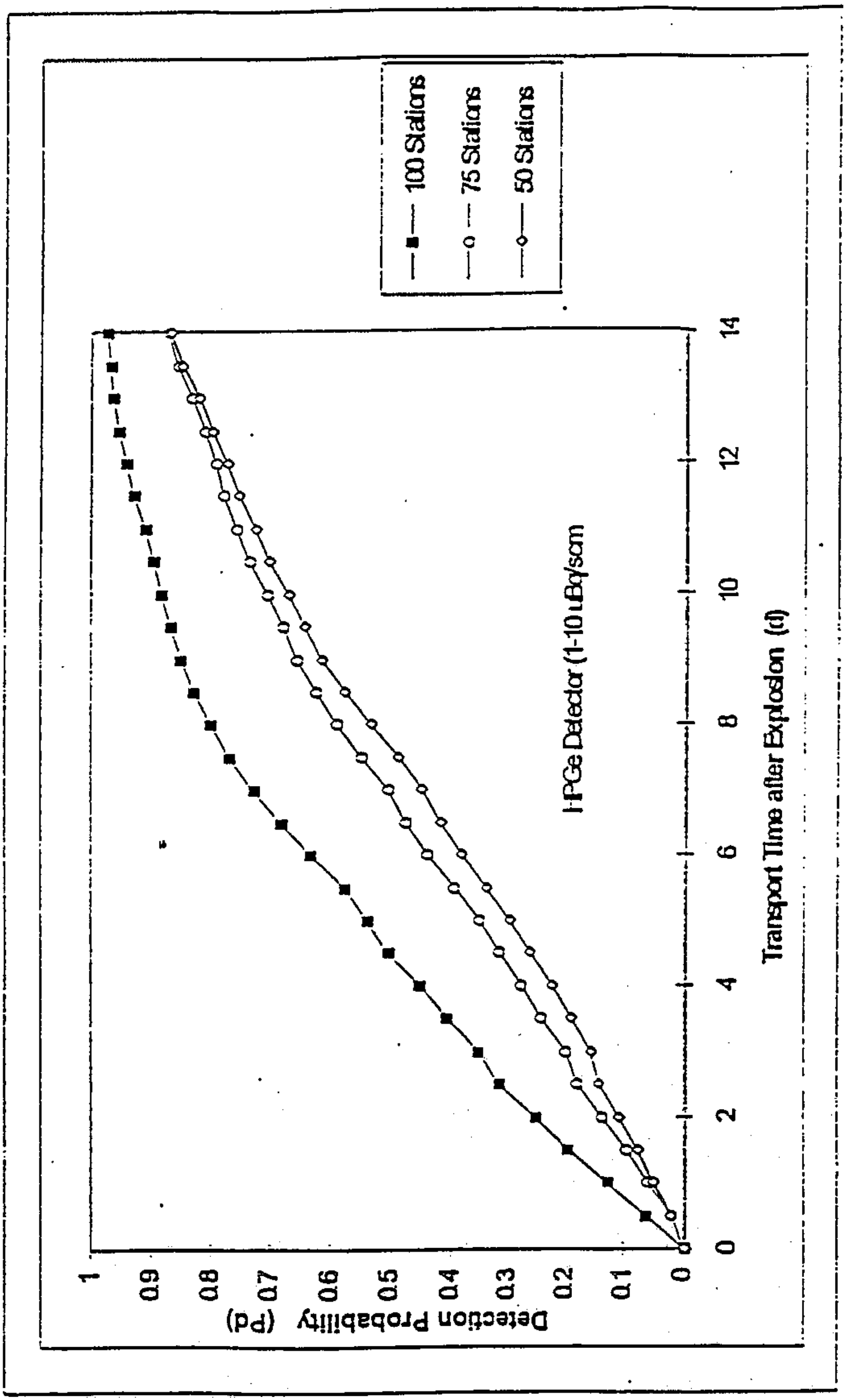

Figure 3-1. Detection probabilities for various network designs.

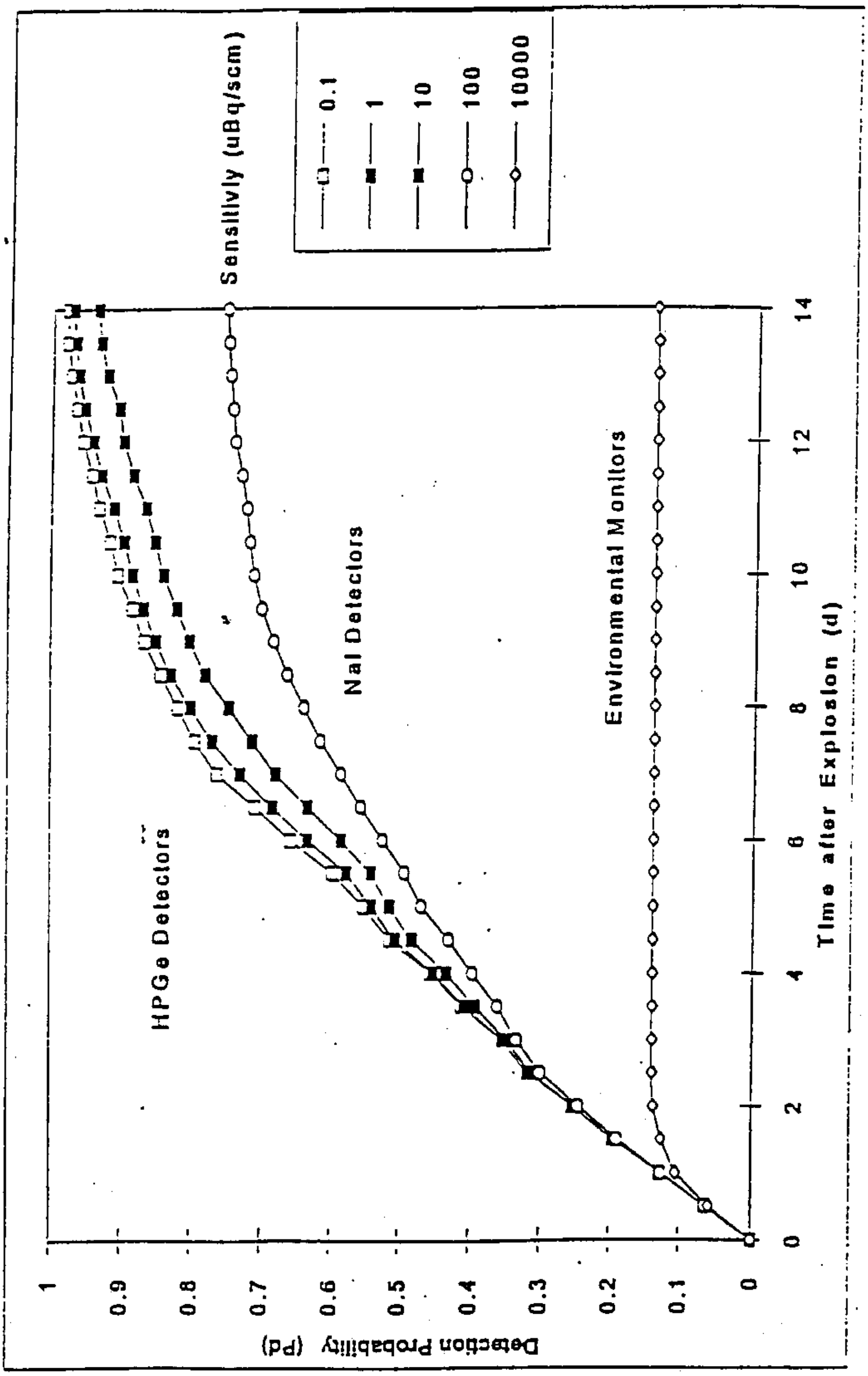

Figure 3-2. Detection probabilities for the 100-station networkand various detector sensitivities.

Therefore, these less capable detectors would greatly reduce the expected synergy with other IMS monitoring systems.

The experts have considered the capability to co-locate xenon samplers to provide detection in scenarios in which particles may not be readily released and transported to the monitoring stations by the atmosphere. In order to evaluate the performance of these samplers, several test cases were run for the network of 100 stations described above (time constraints did not allow completion of the calculations for the 50 and 75 station networks). Figure 3-3 illustrates the probability of detection for an explosion producing a total of 1.3 PBq of Xe-133 (this is equivalent to a fission yield of about 1 kt) and releasing portions of this gas for different test environments. In the atmosphere we assume an evasion scenario in which all of the particulate debris is washed out of the atmosphere but the insoluble xenon gases are allowed to be tracked to the stations. Theoretical explosions are modelled in the ocean areas assuming a 90 per cent instantaneous release of xenon into the atmosphere and tracking it to the stations. For underground tests, only 10 per cent of the total xenon is assumed to be released over a 12-hour period. The underground explosions are simulated only on the continents.

This analysis shows that the 100-station network can detect xenon in all three of these cases. In the case of an evasive atmospheric test, this network reaches a maximum probability of detection of about 10 per cent within 3 days of the test. Similar results are found for the underwater test, reaching a maximum of about 19 per cent in about 3 days. The detection probability for the underground test is 20 per cent after 3 days. Further modelling will be required to better define the performance of xenon samplers as their sensitivity and sampling efficiencies are experimentally verified. However, these results are consistent with our expectations of networks limited to 100 stations or less.

An independent simulation, using a separate atmospheric tracer model, was carried out on networks consisting of 50, 71 and 100 stations. This evaluation showed that, for the detection of aerosols, all three networks performed about equally well for tests conducted in the north and south temperate zones; however, there was a substantial improvement for tests in the tropical zone as the number of monitoring stations increased. The results of this evaluation are shown in Table 3.1. Although the two approaches evaluated different networks and utilized different indicators of performance, they both show that there are improvements in going from 50 to 75 to 100 stations in the network.

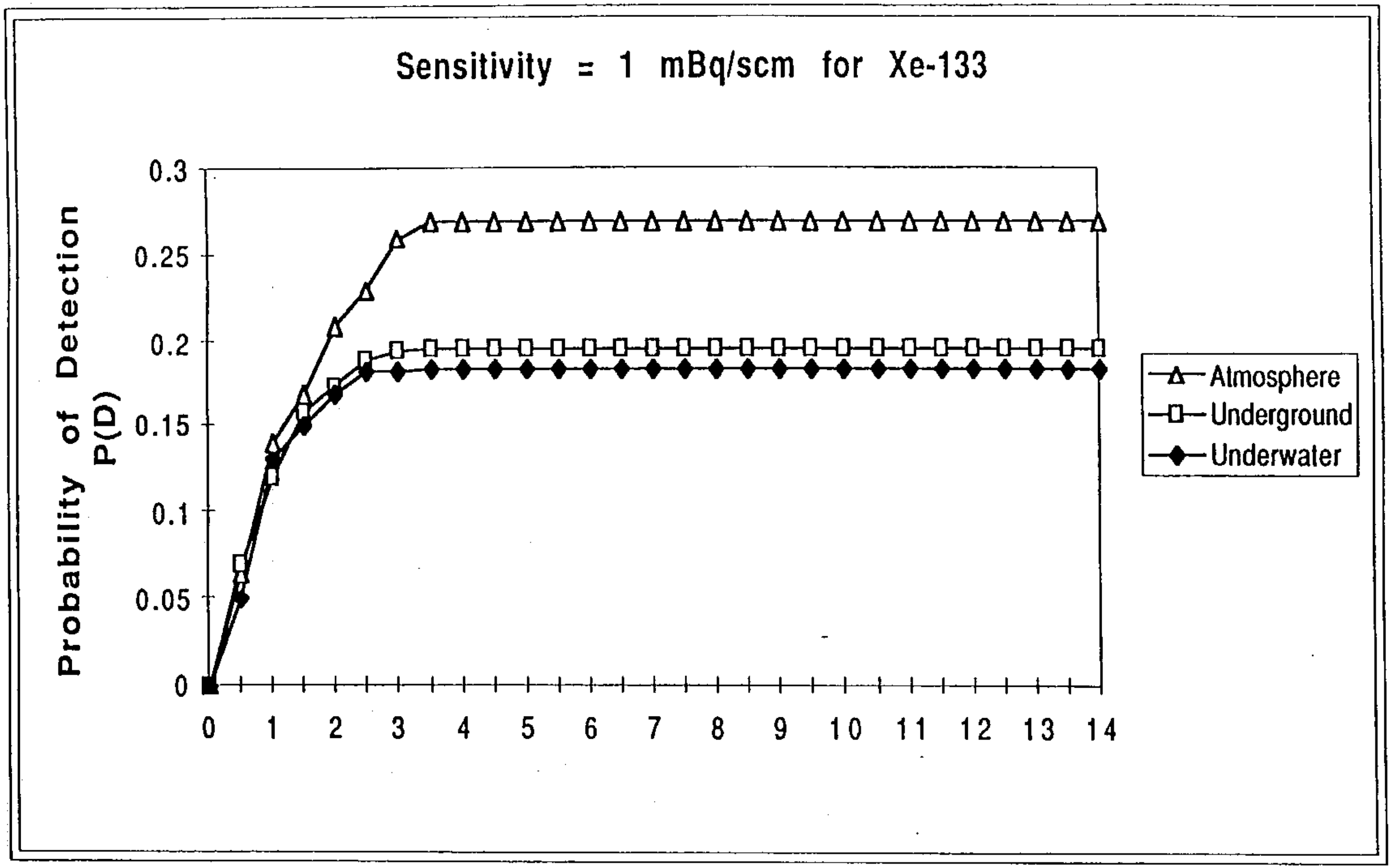

Figure 3-3. Probability of detection for underground, underwater, and evasive atmospheric tests based on Xe-133.

TABLE 3.1. COMPARISON OF THE 50, 71 AND 100 STATION NETWORKS

Test location	Average time to first detection (days)			Average number of stations detecting within 6 days		
	50	71	100	50	71	100
North temperate zone	3	3	3	3	3	3
South temperate zone	3	3	3	1	3	3
Tropical zone	6	4	2	1	1[a]	3[b]

(Source term 5 PBq Ba-140, detection sensitivity = 10 μBq/m^{-3})

a. In the tropical zone, the 71 station network achieved detection in 80% of cases within the six day period.
b. In the tropical zone, the 100 station network achieved detection in 100% of cases within the six day period.

The expectations of the capabilities of identification and localisation have not been discussed by the experts in great detail. Due to the very nature of the network, it is expected that the identification probability will be almost 100 per cent, once a test has been detected by the network. The discrimination capability against other nuclear sources of interest, e.g. for example nuclear power reactors, and the false alarm rate is expected to be very small, e.g., below 5 per cent. Similar figures hold for the network's overall capability to determine source origin time using measured isotopic ratios. In evasive scenarios, if only Xe-133 is detected, identification has to rely on the very likely remoteness of the site, far away from other sources for this radionuclide, such as nuclear reactors and hospitals.

The precision of localisation of an event requires further study. These have to include synergetic effects with seismic, hydroacoustic, and infrasound monitoring as well as system analyses of the backtracking capabilities of meteorological models. The expectation is a desired location error of about 200 km. According to practical experience, this can be achieved with a ground-based network with 100 stations at least in some areas of the northern hemisphere, whereas this might be difficult in tropical regions.

3.2 Ground-based and triggered airborne monitoring of free ocean areas

Some experts believe that the responsiveness is not a time-critical parameter for detection of atmospheric explosions, which are conducted above the ground, while it is in the case of underground nuclear explosions. They base their conclusion on the fact that such critical phenomena as radioactive fallout in the vicinity of a test site stay detectable for years to tens of years. For the other phenomena, there are not equally stringent and time-critical criteria (see CD/NTB/WP.198). In this case, taking into account cost effectiveness, the responsiveness of 20-30 days is regarded as quite sufficient for on-site inspection.

For atmospheric explosions above the ocean areas or underwater explosions when the arrival time of an inspection group is a more essential factor, it is proposed by some experts to use airborne facilities that can improve the response time up to 6-7 days (assuming approval for sampling is given immediately after triggering).

Many experts acknowledge the possibility of enhancing the effectiveness of a radionuclide monitoring subsystem of the IMS by a combination of ground-based and airborne monitoring. The option proposed in CD/NTB/WP.187 comprises 20 ground-based stations (10 aerosol stations plus 10 stations with aerosol and noble gas monitoring) and three specially equipped airborne laboratories. Such a network of ground-based stations (for station positions see Appendix 1) with a sensitivity of 1-60 μBq/m^3 is capable of detecting an atmospheric test with a probability of 99 per cent within a month.

Airborne monitoring is intended to be directed first and primarily at remote neutral regions where it is impossible to set up a sufficiently dense network of ground-based stations. The most efficient mode of operation of the aircraft is for the specific detection of radionuclides in given areas which are specified by other IMS subsystems, in particular the infrasound subsystem.

It is suggested that the required aircraft systems be based in the following areas: Russia, United States, Australia or New Zealand or South America.

Airborne systems have the advantage of providing:

- great rapidity of 2-4 days in reaching the site of a suspicious event over international waters; the samples can be transported to specialized laboratories at almost any place on earth;
- the possibility for the collection of representative radionuclide samples from a test at various layers of the atmosphere and the determination of the contours of the plume;
- a high flow rate for sampling up to 10,000 m^3/hour;
- the possibility of the remote detection of any radioactive material of sufficient activity which is deposited from the radioactive cloud on the water;
- increasing the detection probability of noble gases for underwater nuclear explosions and evasive explosions;
- improving the accuracy or the localisation of a radioactive source.

The experts acknowledged that further consideration should be given for dealing with a potentially contaminated aircraft.

3.3 Operation modes

The experts are agreed that while 1-day sampling is the desired optimum operation mode because it provides the best sensitivity and detection probability, practical and cost considerations may require strong consideration of the following modes:

(a) Triggered systems: where air sampling would proceed routinely on a 3-day (particulate) or 2-day (noble-gas) basis, with sampling frequency increasing to 1-day upon triggering by some other monitoring network. On the basis of cost considerations, triggering by on-line radionuclide monitoring systems has not been considered further.

(b) Bulk analysis: where 1-day sampling would proceed continuously, but the filters would be bulked before analysis. This would have the advantage of preserving the daily record, which would be helpful if the bulk analysis detected radionuclides, while reducing the routine analytical workload. The system could also be triggered as in (a).

Aircraft systems should function on a triggered basis.

3.4 Site selection criteria for radionuclide stations

The selection of a site should be based on further meteorological studies. It depends on the willingness of a State to host such a station and the availability of suitable sites, e.g. in ocean areas. Though co-location with seismic and/or infrasound stations is desirable, the calm atmospheric condition required for infrasound and seismic stations is incompatible with the wind field condition required for radionuclide monitoring.

For the selection of a site, the available infrastructure, the meteorological conditions and possible background radioactivity conditions have to be considered.

Key elements of the infrastructure requirements are the electrical power supply, data links to wide area networks, and transport capabilities for samples and people (maintenance and support). The housing of a station should be robust, weatherproof and safe.

The meteorological conditions at a site should assure that it is capable of monitoring long range atmospheric transport. This means that elevated altitudes are preferable; areas with restricted vertical atmospheric mixing like mountain valleys, large forests, etc., should be avoided. Highly polluted areas with a high dust load in the air should also be avoided.

High values of natural background of the environmental radioactivity can affect the sensitivity and the reporting time of the network. Other sources like nuclear power plants as well as hospitals, research institutions and certain industries with radionuclide applications could result in a variable environmental background of man-made radioactive materials, which could increase the false alarm rate of the station. These aspects should seriously be considered when a site is selected.

3.5 Network reliability function

The reliability of the operation of the network is another key aspect which could influence its detection capability. From past experience the experts believe that a 95 per cent reliability would not seriously affect the overall capabilities of the network described in this chapter. Reliability figures of this kind can be achieved without an unacceptable increase in the costs of the network, as would be the case if the reliability was increased, for example to 99 per cent or higher. Experience shows that there are different ways to achieve this. One way would be to increase the number of stations by 5 per cent, another would be to make provision for maintenance and repair (see also sections 4 and 6).

3.6 Use of existing monitoring stations

The experts agreed that maximum possible use should be made of existing national monitoring stations, subject to practicability of upgrading and cost considerations. There is no clear picture at the present time how many stations are really available and to what degree upgrading would be required. It is agreed that this question requires further consideration. The basis for this work could in part be the response of the various countries to the questionnaire of August 1994. From the experts' judgement this response has been poor and a major effort is needed to obtain better information on the existing situation (see also section 7).

3.7 Synergy

There is agreement among the experts that synergy with other networks such as infrasound could be advantageous in two ways: it could increase the overall capabilities of the IMS and could reduce costs. Although some progress has been made since the last meeting of experts, the potential advantage of synergy between all monitoring networks requires further investigation. Also synergy with other verification techniques will complement the radionuclide monitoring network, especially in event localisation. This includes both the geolocation and the prompt timing of a suspicious event. It is important to state here that the areas where geolocation with the infrasound network seems to be difficult, e.g. in the southern oceans, do not coincide with the areas where detection with the radionuclide network is difficult (tropical areas).

Regarding cost considerations, the possible triggering of ground-based stations with infrasound is highly preferable to other means of triggering, e.g. on-line alpha and/or beta measurements. In this case a limited number of stations of the IMS could be triggered based on estimates of the atmospheric transport. As the false alarm rate of a global infrasound network is not known very precisely at the present time and available estimates are as high as once a month, it can not be decided at present if this triggering mode is acceptable or not. This is particularly true for the triggering of any aircraft system. Further work is needed in this field (see also section 7).

4. Equipment and Analytical Requirements

In order to achieve the required reporting time, it was agreed that a sampling period of one day would be required for both continuous aerosol and noble gas monitoring. In an operational mode which includes triggering of the network, as described elsewhere, routine sampling of aerosols may be carried out with a longer sampling period or less frequent measurements.

To achieve the sensitivity requirements discussed below, a flow rate of about 500 cubic metres per hour would be required for aerosols. Nobel gas monitoring would involve flow rates of at least 10 cubic metres per day.

The appropriate particle size range for collection would be 0.1 - 5 microns, with a minimum collection efficiency of 80 per cent for particles of 0.1 micron diameter.

It was agreed that equipment reliability is a critical requirement to ensure that the downtime of any one sampling station is minimized and should not exceed one week over one year. This will require resources for rapid replacement of faulty equipment, etc.

For the monitoring of airborne particulates, high-resolution gamma-spectroscopy is accepted as the only suitable technique for analysis of air filter samples within the radionuclide monitoring network. The relative efficiency (1.33 MeV) for high purity germanium detectors should be greater than 30 per cent. Noble gas monitoring would involve either gamma ray measurements or a beta-gamma coincidence technique.

The analytical sensitivity for measurement of radioactive aerosols should fall within the range of 1-60 Bq/m^3. The achievable sensitivity will be dependent on the particular radionuclide. This is demonstrated in Table 4.1 which lists achievable detection sensitivities for key radionuclides in CTBT monitoring. This level of sensitivity in the monitoring of aerosols establishes a basis for the sampling and analytical requirements discussed below.

At present, detection sensitivities for noble gases are inherently lower because of relatively low sampling rates. With current technology, an achievable value lies within the range of 1 to 30 mBq/m^3.

Sample analysis time should be as long as required to reach the specified sensitivity for each particular radionuclide. A period of 2 days is considered appropriate to allow for decay and analysis after sampling and still achieve an acceptable reporting period of three days. Within this time period, a typical counting time would be one day.

Spectrum analysis software must meet specified minimum criteria, but it is not essential that identical software be used universally. Quality control of the sampling and analysis procedures is essential and should follow specifications laid down by an international certified laboratory.

Preliminary technical specifications for airborne monitoring stations (aircraft) are a flying range of not less than 7000 km; and a flying speed of between 300 and 700 km/h.

The aircraft should be equipped with the following:

- Aerosol samplers with a capacity of not less than 10,000 m^3/h (see footnote[2]) ;
- Sampler for noble gases with a sensitivity of 2 mBq/m^3 for xenon-133;

other equipment and analytical requirements are the same as for ground-based stations.

Table 4-1

Achievable detection limits (MDA = minimum detectable activity, decay-corrected for the sampling period) for ground-based monitoring assuming a

- one day sampling time,
- one day decay time and
- one day counting time.

Aerosols

The numbers given are based on an air flow rate of 500 m^3/hr (equivalent to a filtered air volume of 12,000 m^3) and a counting efficiency of the detector of 40 per cent; they include the varying Rn-222 background and the second-order effects of uncertainty. For the iodine isotopes lower limits are given, because the fraction of particulate iodine in air in a specific situation is not known.

Radionuclide	**half life**	**MDA ($\mu Bq/m^3$)**
Zr-95	64d	3-10
Nb-95	35d	5-15
Zr-97	17h	20-60
Mo-99/Tc-99m	2.75d	20-60
Ru-103	39d	3-10
I-131	8d	>5
Te-132	3.3d	5-15
I-133	20h	>30
Cs-134	2.1yrs	3-10
Cs-136	13.2d	3-10
Cs-137	30yrs	3-10
Ba-140	12.8d	10-30
Ce-143	1.4d	15-50

Criteria for the identification and origin time determination for an atmospheric test can be based on ratios of the detected radionuclides such as $^{134}Cs/^{137}Cs < 0.01$ and $^{95}Nb/^{95}Zr < 1$. Further details of the identification procedure have to be developed.

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[2] This aerosol sampler capacity is valid at an altitude of 200 to 500 m and at a speed of 320 to 350 km/h.

Xenon isotopes

The numbers given are based on a flow rate of 10 m^3 per day.

Radionuclide	half life	MDA (mBq/m^3)
Xe-131m	11.9d	22
Xe-133	5.2d	2
Xe-133m	2.2d	5

5. Data Flow

Figure 5-1 illustrates the flow of radionuclide data and samples through the IMS. Particulate samples and gas samples should either be collected and analysed on-site, or they may be transported to a national or regional measurement laboratory for gamma ray analysis, or beta-gamma analysis for some xenon measurements. Once these field measurements are complete, the samples should be archived at the national or regional measurement laboratory, or transferred to certified laboratories for in-depth analysis. Particulate samples should be archived for at least one year.

Data collected on site at monitoring stations and at the national/regional measurement laboratories should be transmitted to National Data Centres (NDCs) and the International Data Centre (IDC) simultaneously. These data will include all raw data from the flow-meters from the sample collectors, the raw spectral data from particulate and gas sample measurements, data and results of calibration and background measurements, processed data and results (concentrations in Bq/m^3), state-of-health data for all systems at the station, and any local meteorological data collected at the station. All data from the radionuclide network should conform to a set of formats and protocols to be provided in an Interface Control Document for the IMS.

The IDC, as in the case of seismic, hydroacoustic, and infrasound monitoring networks, should provide the analytical services and products essential to the IMS. As suggested in the CD's Working Paper on the IDC, CD/NTB/WP.192, the IDC should receive and archive the data in its data base, as well as provide essential applications to process, analyse, review and report radionuclide data to all NDCs. The procedures for the receipt of radionuclide data and other information from the radionuclide stations and the processing and flow of data through the IDC are still to be determined. The spectral data should be parsed and stored in the data base. State-of-health data should be monitored and alerts generated for system failures so that the IDC operators can be notified of problems. In addition, requests for data from the NDCs should be processed and radionuclide data sent out to the NDCs.

The IDC should produce a list of fission products for each event detected. An example of this process is illustrated in Figure 5-2. The IDC should also provide for the synergistic fusion of radionuclide data with data from the other monitoring networks. Through a resident capability or the existing Regional Specialized Meteorological Centres (RSMC) of the World Meteorological Organization (WMO), the IDC could provide backtracking of these events to locate the origins of detected nuclear sources. The WMO could also provide the global meteorological and climatological data required to support these analyses.

All raw data and analytic results should be available for review by experts at the IDC and the NDCs. Standard data formats and communication protocols consistent with other technologies should be established for the radionuclide data, reports and bulletins to assure communications with the NDCs.

Figure 5-1. Data flow from the radionuclide monitoring network.

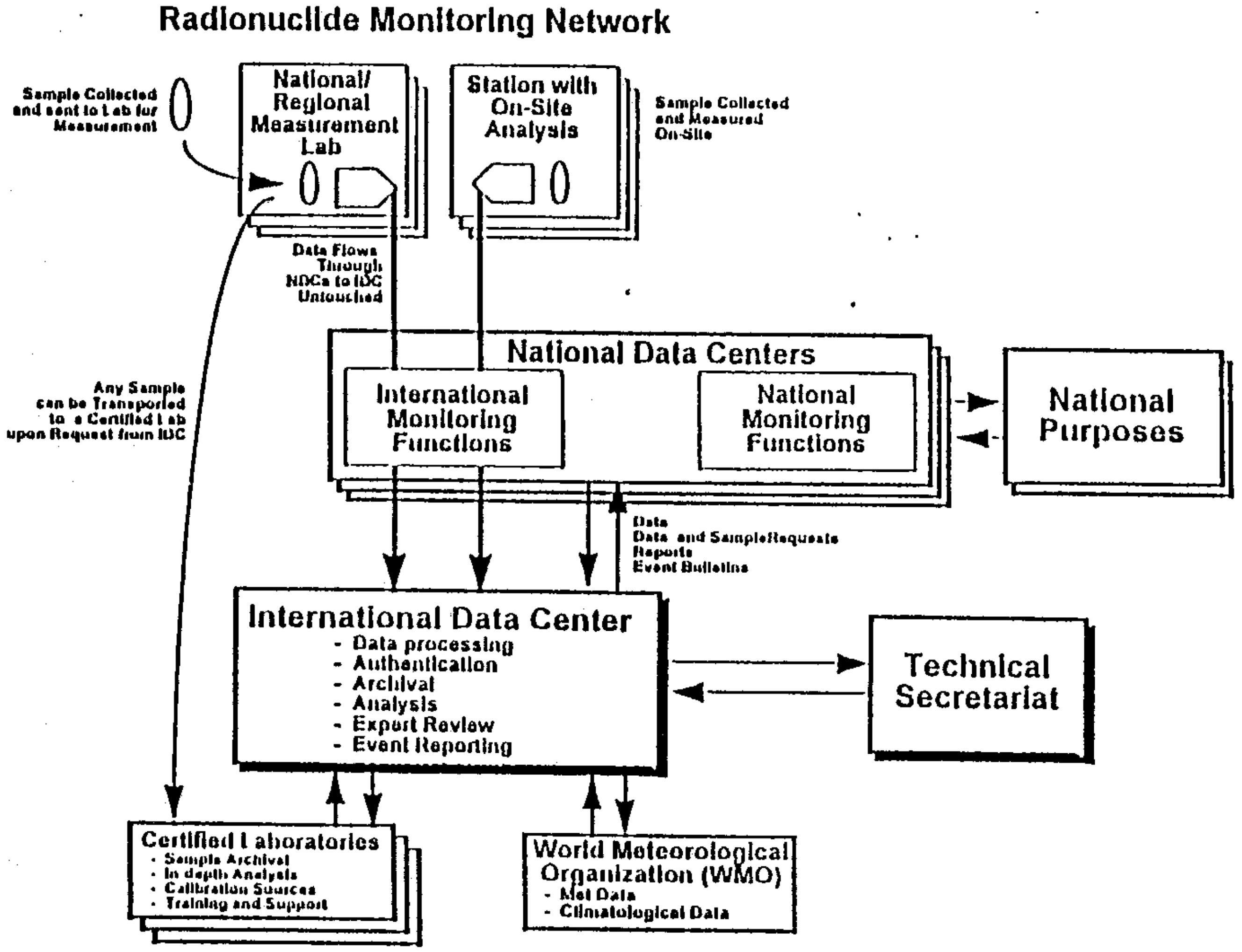
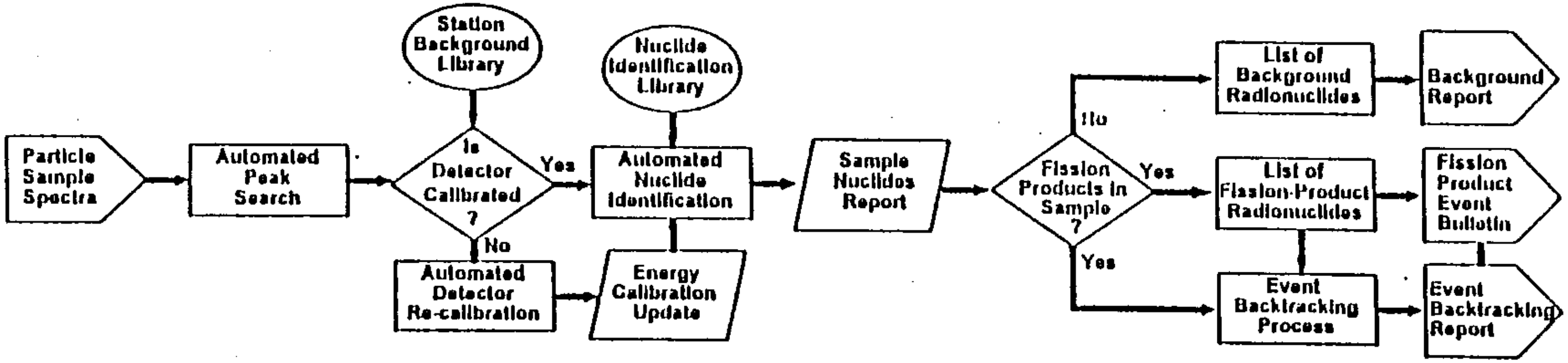


Figure 5-2. Radionuclide data analysis for event detection and reporting.



6. Costs

The experts took as their starting point the cost estimates for the individual components necessary for both particulate/aerosol and noble gas monitoring stations, the values given in CD/NTB/WP.171, modified, where relevant, by revised figures.

On this basis the capital costs for a new station meeting the requirements set out in section 3 are:
a) $225K per station for particulate/aerosol;
b) $380K per station for both particulate/aerosols and noble gases, assuming co-location of the two types of monitors and maximum utilization of supporting infrastructure for maintenance, uninterruptable power supply, communication links, building, roads etc.

The experts still consider that the monitoring stations will need to be supported by a "certified laboratory" for quality assurance, data security, accreditation and general support. The experts now considers that one such laboratory will support about twenty monitoring stations. This capability should be provided by existing laboratories and thus no new capital costs are envisaged. However, operating costs will be incurred, currently estimated to be $500K per annum, which, when shared, equates to about $25K per station.

Thus, the annual running costs per station are:
a) $55K for particulates/aerosols only
b) $75K for a combined particulate/aerosol and noble gases.

Costs for the options involving the use of aircraft as mobile monitoring platforms are based on cost estimates for equipping three aircraft of $1.5M and an annual running cost of between $3M to $12M. The wide range for operating costs of the aircraft arises because of the different perceptions of members of the experts for individual costs of fuel, wages, takeoff/landing fees, support services, etc. in different areas of the world.

Costs for the options involving ground-based stations only are set out in Table 6.1 for both the particulate/aerosol systems and the combined particulate/aerosol and noble gases systems.

At this stage it is not possible to estimate to what extent individual components of the equipment at the monitoring stations will need replacement due to aging, wear and tear, damage, etc. However, the experts consider that provision should be made on an annual basis after about ten years of operation. This would lead to replacement costs in the range $ 1.5-4M per annum at current costings.

Table 6.1 Cost Estimates for Networks of Ground-based Stations and combined Ground-based Stations and Aircraft

No. of Stations in Network	Cost ($M)			
	Particulate/Aerosol Only		Combined Particulate/Aerosol and Noble Gases*	
	Capital	Annual	Capital	Annual
50	11.3	2.8	19.0	3.7
75	16.9	4.1	28.5	5.6
100	22.5	5.5	38.0	7.5
20 + 3 aircraft				
10 (aerosol)	2.3	0.6		
10 (aerosol/gas)			3.8	0.8
3 aircraft			1.5	3-12
Total for 20 stations + 3 aircraft			7.6	4.4-13.4

* Assuming combination at every station

7. Next Steps toward the Implementation of a Radioactivity Network

So far, the experts' work has concentrated on the specification of equipment, analytical procedures and principles of network design. This has been and still is a very important prerequisite for the implementation of the radioactivity monitoring system. It is obvious that a major effort is still needed towards network implementation. The next step towards this goal is the development of a detailed system specification and design, which includes all the technical aspects of the operation of the stations, the aircraft, the laboratories, the data centres, the analytical procedures to be followed, details of data analysis and transmission, quality assurance, and the interaction between the different participants in the network. There is agreement among the experts that this step requires some permanent expert work and financial support.

One important requirement for a final decision on the details of the ground-based component of a network is the need for further evaluation studies. Although much progress has been made since the experts' meeting in August 1994, more work is needed to improve the reliability of the present findings under various meteorological conditions and to optimise the geographical positions of the ground-based stations. This work should further address the question of the geolocation capability of the network, a field which so far has not been covered sufficiently and which caused some controversial discussion by the experts. The evaluation studies should further include the possibilities offered by infrasound and other verification methods for geolocation and prompt timing of a suspicious event. As described in CD/NTB/WP.171, this work requires funding. The previous cost estimates still seem to be valid.

The experts have stressed the importance of quality assurance at any step of data sampling and evaluation within the monitoring network. Some criteria have been specified in this report. There is agreement that quality assurance programmes have to be developed and enforced before the monitoring network can go into operation. This could require the help of external consultants.

It has been found advantageous in similar projects to establish a network of this kind by a step-by-step approach. This can and should be done parallel to the work of detailed system specification. Such an approach of a permanent interaction between planning and practical experience in the past has been found most profitable for the final operation of the network. The experts therefore strongly propose that an experimental assessment of existing monitoring stations, including a data exchange similar to the GSETT-3 approach, be made. At the present time this can only be done on a voluntary basis. From the response of the various countries to the questionnaire of August 1994, there seem to be enough nations willing to participate in such an exercise to expect the required feedback. During such an experimental period the criteria and technical means for the data exchange between national stations and the IDC could be tested as well as the appropriateness of site selection criteria. In addition, stations which would be willing to participate in an IMS could be evaluated and upgrading costs could be estimated much more precisely than without practical experience.

The experts are agreed that maximum possible use should be made of existing national monitoring stations, subject to practicability and cost considerations. This requires two kinds of activities, namely the specification of the criteria to be applied for certification and integration of these stations in the IMS and a comprehensive assessment of the existing stations and laboratories to meet the criteria of the IMS. This assessment could be based on the technical specifications of this report. From the experience with the poor response to the questionnaire of August 1994, it is proposed that such an assessment should be organized differently, e.g. by an external consultant or body.

The practical aspects of noble gas monitoring are still not covered to an extent which would enable the experts to specify an automated technical device, in detail, which could be used within the proposed monitoring network (see section 4). From a technical point of view and from the available experience there is no doubt that an automated system, which meets the specifications of the proposed network, could be developed. The experts acknowledge the ongoing development in this field and propose to develop a prototype of a noble gas sampling and detection system at the earliest possible time which could and should then be tested in the framework of the experimental assessment of existing monitoring stations described above. It is expected that such a prototype would be available within about three years.

The steps for network implementation and the experimental activities proposed in this section are considered mandatory before the network can be established. There are no indications to the experts that the establishment time of 3-5 years as stated in CD/NTB/WP.171 is no longer valid. It must be pointed out that the practical steps proposed in this section will take about 2 years, with costs of about $ 2 M per year. From the experts' point of view, all the work described in this section could and should be started immediately.

It seems very reasonable that a core group of experts be established which coordinates all the above activities. This group could also help the Chairman of the Verification Working Group to prepare and organize any further expert work needed and make the expert work much more efficient. From the experts' judgement, one to two expert group meetings would be needed this year, once the necessary political decisions are made.

Appendix 1. Combined list of locations

Russian Federation proposed 20.
The US proposed 100.
Canada proposed 75 and added 25.
France proposed 75.

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+25]	US [100]	FR [75]
1	South America	Argentina	Buenos Aires	34.00 S	58.00 W	-	X	-	-
2		Argentina	Manantiales	25.00 S	61.00 W	-	-	X	-
3		Argentina	Puerto Deseado	47.50 S	66.00 W	-	-	X	-
4		Argentina	Salta	24.00 S	65.00 W	-	X	-	-
5		Bolivia	Santa Cruz	18.00 S	63.00 W	-	-	-	X
6		Brazil	Altamira	3.19 S	52.21 W	-	-	X	-
7		Brazil	Boa Vista	2.82 N	60.67 W	-	-	X	-
8		Brazil	Brazilia	15.64 S	48.01 W	X	X	-	-
9		Brazil	Recife	5.00 S	35.00 W	-	X	-	X
10		Brazil	Rio de Janeiro	22.58 S	43.31 W	-	X	X	-
11		Brazil	Salvador	12.99 S	38.48 W	-	-	X	-
12		Chile	Punta Arenas	53.00 S	71.00 W	-	X	-	X
13		Chile	Santiago	33.00 S	70.00 W	-	X	-	-
14		Chile	Santiago	34.77 S	70.36 W	-	X	X	X
15		Colombia	Bogota	4.00 N	74.00 W	-	-	-	X
16		Ecuador	Quito	0.23 S	78.53 W	-	-	X	-
17		Fr. Guyana	Cayenne	5.00 N	52.00 W	-	X	-	X
18		Peru	Lima	12.08 S	77.86 W	-	X	X	X
19		St. Lucia		13.00 N	61.00 W	-	X	-	-
20		Uruguay	Porto Alegre	30.00 S	51.00 W	-	-	-	X
21	North America	Canada	Alert	83.03 N	60.00 W	-	X	X	X
22		Canada	Coral Harbour	64.13 N	83.17 W	-	-	X	X
23		Canada	Queen Elizabeth Is.	80.00 N	100.00 W	-	-	-	X
24		Canada	Goose Bay	53.25 N	60.33 W	-	-	X	-
25		Canada	St. John's	47.00 N	53.00 W	-	X	-	X[1]
26		Canada	Vancouver	49.25 N	123.17 W	-	X	X	X
27		Canada	Winnipeg	49.90 N	97.15 W	-	X	X	-
28		Canada	Yellowknife	62.45 N	114.48 W	-	X	X	-
29		Cuba	Sancti Spiritus	23.00 N	80.00 W	-	X	X	-

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[1] Indicates approximate position.

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+25]	US [100]	FR [75]
30		El Salvador	San Salvador	14.00 N	89.00 W	-	X	-	X[1]
31		Guadalupe	Pointe à Pitre	17.00 N	62.00 W	-	-	-	X
32		Mexico	Baja Calif.	28.00 N	113.00 W	-	X	-	X[1]
33		Mexico	Los Lavaderos	23.00 N	98.00 W	-	-	X	-
34		Mexico	Mexico City	19.00 N	99.00 W	-	X	-	-
35		Panama	Colon	9.37 N	79.90 W	-	X	X	-
36		USA	Ashland, KS	37.19 N	99.77 W	-	X	X	-
37		USA	Minneapolis, MN	45.00 N	94.00 W	-	-	-	X
38		USA	Dodgeville, WI	42.96 N	90.13 W	-	X	X	-
39		USA	Fairbanks, AL	66.00 N	148.00 W	-	X	X	X
40		USA	New York, NY	41.00 N	75.00 W	-	-	-	X
41		USA	King Hill, ID	43.25 N	115.20 W	-	X	X	-
42		USA	Mount Ida	34.55 N	93.57 W	X	-	-	-
43		USA	Sacramento, CA	38.00 N	122.00 W	-	X	X	X
44		USA	Virginia Beach, VA	36.85 N	76.98 W	-	X	X	-
45		USA	West Bay, FL	30.29 N	85.86 W	-	X	X	X
46	Antarctica	Antarctica	Dumont d'Urville	66.00 S	140.00 E	-	X	X	X
47		Antarctica	Mawson	67.00 S	64.00 E	X	-	X	X
48		Antarctica	Palmer	64.00 S	62.00 W	-	-	X	-
49		Antarctica	Halley	76.00 S	28.00 W	-	X	X	X
50		Antarctica	Queen Maud L.	85.00 S	160.00 W	-	X	-	-
51	Africa	Algeria	Reganne	27.00 N	0.00 W	-	X	-	-
52		Angola	Luanda	8.81 S	13.23 E	-	X	X	X
53		Burkina Faso	Ouagadougou	12.00 N	3.00 W	-	-	X	-
54		Cameroon	Yaounde	4.00 N	12.00 E	-	X	-	X[1]
55		C. African Rep.	Bangui	5.18 N	18.42 E	X	-	-	-
56		Djibouti	Djibouti	12.00 N	43.00 E	-	-	-	X
57		Egypt	Asyut	25.70 N	30.00 E	-	-	X	X[1]
58		Ethiopia	Filtu	5.50 N	42.70 E	-	-	X	-
59		Reunion	St. Denis	21.00 S	56.00 E	-	X	-	X
60		Kenya	Mombasa	4.00 S	40.00 E	-	-	-	X
61		Liberia	Greenville	5.50 N	9.00 W	-	X	X	-
62		Libya	Misratah	32.50 N	15.00 E	-	X	X	-
63		Madagascar	Mandabe	21.05 S	44.93 E	-	-	X	-
64		Mauritania	Nouakchott	18.00 N	17.00 W	-	X	X	-
65		Morocco	Safi	32.32 N	9.24 W	-	-	X	X[1]

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+25]	US [100]	FR [75]
66		Namibia	Okombahe	21.36 S	15.39 E	-	X	X	-
67		Niger	Bilma	18.00 N	17.00 E	-	X	X	-
68		Senegal	Dakar	15.00 N	18.00 W	-	-	-	X
69		South Africa	Boshof	28.61 S	25.42 E	X	-	-	-
70		South Africa	Bredasdorp	34.53 S	20.03 E	-	X	X	X[1]
71		Sudan	Al Lagowa	11.41 N	29.13 E	-	-	X	-
72		Sudan	Khartoum	13.00 N	32.00 E	-	X	-	-
73		Tanzania	Dar es Salaam	6.00 S	39.00 E	-	X	X	-
74		Chad	Faya Largeau	18.00 N	19.00 E	-	-	-	X
75		Zaire	Walikale	1.41 S	28.05 E	-	-	X	-
76		Zambia	Rufunsa	15.07 S	29.62 E	-	X	X	-
77		Cape verde		15.00 N	23.00 W	-	X	-	-
78	Europe	Austria	Vienna	48.00 N	13.00 E	-	X	-	-
79		Denmark	Kullorsuag, GL	75.00 N	57.00 W	-	-	X	-
80		Finland	Rovaniemi	67.00 N	26.00 E	-	X	-	-
81		France	Paris	49.00 N	2.00 E	-	-	-	X
82		Germany	Hamburg	54.00 N	10.00 E	-	X	-	-
83		Iceland	Reykjavik	64.40 N	21.90 W	-	X	X	X
84		Italy	Milano	45.42 N	9.18 E	-	X	X	-
85		Italy	Taranto	40.00 N	17.00 E	-	-	-	X
86		Norway	Hamar	61.04 N	11.22 E	X	-	-	-
87		Norway	Svalbard	78.00 N	15.00 E	-	X	-	X
88		Poland	Warsaw	52.00 N	21.00 E	-	-	-	X
89		Portugal	Vila do Porto	38.00 N	26.00 W	-	X	X	X
90		Russia	Bukhte	80.00 N	51.00 E	-	-	X	-
91		Russia	Moscow	56.00 N	37.00 E	-	X	X	-
92		Russia	Ufa	55.00 N	56.00 E	-	-	X	-
93		Russia	Verkhnyaya	66.40 N	48.50 E	-	-	X	-
94		Russia	Zachiversk	67.00 N	142.00 E	-	-	-	X
95		Sweden	Goteborg	58.00 N	12.00 E	-	X	-	-
96		Sweden	Umea	63.83 N	20.30 E	-	-	X	X
97		UK	Chilton	52.00 N	1.00 W	-	X	-	-
98		UK	London	51.50 N	0.00 E	-	-	X	-
99	Asia	U. Arab Emirates	Abu Dhabi	24.00 N	54.00 E	-	-	-	X
100		China	Beijing	40.00 N	116.00 E	-	-	-	X

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+ 25]	US [100]	FR [75]
101		China	Bobai	21.50 N	110.00 E	-	-	X	-
102		China	Comai	28.40 N	92.30 E	-	-	X	-
103		China	Guiyang	26.50 N	106.50 E	-	X	X	-
104		China	Hai Lar	49.27 N	119.74 E	X	-	-	-
105		China	Hotan	37.00 N	80.00 E	-	X	X	-
106		China	Ruoqiang	39.00 N	88.00 E	-	-	-	X
107		China	Urumchi	43.82 N	87.70 E	X	-	-	-
108		China	Yuncheng	35.00 N	111.00 E	-	-	X	-
109		India	Bombay	19.00 N	72.00 E	-	X	-	-
110		India	Gauribidanur	13.60 N	77.44 E	X	-	-	X
111		India	Kenniyakumari	8.00 N	77.00 E	-	-	X	-
112		India	Mayabandar	13.00 N	93.00 E	-	-	X	-
113		India	Mehekar	21.00 N	77.00 E	-	-	X	-
114		Indonesia	Jakarta	6.00 S	107.00 E	-	X	-	X[1]
115		Iran	Teheran	35.00 N	52.00 E	-	-	-	X
116		Japan	Aomori	40.83 N	140.80 E	-	-	X	-
117		Japan	Okinawa	26.31 N	127.31 E	-	X	X	-
118		Japan	Osaka	35.00 N	136.00 E	-	X	-	X[1]
119		Kazakhstan	Aktubinsk	50.43 N	58.02 E	X	-	-	-
120		Kazakhstan	Ganyushkino	46.50 N	51.00 E	-	-	X	-
121		Kiribati	Tarawa	2.00 N	173.00 E	-	X	-	-
122		Malaysia	Kuala Lumpur	3.00 N	102.00 E	-	-	-	X
123		Malaysia	Matoh	4.50 N	115.50 E	-	-	X	-
124		Mongolia	Tamch	46.00 N	94.00 E	-	-	X	-
125		Papua N. Guinea	Papua New Guinea	3.00 N	150.00 E	-	-	-	X
126		Pakistan	Karachi	25.00 N	66.00 E	-	X	-	X
127		Pakistan	Pari	33.65 N	73.25 E	X	-	-	-
128		Pakistan	Turbat	27.00 N	62.50 E	-	-	X	-
129		Philippines	Batangas	13.50 N	121.00 E	-	-	X	X[1]
130		Philippines	Tupi	6.00 N	125.00 E	-	-	X	-
131		Rep. of Korea	Wongu	37.45 N	127.92 E	X	-	-	-
132		Russia	Bratsk	57.00 N	101.00 E	-	-	X	-
133		Russia	Chukotsky	67.00 N	180.00 E	-	X	-	-
134		Russia	Irkutsk	52.00 N	104.00 E	-	-	-	X
135		Russia	Novosibirsk	55.00 N	82.00 E	-	X	X	-
136		Russia	Olekminsk	61.00 N	120.00 E	-	X	X	-

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+ 25]	US [100]	FR [75]
137		Russia	Peleduy	59.63 N	112.70 E	X	-	-	-
138		Russia	Petropavlovsk	53.00 N	158.00 E	-	X	X	X
139		Russia	Sibirskiy	61.00 N	68.00 E	-	-	X	-
140		Russia	Syndassko	73.00 N	107.00 E	-	-	X	X
141		Russia	Ussuriysk	44.00 N	132.00 E	-	X	X	-
142		Russia	Yekaterinburg	56.00 N	61.00 E	-	-	-	X
143		Russia	Zvezdnyy	71.00 N	180.00 E	-	-	X	X
144		Saudi Arabia	Riyadh	24.50 N	47.00 E	-	X	X	-
145		Sri Lanka	Colombo	7.00 N	80.00 E	-	X	-	-
146		Thailand	Bangkok	15.00 N	101.00 E	-	X	-	-
147		Turkey	Cakmak	39.20 N	32.40 E	-	X	X	-
148		Turkmenistan	Alibek	36.31 N	59.29 E	X	-	-	-
149		Uzbekistan	Tashkent	42.00 N	69.00 E	-	-	-	X
150		Vietnam	Hanoi	21.00 N	105.00 E	-	-	-	X
151	Australia	Australia	Alice Springs	24.00 S	134.00 E	-	X	-	-
152		Australia	Brisbane	27.00 S	153.00 E	-	X	X	-
153		Australia	Darwin	12.00 S	131.00 E	-	X	X	-
154		Australia	Melbourne	34.00 S	145.00 E	-	X	X	X
155		Australia	Perth	33.00 S	115.00 E	-	X	X	X
156		Australia	Port Hedland	20.00 S	118.00 E	-	-	-	X
157		Australia	Townsville	19.00 S	147.00 E	-	-	-	X
158		Australia	Yerdonic Roch	31.19 S	120.63 E	X	-	-	-
159	New Zealand	New Zealand	Auckland	32.00 S	175.00 E	-	X	-	X
160		New Zealand	Chatham Is.	44.00 S	176.00 W	-	X	X	-
161		New Zealand	Hokitika	42.72 S	170.97 E	-	X	X	-
162		New Zealand	Rarotonga	21.25 S	159.75 W	-	X	-	-
163	Oceans	Cocos Is.		12.00 S	97.00 E	-	-	X	-
164		MacQuane Is.		54.00 S	159.00 E	-	X	X	-
165		Bermuda		32.30 N	64.75 W	-	X	X	-
166		Diego Garcia		7.00 S	72.00 E	-	-	X	X
167		Easter Is.		25.00 S	106.00 W	X	X	X	X'
168		Galapagos		1.00 S	91.00 W	-	X	-	-
169		Fiji	Suva	18.00 S	177.50 E	X	X	X	-
170		Ile Amsterdam		38.00 S	78.00 E	-	X	-	-
171		Marquesas Is.		9.00 S	140.00 W	-	X	-	-
172		Pr. Edward Is.		46.00 S	38.00 E	-	X	-	-

	Region	Country	Location	Lat.	Long.	RF [20]	CAN [75+ 25]	US [100]	FR [75]
173		Western Samoa		13.00 S	172.00 W	-	X	-	-
174		Wallis		15.00 S	177.00 W	-	-	-	X
175		Guam	Barrigada	13.50 N	145.75 W	-	X	X	-
176		Kerguelen Is.	Port-aux-France	49.00 S	70.00 E	-	X	X	X
177		Marion Is.	Marion Is.	46.50 S	37.00 E	X	-	-	-
178		Philippines	Cebu	11.00 N	124.00 E	-	X	-	-
179		S. Georgia Is.		54.00 S	37.00 E	-	-	X	X
180		St. Helena Is.		16.00 S	6.00 W	-	X	X	X
181		Tahiti	Papeete	17.00 S	150.00 W	-	X	-	X
182		Tristan da Cunha	Edinburgh	37.00 S	12.33 W	-	-	X	X
183		Ascension Is.		8.00 S	15.00 W	-	X	-	-
184		Falkland Is.		52.00 S	60.00 W	X	X	-	-
185		Christmas Is.		2.00 N	157.00 W	-	X	-	-
186		Hawaian Is.	Honolulu	22.00 N	157.00 W	-	X[1]	X	X[1]
187		Wake Is.		19.30 N	166.60 E	X	-	X	-
188		Marshall Is.		12.00 N	165.00 E	-	-	-	X

PART III: HYDROACOUSTIC MONITORING

Executive Summary

The hydroacoustic monitoring system is capable of detecting underwater and sub-oceanic events and provides a unique discrimination capability for these events (to distinguish between explosions and sub-oceanic earthquakes), even below the seismic threshold. Additionally, the hydroacoustic system may detect some explosions in the low atmosphere that neither the seismic nor the infrasound systems detect. Further, the hydroacoustic system can provide independent location of events if they are detected by a minimum of three stations.

There is outstanding synergy with the seismic technique, with the amount and nature of the synergy dependent upon the number of hydroacoustic stations and their positions. Even a minimal hydroacoustic network can discriminate between underwater explosions and sub-oceanic earthquakes that are detected and located by the seismic network. Joint infrasound/ hydroacoustic observations may distinguish between atmospheric and underwater explosions and may provide a location capability when the seismic network fails to detect explosions in the lower atmosphere.

Three options for a hydroacoustic system capability are proposed:

Option one provides detection, discrimination and good location capability over the world's ocean basins. This option provides an independent hydroacoustic capability worldwide, using 2 MILS stations and 19 autonomous moored buoys. It is estimated to cost $8.5 million initially and $6.9 million annually. According to one expert, this option would cost $7.7 million initially and $2.6 million annually.

Option two provides detection and discrimination over most of the world's oceans, with good location capability in the Southern Hemisphere. This option provides an independent hydroacoustic capability in the Southern Hemisphere, relying upon synergy with the seismic and infrasound networks in the Northern Hemisphere to reduce costs. It consists of the 2 MILS stations and 8 new fixed cable stations. The initial costs of this option are estimated to be $35 million with an annual cost of $0.5 million.

Option three provides detection and discrimination over most of the world's broad ocean areas with minimum location capability in the Southern Hemisphere. This network is completely dependent on synergy with the seismic and infrasound networks for location. This measure reduces costs beyond option two, but does not provide for adequate location of explosions in the lower atmosphere. The network consists of the 2 MILS stations and 4 new fixed cable stations. The initial costs of this option are estimated to be $22 million with an annual cost of $0.25 million.

The hydroacoustic stations proposed in this paper will be incapable of tracking submarines. Such a capability is precluded by a number of design features, many of which would suffice completely on their own.

There are two principal station types: autonomous moored buoy and fixed cable. The autonomous moored buoy station has the advantage of lower initial cost, but the major disadvantage of poor survivability (reliability). The fixed cable station has the advantage of high survivability (reliability), but the disadvantage of high initial cost. Due to the low maintenance costs of fixed cable stations, it appears that over a 10 to 20-year period, they may become more cost effective.

The option I network is comprised primarily of autonomous moored buoys, whereas the option II and III networks are comprised entirely of fixed cable stations. However, depending upon local conditions, cost reduction potential and the results of further research, any of the options could be reconfigured to use a mixture of autonomous moored buoys, fixed cable stations, and coastal or island seismic stations.

In both cases, the cost figures in this document are better estimates than those included in CD/NTB/WP.172. **However, the final cost determinations for either type of station should be the subject of future work.**

Introduction

The primary criteria used to evaluate the hydroacoustic networks under consideration are their capabilities for detection, discrimination and location of nuclear explosions in the world's oceans. All the networks considered in this paper can readily detect signals generated by explosions and also discriminate explosions from naturally occurring events. These networks differ primarily in their ability to locate events. This ability is important for situations where other techniques are unable to detect or locate well, such as some explosions in parts of the southern oceans. A hydroacoustic system cannot differentiate between nuclear and conventional explosions.

A hydroacoustic signal is a sound wave that propagates through the ocean, similar to the seismic P wave that propagates through the body of the earth. The loss of signal intensity is much smaller during propagation through the ocean than through the interior of the earth for two reasons:

- the rate of absorption of sound energy in sea water is very low
- the ocean has a layer of low sound speed, called the SOFAR channel (SOFAR is an acronym for <u>So</u>und <u>F</u>ixing <u>A</u>nd <u>R</u>anging) which acts as a waveguide: the sound energy propagates horizontally in the waveguide, instead of propagating downward to the sea floor where bottom interaction causes significant sound attenuation. The waveguide nature of propagation limits the geometrical spreading attenuation of the sound wave, so that the effect of spreading increases only linearly with distance, instead of as the square of distance (as with seismic body waves). The axis of the SOFAR channel occurs at depths near 1 km in equatorial and mid-latitude waters and becomes progressively shallower at high latitudes, reaching the surface in polar regions.

Due to the small loss of signal energy, a hydroacoustic sensor, called a hydrophone, can detect the signal from a nuclear explosion across an entire ocean basin. Due to the properties of the hydroacoustic signals generated by explosions, it is also possible to discriminate explosions reliably from naturally occurring events. If at least three hydroacoustic stations observe the same event, it is possible to locate the position of the event with an accuracy comparable to seismic systems but without the limitations for low-yield events that occur with seismic networks.

Hydroacoustic systems can detect all oceanic events that can be detected by seismic systems, and can provide discrimination of these events, even below the seismic system's discrimination threshold. Further, for shallow explosions or explosions at the surface of the ocean, the hydroacoustic systems will frequently be the only system capable of detecting and providing accurate locations over broad ocean areas, allowing for the possibility of on-site sampling for positive identification of these events as nuclear or non-nuclear.

Some reservations have been expressed about the possibility of hydroacoustic stations being a threat to national maritime security, in particular in regard to the ability to track submarines. *No station being proposed here will have that capability.* In fact, that capability is precluded by multiple design characteristics, many of which would eliminate that capability on their own. The important characteristics are:

- Without multiple closely-spaced sensors and array signal processing, the sensitivity of the proposed stations is insufficient for tracking.
- All stations in the proposed options will have known locations.
- Site selection can be chosen to avoid proximity to any sensitive site (e.g. Naval bases).
- The hydrophones in the MILS stations proposed for use in all options are of sufficient separation (tens of kilometres) to preclude the beam-forming that is essential for tracking submarines.
- Low sampling rates on the data could preclude processing to detect submarines.

Synergy with Other Technologies

Outstanding synergy between the hydroacoustic and seismic networks can be achieved with the appropriate mix of stations. For a summary, see Tables 1 and 2. Since the hydroacoustic method has a much lower detection threshold for oceanic events, this synergistic effect is primarily dependent upon the seismic detection threshold. The seismic technique can provide detection but not high confidence location and discrimination of fully-contained oceanic events near the seismic threshold. The hydroacoustic network can complement the seismic network by providing high confidence discrimination between underwater explosions and sub-oceanic earthquakes. Additionally, an appropriate number of hydroacoustic stations can provide improved location capability.

Furthermore, for events with magnitudes below the seismic detection threshold, such as vented or low altitude explosions, the hydroacoustic network may be the critical IMS component for detection, location and discrimination between sub-oceanic earthquakes and explosions. The infrasound network may serve in the detection function for events in the low atmosphere, but infrasound coverage is lacking in certain parts of the broad-ocean areas. Again, see Tables 1 and 2. More work is required to establish the relative capabilities of infrasound and hydroacoustic systems, but the greater stability and predictability of the ocean acoustic channel may mean that locations derived from hydroacoustic observations will be more accurate.

The kinds of synergy possible between the seismic, hydroacoustic and infrasound networks fall into two categories.

For events detected by the seismic network of the IMS, these results may be achievable:

- seismic detection and location of oceanic events, and hydroacoustic discrimination between underwater explosions and sub-oceanic earthquakes;
- joint seismic/hydroacoustic detection and location, and hydroacoustic discrimination between underwater explosions and sub-oceanic earthquakes; and
- dispatch of radionuclide sampling assets to hydroacoustic/seismic event locations to distinguish nuclear from chemical explosions.

For events detected by the hydroacoustic network, but not by the seismic network, these results may be achievable:

- hydroacoustic detection and location of oceanic events (including vented explosions and explosions in the lower atmosphere);
- joint infrasound/hydroacoustic detection, location and limited discrimination where infrasound coverage extends;
- hydroacoustic discrimination between underwater explosions and sub-oceanic earthquakes; and
- dispatch of radionuclide sampling assets to hydroacoustic or hydroacoustic/infrasound event locations for distinguishing nuclear from chemical explosions.

Some Synergies of the Hydroacoustic Technique with Seismic and Infrasonic Techniques for One Kiloton Explosions

Table 1: Open Areas of the N. Atlantic and N. Pacific

		Criterion	Seismic	Infrasonic	Hydro Option I	Hydro Option II	Hydro Option III
Under-water	Fully Contained	Location	●	○	●	○	○
		Discrimination	◒	○	●	●	●
	Near Surface	Location	●	○	●	○	○
		Discrimination	◒	○	●	●	●
Atmo-spheric	Near Surface	Location	○	◒	●	○	○
		Discrimination	○	●	●*	●*	●*

Areas needing Synergy

Areas of Critical Function

● - Full Capacity
◒ - Partial Capacity
○ - No Capability
●* - Based on theoretical results; not yet operationally tested.

Note: Discrimination refers to distinguishing between earthquakes and explosions; none of these techniques can identify an explosion as nuclear.

Some Synergies of the Hydroacoustic Technique with Seismic and Infrasonic Techniques for One Kiloton Explosions

Table 2: Open Areas of the Southern Hemisphere Oceans

		Criterion	Seismic	Infrasonic	Hydro Option I	Hydro Option II	Hydro Option III
Under-water	Fully Contained	Location	●	○	●	●	◒
		Discrimination	◒	○	●	●	●
	Near Surface	Location	◒	○	●	●	◒
		Discrimination	○	○	●	●	●
Atmo-spheric	Near Surface	Location	○	◒	●	●	○
		Discrimination	○	◒	●*	●*	●*

Areas needing Synergy

Areas of Critical Function

- ● - Full Capability
- ◒ - Partial Capability
- ○ - No Capability
- ●* - Based on theoretical results; not yet operationally tested.

Note: Discrimination refers to distinguishing between earthquakes and explosions; none of these techniques can identify an explosion as nuclear.

Types of Stations

Station specifications fall into two categories: instrument specifications, which define the hydroacoustic characteristics of the system, and platform specifications, which define the station type (i.e. mechanical configuration). The hydroacoustic characteristics are designed to match the expected signal characteristics, and, consequently, are independent of the choice of platform.

Instrumentation

General Remarks

The propagation of hydroacoustic signals across entire ocean basins at extremely low loss enables simple and robust receiving systems. There are no particular requirements of sensitivity and self noise for the stations of the CTBT hydroacoustic monitoring network, because the signal received from nuclear explosions is far larger than both ambient noise and system noise even for yields in the sub-kiloton regime and at ranges exceeding 5,000 kilometres.

Furthermore, there are no particular sensor geometry requirements. The following discussion and recommendations should be interpreted as general guidelines and should not limit future technical solutions. For the purpose of CTBT ocean monitoring, hydrophones of spherical shape should be chosen, which are omnidirectional by virtue of their geometry. Modern hydroacoustic sensors consist of robust ceramics, usually of lead zirconate. The aging of this material is negligible over twenty years in terms of the sensitivity. The hydrophone ceramics can withstand the high static pressures of the deep ocean. These are higher than the peak pressure from a 1 kiloton nuclear explosion in water at a distance of less than 200 metres. Ceramic hydrophones have no mechanical parts and are directly coupled to the water; the rubber coating is fully transparent for hydroacoustic signals.

The decoupling of the hydrophone from the suspension cable against flow induced vibrations (cable strum) is the only mechanical requirement that should be met, since these vibrations occur around 10 Hz.

The hydrophone should be positioned at the SOFAR channel axis depth, but an accuracy of 10 metres is sufficient because the sound speed minimum is broad. The horizontal position accuracy requirement is also very modest because the hydrophone is a stand alone unit, and not part of an array which would require high precision positioning. The GPS location precision of about 30 metres is sufficient because the motion of the suspension cable of the hydrophone due to ocean currents can be more than 100 metres. The restriction to single hydrophones is one design feature that excludes abuse of the stations to detect and track vessels of military interest.

To check the hydroacoustic function of the station, it is highly recommended to transmit 10 seconds of the received ambient noise to the IDC on a daily basis. The restriction of the noise transmission to only 10 seconds by itself excludes any possibility of tracking vessels of military interest. System state of health data should be transmitted along with the hydroacoustic data sample.

One of the most stringent requirements is the accuracy of the time signal, which must be referenced to GMT. A maximum deviation of 10 milliseconds makes access to an international time standard mandatory. Access is achieved by satellite for the autonomous moored buoy stations, and by telephone line or satellite for the fixed cable stations. A time stamp, as well as the station code, must be included in the data protocol for either data transmission or storage at the station.

Since the requirements to be met by the essential parts of the instrumentation are considered the general standard, it is not necessary to define a standard station, comprising blueprints of all the technical details including the electronic specifications, or to specify particular equipment manufacturers. It is sufficient that the listed system specifications be used as goals. However, alternate design solutions may be acceptable, on a case-by-case basis.

The technical institutions responsible for the operation of the stations entrusted to them should be given the freedom and flexibility to find appropriate technical solutions to implement the technical specifications. This freedom of action may be necessary to respond to local logistical, deployment or procurement constraints.

Recommended Technical Characteristics

The characteristics of the hydrophone, amplification, signal conditioning, recording and data transmission (communication) elements of the system are specified below, following where applicable the *station requirements for an International Seismic Monitoring System (ISMS) standard station* of the seismic network.

	Category	Requirement
1	Pass Band	5 - 100[2] Hz, with steep high pass rolloff at 5 Hz
2	Hydrophone Noise	Irrelevant because of very high signal/noise ratio
3	Calibration	Within 1 dB; no phase requirements
4	Sampling Rate	200 samples per second
5	Resolution	16 bits with 6 gain ranging steps of 12 dB
6	Sensitivity	To avoid saturation, the level of 1 volt shall correspond to the peak pressure level of 244 dB re 1 microPascal (the anticipated peak pressure at 10 km for a 10 kt explosion fully coupled). The sensitivity shall correspond to ambient noise at the highest gain (94 dB rms wideband noise level 0 - 100 Hz).
7	System Noise	Irrelevant as in 2.
8	Dynamic Range	The dynamic range of the recording system shall be 150 dB with gain ranging specified as in 5.
9	Linearity	Not applicable; the peak pressure for a 1 kt yield at 200 m distance is well below the static pressure at channel depth
10	Timing Accuracy	10 milliseconds, to be updated by GPS clock
11	Operating Temperature	For underwater units, including deployment phase: 0 to 30 degrees C. For land based units, -60 to +50 degrees C.
12	Authentication	Required
13	State of Health	As required
14	Protocol	TCP/IP (beta or optionally alpha)
15	Delay of Transmission	
16	Data Frame Length	As required
17	Data Access	Real time for incoming data; priority to be given to the IDC, then NDCs
18	Data Buffer	12 days, corresponding to about 500 Mbytes (16 + 4 bit recording)

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[2] Experts from two States propose that the frequency range should be 5-50 Hz.

19	Data Availability	Bit error rate to be specified
20	Timely Data Availability	Same as 19
21	Station Location	Routine check of autonomous buoys by GPS, daily within 100 metres.
22	Shock Pressure Tests	50 bar, rise time 0.1 millisecond.
23	Discrimination Criteria for Signals from Explosions and Features of Relevance	- threshold setting: to be defined - rise time: to be defined - peak level - total energy of received signal - peak structure: to be defined - bubble pulse time delay: by autocorrelation - spectrum of signal: 100 samples between 5 and 100 Hz, where applicable.
24	Maritime Security Provisions	- ambient acoustic noise sample transmitted daily limited to one ten-second interval - one active hydrophone (spares permitted within 1 meter); no array processing possible - smallest resolvable signal level: 92 dB wideband rms re 1 microPascal

Platforms

Two platforms are under consideration, both of which suspend the omnidirectional hydrophone at the depth of the SOFAR channel axis. The platforms use a bottom anchor, mooring cable and buoyancy elements for that purpose. The first type is *autonomous* with power supplied by a battery. The second type depends on a *cable connection* to shore for power supply and data transmission.

Autonomous Moored Buoy Stations

Autonomous moored buoy stations, which are moored to the sea floor, need a surface element with an antenna for satellite communication. These moored buoys enjoy the advantage that they can be placed anywhere in the broad oceans to optimize the network configuration to achieve the best location accuracy. Energy limitations imply that the data transmission must be triggered by events rather than continuous.

The surface element and its mooring connection are vulnerable to high sea states and high winds can break the mooring line or damage the buoy at the surface. The expected lifetime of currently-deployed buoy systems rarely exceeds one year. Longer lifetimes may be achievable with further development. In addition, moored buoys are vulnerable to intentional or unintended damage by passing vessels; for example, they may be snagged by nets spread from fishing vessels.

Despite the short projected lifetimes of moored buoy stations, their advantage of mobility and relative ease of deployment suggests several roles in a monitoring system. First, there may be circumstances where, for reasons of network optimization, it may be necessary to place permanent stations in positions far from land. Such station positions may be required to improve event detection and location capability. In such cases, cabled stations are impractical. Second, it may be necessary to test several candidate station positions during the initial network deployment; again, in order to optimize network performance. Movable moored buoys may be used to assess candidate positions sequentially. Fixed cable systems are not suitable for this purpose, since they cannot be moved economically. Finally, the time required to procure and mobilize resources to replace a damaged cabled station may be long. If the IDC cannot tolerate the resulting loss of coverage, a moored buoy station could temporarily serve in its place. This option is especially appealing if critical components of the moored buoy station are light enough to be transported by air to a nearby port.

Fixed Cable Stations

Cabled stations may consist of single hydrophones anchored to the sea floor, with a cable to a nearby land station for data and power transmission. One or more backup hydrophones may be provided to insure against primary hydrophone failure.

Cabled stations enjoy lifetime, power and communication advantages. Lifetimes are greater than moored buoy stations because there are no surface components to be battered by wind and waves. Power and communication services are available on land through the shore cable; consequently continuous data transmission is a possibility with these stations. Nonetheless, the remote location of some deployment sites may make satellite transmission necessary. In this event, the fact that the communication subsystem is on land simplifies satellite transmission since power should be available and large antennas are practical. The use of geosynchronous satellites may be practical.

The geographical location of cabled stations is limited by the availability of islands and appropriate continental sites. If deployed from an island, two cables may be required on opposite sides of the island to ensure unblocked reception from all directions. Cables are vulnerable to anchors dragging from surface vessels (particularly fishing vessels). If deployed in areas with heavy fishing traffic, the cables may be buried in shallow sea floor trenches to prevent anchor drags (at a significantly increased deployment cost). Sites may be selected to avoid high-traffic areas; indeed, high-latitude southern ocean locations are remote and may satisfy this condition.

Reliability

The current reliability of moored buoy stations is considered to be low beyond one year of operation. The principal point of failure is the connection between the surface buoy and the mooring line, which is subjected to constant repetitive stress by the actions of waves, currents and wind. These stresses are, of course, most pronounced during storms. The frequency of storms has a major impact on buoy life; buoys moored at mid- and high latitudes in the Southern Hemisphere will be subjected to more storms than those at most other locations. Another consideration is the impact of ice at high latitudes, which may disrupt buoy operation.

A type of moored buoy that may be most useful is the spar buoy. Spar buoys may maximize the lifetime of the connection, and should be investigated as a possible means of increasing overall service lifetime. Spar buoys are long, narrow buoys which have only slightly positive buoyancy. They project just above the surface to support an antenna for communication, but extend far below the surface. They can be designed to have their centre of mass at depths below the largest water motion caused by waves. The amplitude of vertical spar buoy motion is much lower than that of surface (wave-following) buoys.

Cabled stations are considered to be the most reliable option for long-term hydroacoustic monitoring, mainly because there are no parts exposed to the surface of the ocean. Examples of cabled station operation in excess of 20 years with little or no maintenance are known. The principal threat to cabled stations are two: destruction of the cables at the land-sea interface, and cable breakage when the cables are snagged by anchors dragging behind surface vessels or by fishing apparatus. The solutions to these problems are to choose armoured cables for deployment on the continental shelf locations where surface vessels are a problem and, in the surf zone, to bury the cables. Alternatively, the cable can be threaded through pipe for protection in the surf zone. All solutions raise the initial cost of the system, but these costs are likely to be offset by reduced maintenance and repair throughout the lifetime of the network.

Communication reliability is likely to be much higher with cabled stations. The antenna is mounted on land, and not subjected to possible immersion and the corrosive action of salt water. Interruption or depletion of the power supply is less likely with cabled stations, since power may be obtained from a local grid or from a dedicated generator. Both platforms may suffer from vandalism. However, due to the remote locations, it is unlikely to be a serious problem. It is likely to be easier to protect a land-based installation than a remote buoy.

Network Designs Required to Achieve Desired Coverage

The design of the hydroacoustic network and the number of stations required depends on the type of coverage desired. Although several options have been proposed, the number of options has been reduced to three. All three options make use of the location capability of the seismic and infrasound networks in varying degrees to limit the geographic distribution of the hydroacoustic stations. Final determination of station locations and, in one case, the total number of stations will depend on the results of detailed site evaluations and optimization studies.

In the following option definitions, discrimination refers to having sufficient information to determine whether a detected event is an explosion. Location refers to having sufficient information to determine the position of a detected event. The following descriptions of coverage for discrimination and location apply to all events below the water surface. It is appropriate to note here that, in regions where the hydroacoustic technique can locate underwater events, it is also possible to detect, locate and perhaps to discriminate nuclear explosions with yields of one kiloton occurring within 100 metres above the ocean surface. This capability provides a possible complement to the infrasonic technique.

Option I: Complete coverage for detection, discrimination and location in the Southern and Northern Hemispheres, with detection and discrimination coverage in the Arctic basin. This design option may be implemented with 21 stations (2 MILS stations + 19 moored buoys).

The design of the Option I network is intended to provide complete hydroacoustic coverage of the world as a technique independent of the other monitoring techniques. As such, its primary synergy with the seismic system is for events in the Arctic Ocean. The network consists of the 2 MILS arrays and 19 autonomous moored buoys distributed throughout the world's oceans. This network has the capability to monitor underwater explosions in the open ocean areas of the world and explosions in the low atmosphere occurring within 100 metres of the ocean surface (except for the Arctic basin, where the network can still discriminate events, but must rely on the seismic technique for location).

Option II: Complete coverage for detection, discrimination and location in the Southern Hemisphere, and partial detection and discrimination coverage in the Northern Hemisphere (no coverage in the Arctic basin). This option requires a minimum of 10 stations (2 MILS + 8 new cabled systems), although detailed optimization studies may result in an increase to 11 stations.

The design of the Option II network is guided by the principle that each major ocean basin in the Southern Hemisphere have a redundant set of stations to permit location under normal conditions and when one station is inoperative. In the northern oceans where seismic detection and location capability is good for one kiloton underwater explosions, only one detection at a hydroacoustic station is needed in order to discriminate events (in the Arctic, seismic capability should be adequate without any hydroacoustic participation). In the Southern Hemisphere, three stations are required to provide a minimal triangular sub-network allowing location; a fourth station is recommended to provide redundant coverage. Thus, with three major ocean basins to be covered (the south Pacific, the south Atlantic, and the Indian Ocean), twelve stations nominally are required to implement this design philosophy. Because a gap exists between the southern tip of Africa and Antarctica, it may be possible for the south Atlantic and Indian Ocean sub-networks to share one or two stations. In consequence, a minimum network of ten stations may be adequate to implement the design philosophy.

Option III: Complete coverage for detection and discrimination plus joint seismic and hydroacoustic event location in the Southern Hemisphere, and partial detection and discrimination coverage in the Northern Hemisphere (no coverage in the Arctic basin). This option requires a minimum of 6 stations (2 MILS + 4 new cabled systems).

The design of the Option III network is guided by the principle of reducing the number of hydroacoustic stations required by relying on synergy with the seismic system and reducing the capability of the hydroacoustic system to monitor explosions in the low atmosphere. If the hydroacoustic network is only required to monitor underwater explosions, signals at only one or two hydroacoustic stations are needed for coverage, because the seismic system can supply some location information. As discussed above for Option II, in the Northern Hemisphere (apart from the Arctic basin), one detection at a hydroacoustic station is needed in order to discriminate events. Seismic and infrasound stations are assumed to cover the Arctic basin for detection. In the southern oceans, detection by two hydroacoustic stations should also be adequate for location of underwater explosions when the IMS hydroacoustic data are combined with primary seismic station data. The resulting requirement is for two hydroacoustic stations of high reliability in each major southern ocean basin, resulting in a network of 6 fixed cable systems. Such a hydroacoustic network would have no capability to locate explosions in the low atmosphere occurring within 100 metres of the ocean surface, but should detect and may be able to discriminate such events. Synergy with infrasound might also allow some joint location capability.

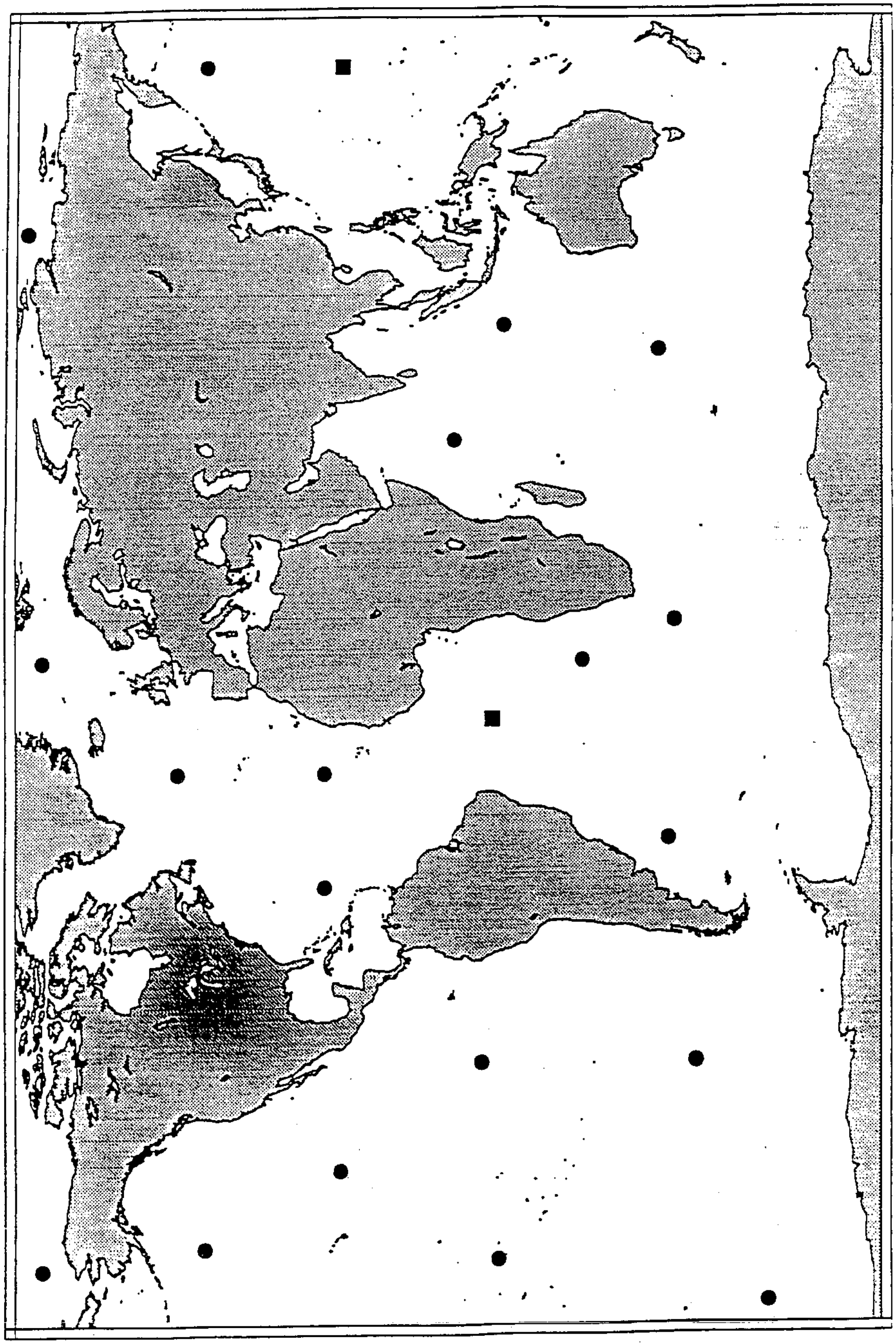
On a case by case basis, it may be possible to substitute seismic stations located on islands or on the coasts of continents for hydroacoustic stations in network Options I or II. The key requirement placed on such seismic stations is that they be able to detect the T phase (the underwater acoustic wave converted to a seismic wave at the edge of a land mass). The principal use of this substitution scheme would be to reduce the cost of monitoring ocean regions; seismic stations are generally less expensive than hydroacoustic stations. The seismic stations would be used primarily to supplement the hydroacoustic stations for the location function. This cost-saving approach will require a significant future research effort to validate its utility.

Geographic Locations

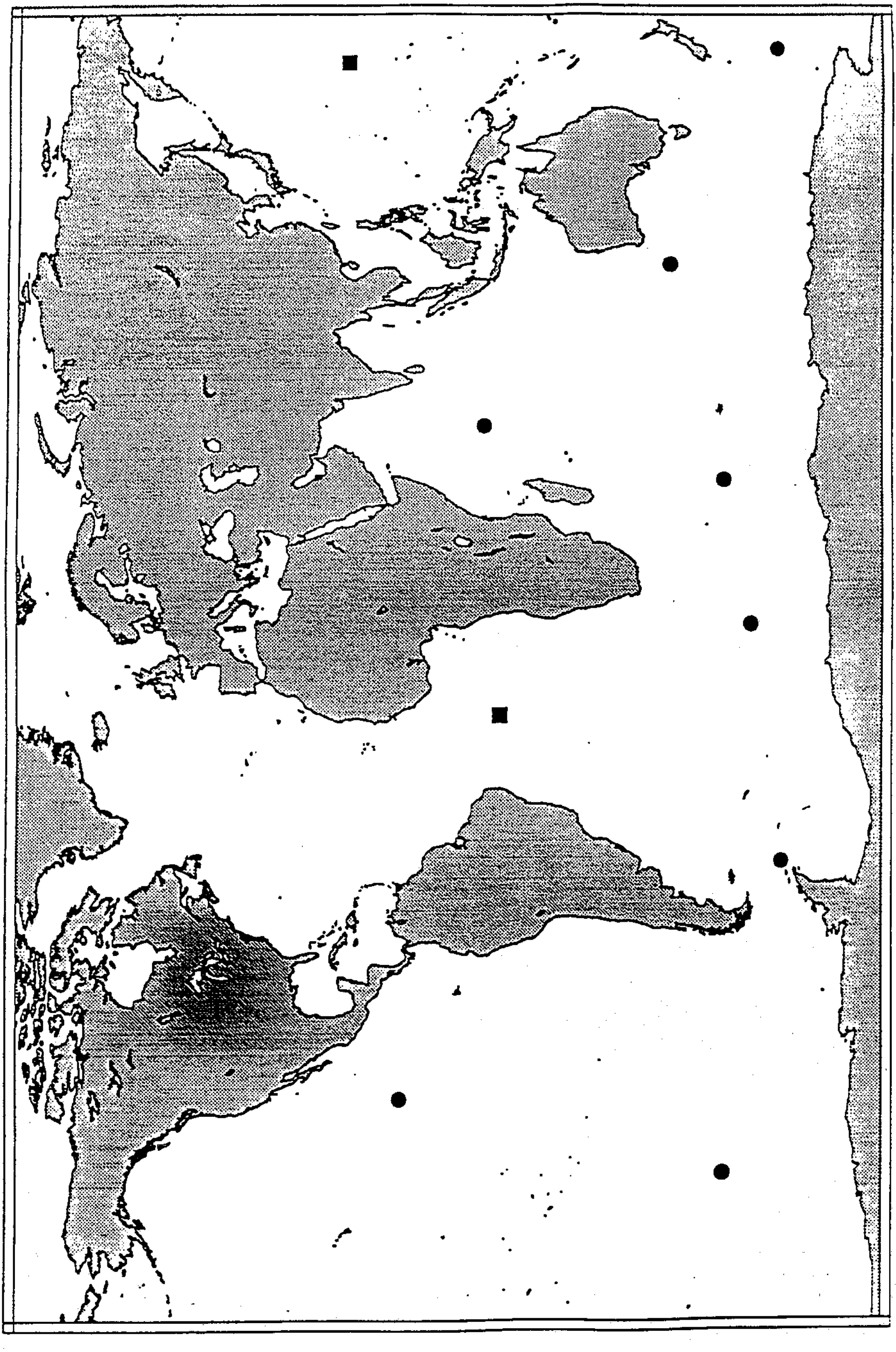
Figure 1: Suggested Hydroacoustic Station Locations for Option 1

Figure 2: Notional Hydroacoustic Station Locations for Option 2

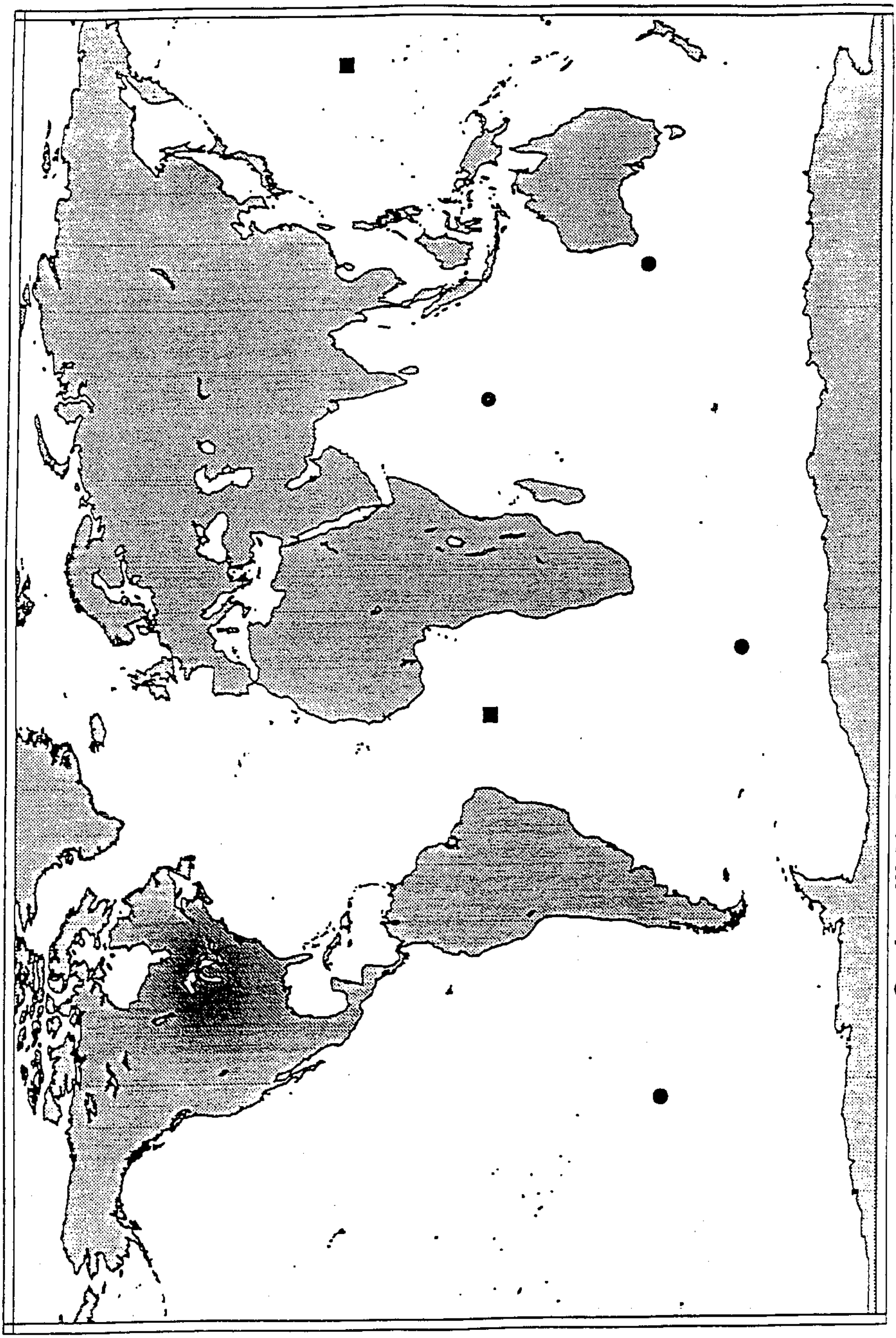
Figure 3: Notional Hydroacoustic Station Locations for Option 3



Option I Suggested Hydroacoustic Network



Option II Notional Hydroacoustic Network



Option III Notional Hydroacoustic Network

Expected Network Performance

The hydroacoustic network can complement the seismic network by providing high confidence discrimination of underwater explosions and sub-oceanic earthquakes based on the presence or absence of bubble pulses. Explosions in the low atmosphere may be discriminated from sub-oceanic earthquakes by using the short rise times and duration of transient signals associated with explosions. It can also provide an excellent trigger for the deployment of On-Site Inspection (OSI) sampling assets to distinguish between oceanic nuclear and chemical explosions. Additionally, the hydroacoustic network provides detection, location and discrimination of underwater explosions near the surface and explosions in the low atmosphere over the oceans that are not detectable by the seismic network.

The accuracy of the network event location is governed by two effects. The first is the unpredictable variability of the sound speed structure along the sound propagation path. These variations appear as small deviations from the long-term averages derived from global sound speed maps of the SOFAR channel. The resulting uncertainty of the travel time and therefore the error of the determination of the event distance amounts to a few tenths of a percent. The travel time dispersion of the received signal due to the unresolvable multipath structure contributes an error of the same order of magnitude as the first effect. The combined error of both effects may range up to one percent. For example, location errors up to 50 kilometres are possible in a network spanning 5,000 kilometres.

We consider it possible to reduce this error significantly by relocating each event relative to one or more test charges of 10 to 100 kilogram TNT dropped by aircraft at the initial event location estimated by the hydroacoustic network.

Data Processing and Data Flow Requirements

Digital data can be automatically telemetered from the hydroacoustic stations to the International Data Centre (IDC), either directly or through National Data Centres (NDC) operated by States Parties. Data can be transmitted on a segmented basis or, if deemed appropriate, on a continuous basis (possible only for fixed cable stations). The data should be checked for quality and authenticity, and placed in a long-term archive. The data would undergo automated detection processing to reduce the data to a series of detected signals and associated parameters. Then automated location processing would use models of the ocean acoustic channel to estimate the location of the detected events. The IMS detection and location capability would be improved beyond that available from analysis of just hydroacoustic data by fusing or correlating the hydroacoustic data with data from other IMS technologies.

The analysis of hydroacoustic data should include automated signal detection to generate a detection list, frequency analysis to identify a bubble pulse and to determine the primary signal bandwidth, characterization of the rise time of the primary signal, and a location algorithm.

Estimated Costs

Autonomous Moored Buoy Stations

The costs of autonomous moored buoy stations are dominated by two factors: the lifetime of the surface unit and the ship time required to maintain and replace buoys.

Currently, autonomous moored buoy stations will not survive much more than one year. A two-year lifetime may be achieved with further development. Approximately 1/3 of the stations are assumed to be lost within the one or two-year lifetime. Because of their short life expectancy, and the low maintenance cost associated with fixed cable stations, fixed cable stations may become more cost effective over a 10 to 20-year period.

The maintenance costs for the autonomous stations assume battery replacement every year or, alternatively, every second year, depending on whether the buoy maintenance cycle is assumed to be one year or two years.

The cost of ship time to service each station every one or two years is the principal component of long-term cumulative cost. However, professional ship service might be available free or at low cost by research vessels making regular voyages to supply research sites (for example, in Antarctica), if mandated by the States Parties owning the vessels.

Fixed Cable Stations

The costs of the *cabled systems* are dominated by the costs of the cable connection between an anchored receiving unit on the sea floor and the land station. Cable laying requires careful inspection of the selected site before deployment. Local conditions that may require burial of the cable vary greatly. Further, the costs depend on the number of stations which are serviced by one cable-laying vessel on a single mission. Maintaining multiple stations on one mission reduces the vessel's transit time, thus reducing cost.

When a cabled system is to be operated from an island, it is necessary to deploy *two* underwater sensor units on opposite sides of the island to avoid blind sectors and provide full coverage. Only when such an island is near a continental shore might it be treated as a coastal projection where one underwater sensor unit is sufficient.

It is desirable to solicit bids from cable manufacturers, cable laying companies, and ship owners to take advantage of local price advantages. The technical crew and necessary material for cable installation could travel independently of any ship from one region to another, using ships-of-opportunity for actual deployment of the hydrophones. The cost reduction from this approach is very difficult to estimate and, in fact, can not be standardized. However, we have assumed that a 30 per cent reduction in cost may be achievable in our calculations below.

It is further assumed that only one of 10 or 11 fixed cable stations will have a serious defect within a 20-year time period requiring replacement of the complete underwater hydroacoustic unit and the connecting cable. This cost is pro-rated on an annual basis.

For option one: there were two opinions regarding the assumptions to be used for calculating network costs. One expert believes that autonomous moored buoy stations can be designed to have a two-year lifetime, and that inexpensive ships can be used for deployment and maintenance. The remaining experts believe that a more realistic lifetime is one year, and that more expensive dedicated ships will be required, some with ice-breaking capability.

For options two and three: Since there are no statistical cost figures available that rely on actual experience with cable stations under various local conditions, reasonable estimates of average cable lengths and ship time needed for cable laying have been applied. To be as realistic as possible, the figures presented in the table are considered to lie within the upper third of the range between the highest and lowest installation costs assumed plausible. Depending on the results of future work, further optimization to reduce costs (without performance loss) may result in a mixture of autonomous moored, fixed cable, and/or coastal stations.

The following table lists cost estimates for the three options. The costs are in millions of 1995 US dollars. The initial costs consist of development (research and engineering), procurement and deployment costs. All recurrent costs, required for routine station maintenance as well as replacement of damaged stations, are listed under annual costs. Estimates of 5 and 20-year cumulative costs (which include the initial costs) are provided to illustrate lifetime costs of the networks.

Option		**Initial Costs**	**Annual Costs***	**5-Year Cumulative Costs**	**20-Year Cumulative Costs**
Option I** **19 moored buoys + 2 MILS**	One expert	7.7	2.6	21	60
	Remaining experts	8.5	6.9	43	147
Option II*** **8 fixed cable + 2 MILS**	Dedicated Ship	35	0.5	37	45
	Ship of Opportunity	25	0.5	27	35
Option III **4 fixed cable + 2 MILS**	Dedicated Ship	22	0.25	23	27
	Ship of Opportunity	16	0.25	17	21

* Communication costs not included, to be borne by the IDC.

** Substitution of one coastal or island seismic station may save 0.25 million in annual costs, resulting in a $5 million savings in 20 years.

*** Substitution of one coastal or island seismic station may save up to $3 million in initial costs.

Recommendations for Future Work

It seems reasonable that a core group of experts be established which coordinates all the activities described below. This group could also help the Verification Working Group I to prepare and organize any further expert work needed and make that work more efficient. From the expert's judgement, at least one more expert group meeting should take place this year. Such a meeting should take place during the third part of the current CD session.

A major technical issue to be addressed is the survivability of autonomous moored buoys in energetic surface conditions. The lifetime of current buoys moored in the deep ocean is generally of the order of one year. To increase this lifetime to a two-year target will require some development of a hardened buoy (such as a spar buoy), which reduces the mechanical sensitivity of the system to the action of waves and wind. We propose a short research phase (lasting two years) to determine the reliability of moored buoys, and whether their lifetime can be extended to two years or more.

Calibration and evaluation of existing stations should be performed to ensure that sensor and cable degradation has not occurred. We propose the use of controlled acoustic sources lowered into the vicinity of the existing hydrophones to perform the calibration function.

The experts believe that additional work is required to validate the cost-saving approach exploiting the use of coastal/island seismic stations in place of hydroacoustic stations.

Quality measures and standards for evaluation of performance should be defined by further research. Studies on the station locations suggested in this working paper should be conducted to determine how the locations of the new stations to be installed should be adjusted. The previously discussed subgroup of the technical experts should conduct and review these studies. The recommendations should then be forwarded for consideration by the States Parties.

Time for Deployment (Timeline)

A bidding phase for the work would take 6 months.

Development and testing of autonomous moored buoy stations will be complete 18 months after funding. An extensive testing phase is recommended.

Preparation (including site surveys) for fixed cable stations will be complete 18 months after funding.

Regardless of the type(s) of stations (autonomous moored buoys or fixed cable), deployment could take up to 24 months after the preparation/development phase.

The total time, after funding, for full deployment of a hydroacoustic network will be 48 to 60 months.

PART IV: SEISMIC MONITORING

Executive Summary

The experts on seismic monitoring met from 21 February to 3 March 1995 and worked toward providing the information requested in CD/NTB/WP.203. In carrying out its work, the experts considered and took into account the results of the 1994 expert work for the NTB as well as the relevant contributions by the CD delegations to seismic monitoring and the extensive work done by the Ad Hoc Group of Scientific Experts (GSE).

The group had the great benefit of drawing upon the practical experience provided by the seismic network contributing to the GSETT-3 as well as sophisticated computer modelling assessments for potential future IMS networks.

In contrast to the radionuclide, hydroacoustic, and infrasound networks, there are globally coordinated seismic monitoring facilities in operation today. The three network options presented for consideration each have approximately 65 per cent of the proposed monitoring components available today. By the end of 1996, this percentage will rise to approximately 85-90 per cent primarily because of the investments and preparations being made for the GSETT-3 experiment.

Options for structuring the seismic component of an International Monitoring System (IMS) are presented in this report. These options are aimed at contributing to the basis for an evaluation of the International Monitoring System by the Conference on Disarmament. The options presented in this report have both a higher level of specificity than those previously presented by expert groups and a narrower range of variability in the basic network design, reflecting a convergence of technical views among the experts taking part in the working group.

Each of the options for consideration draws upon existing seismic monitoring stations and planned investments in such stations which have a value of over $US 100 million. Consideration has been given to both the new capital investments needed (beyond those currently underway or planned on a national level) and operating costs.

The capabilities and costs of these options for the primary network are summarized in the following table:

Option	Primary Stations	Detection	Operating Costs/year	New Investment Requirements	Dec/1996 Avail.
1	40	1-2 kt	$US 7	$US 5	90%
2	46	0.5-1 kt	$US 9	$US 6	90%
3	53	0.5-1 kt	$US 10	$US 11	85%

(Costs are in $US millions)

Some portion of the new investment requirement given in the table above is planned, but not in the near future, e.g., not within two years. To accelerate the completion of the networks would require new sources for these funds.

The Option 2 network is an intermediate network developed by the experts.

A network of up to 100 auxiliary stations could be used with each of the primary network options above to improve the location of events, particularly those of small magnitude. Specific numbers and locations of these stations can not be identified at this time, but experience gained in

GSETT-3 will help in this regard. These stations can be selected from already existing facilities.

The experts met with the hydroacoustic expert sub-group and discussed ways to improve the synergy between the two networks. The number of stations in the seismic network has been reduced to take advantage of the capability of the hydroacoustic network to detect explosions in oceanic areas. In general, the networks are highly complementary since in those areas where the seismic capability is least, the hydroacoustic capability is best.

A number of suggestions for practical steps which could be taken to assist in putting the IMS into operation were identified. These include:

- Continue the operation of GSETT-3 and its evaluation, incorporating modifications to reflect decisions made by the CD on the components and structure of the IMS.

- Evaluate, using the GSETT-3 resources, the number and geographical distribution of auxiliary seismic stations which would be needed to enhance the location and identification capacity of the primary network.

- Expand the training of technical personnel in seismic data processing, especially at the GSETT-3 IDC.

- As political decisions are made concerning the IMS, work could begin immediately on preparing the technical operational manuals for the seismic IMS using the documentation already developed by the GSE as a basis.

- In order to develop the synergy between the seismic and hydroacoustic networks, small-scale experiments could be planned and carried out.

I. Introduction

It has been accepted that seismic monitoring would be an essential component for the International Monitoring System. Seismic monitoring is the core technology for monitoring underground nuclear explosions and contributes to the monitoring capability for explosions underwater.

In August 1994, a working paper, CD/NTB/WP.177 was prepared by an expert group and submitted to the Working Group on Verification. This paper presented three seismic monitoring network options with varying capabilities and gave cost estimates, including the details of an envisaged International Data Center.

A further working paper (CD/NTB/WP.181 of 2 September 1994) from the Friend of the Chair, presented six options of an integrated International Monitoring System. These options drew upon various individual options presented by expert groups in four technologies, viz., seismic, radionuclide, infrasound, and hydroacoustic.

The Ad Hoc Group of Scientific Experts (GSE) has devoted significant effort to the development of seismic monitoring methodologies and has accumulated a large reservoir of practical experience in this field. The Group has conducted two technical tests in the past. The GSE currently has underway a large scale test with the planned involvement of more than 100 seismic stations distributed around the globe. A comprehensive report (CD/1254) on the details of this test, called GSETT-3, was submitted to the Ad Hoc Committee on a Nuclear Test Ban in March 1994. The GSE has reported that a total of 32 primary stations and 44 auxiliary stations are currently participating in GSETT-3.

The Chairman of Working Group 1 on Verification gave a new mandate (CD/NTB/WP.203 of 16 December 1994) for expert work to proceed further with the specification of the IMS. To meet these objectives, a Group of Experts met during the period 20 February-3 March 1995.

In the course of its work, the sub-group considered in detail Options 2 and 3 of the FOC's working paper as well as the national options proposed by the United States (CD/NTB/WP.184), the Russian Federation (CD/NTB/WP.187) and China (CD/NTB/WP.219). In response to considering these proposals, the group developed an intermediate option.

Further, in view of the fact that more than 70 per cent of the globe is covered by oceans, and seismic events in the oceans can be detected by a properly-equipped hydroacoustic system, there is a natural synergy between the two systems. The seismic experts met with the hydroacoustic experts and benefitted from detailed discussions on the monitoring options. The interaction is also discussed in this document. There are synergies among all the monitoring technologies of which the sharing of a single International Data Centre is most important. Many of the techniques for receiving and handling data at the IDC which have been developed for the seismic method apply equally to data from the other monitoring methods.

II. Basic System Requirements

In carrying out its work, the group considered the following factors:

- The number of stations and their geographic distribution to achieve global coverage.

- The type of data to be collected for verification and identification, and rapidity in which events could be detected and located and the precision of the locations for possible use in connection with an on-site inspection.

- The cost effectiveness of the system using existing facilities and the time required to develop the needed facilities. In particular, consideration was given to the equipment that has been developed and installed for the GSETT-3 experiment and the plans that States have for further development in support of GSETT-3.

- The synergy with other monitoring systems.

Each of the networks proposed for the IMS contains a mix of station types. An adequate distribution of the most sensitive primary stations, especially arrays to improve detection capabilities, would provide for the detection of seismic events on a global scale. As discussed in a later section, data from additional auxiliary stations and supplementary local data could be requested as needed, so that events detected could be located with improved accuracy and additional data for event identification could be provided.

The network should be capable of being modified and improved over time depending on its performance and the availability of technology and funding. This is an important aspect of the IMS. Stations could be upgraded from three component sites to arrays, or the status of others changed from auxiliary to primary, or vice-versa. With appropriate review, stations that are found in the future to contribute little to the capability of the IMS could be discontinued or replaced with a more capable station.

Participating States could also make available to the IDC supplementary data from national and regional networks. Such networks would be maintained to individual national or regional standards. However, participating States should be encouraged to maintain networks to high standards. These data cold be available by request, but the rapidity of response may vary from one national network to another.

The seismic monitoring system would not stand alone but would operate in conjunction with other monitoring technologies such as hydroacoustics, radionuclides and infrasound. Data from these different technologies would be collected at a single point (the IDC) thus maximizing the use of resources and the synergy between the monitoring networks.

The seismic monitoring system should be able to perform the following functions:

- Signal Detection. Individual seismic sensors with modern emplacement techniques and digital data acquisition should detect seismic waves from small explosions and should be limited only by natural and cultural sources of vibration. The detections should be prompt. Arrays, groups of closely spaced seismic sensors, could be used to improve these signal detection capabilities and facilitate cost-effective automated processing of the data.

- Event Location. The locations should be accurate enough to be of value in planning an on-site inspection. The accuracy of event location depends on the number, type (single station or array) and the geographic distribution of seismic stations. It is highly desirable that the uncertainty area of these locations be less than 1,000 square kilometres. These location bounds are important to take into consideration when making estimates of the necessary resources and time needed for an OSI.

- Event Identification. The monitoring network should provide the data necessary for event identification. This process becomes increasingly more difficult as the size of the source decreases. The false alarm rate should be kept as low as possible. The monitoring network should provide the analysis products in a form easily used by the States Parties.

The experts believe that further consideration should be given to the capacity to detect an explosion on the territory of a country, even if the data from stations located on that territory are not available, or are incomplete.

III. Types of Stations to be Used

The seismograph is the basic instrument of the IMS used for recording seismic signals. The elements of an IMS seismic station are described in Annex 1.

The equipment at the IMS stations should meet defined minimum technical specifications regarding sensitivity, instrument response, recording hardware, computer software, operation and management. These specifications are specifically applicable to the detection of signals from underground nuclear explosions. Table 1 contains the proposed minimum technical characteristics of this equipment. More detailed specifications of the equipment have been developed by the GSE and are being currently tested in GSETT-3. These highly detailed specifications are subject to modification as the stations are evaluated in the course of this test.

The definition of standards for the IMS stations does not mean that these facilities must consist of identical components, but rather that components must meet basic functional and technical requirements. The basic seismographic sensor and the associated electronic equipment which meet the required technical specifications are readily available from a number of commercial vendors.

Table 1

Minimum Recommended Station Requirements

Pass Band	0.04 - 16 hertz (broadband) or 0.04 - 1 hertz (long period) and 0.5 - 8 hertz (short period)
Seismometer Noise	10 dB below the minimum local seismic noise over the passband
No. of Components	three orthogonal (one vertical component for array elements)
Calibration	within 5% in amplitude and 5 degrees in phase
Sample rate	greater than or equal to 20 samples per second
Resolution	18 dB below the minimum local seismic noise over the passband
Total System Noise	10 dB below the minimum local seismic noise over the passband
Dynamic Range	96 dB minimum
Linearity	90 dB over the passband
Timing Accuracy	less than 10 milliseconds (network standard timing required, e.g., GPS)
Operating Temp	-10 deg C to +45 deg C (to lower temperatures where required by local conditions)
Authentication	as required
State of Health	a minimum of clock status, calibration status and vault status
Format	GSE format
Protocol	TCP / IP
Transmission Delay	less than 5 minutes
Data Frame	less than one minute in length
Disk Buffer	7 days (either at station or NDC)
Data Availability	greater than 99% (primary) 95% (auxiliary)
Timely Data Avail	greater than 98%
Station Location	known within 100 metres; relative location of array elements known to within 1 metre
Seismometer orientation	Aligned to better than 3 degrees

Where possible, arrays are preferred elements of the IMS. The advantages of arrays are their superior signal detection capability and their ability to provide distance and direction estimates which facilitate automated processing at the IDC.

Many years of practical seismological monitoring experience has shown that critical to the performance of these instruments is the location of their deployment and the manner in which the stations are operated. Therefore, the selection of stations should take into account siting in "quiet" areas (i.e., locations where seismic noise is minimal) with good signal recording conditions.

All stations should be equipped with reliable communication systems for transmission of data to the IDC on a continuous basis for stations in the primary network and on demand for stations in the auxiliary network.

IV. Data Flow

The flow of data from the seismic components of the IMS follows the concept proposed by the GSE and is being tested in GSETT-3. The data flow steps would proceed as follows:

- Raw waveform data collected at the seismic facilities certified as part of the IMS would be transmitted to the IDC, either directly or through National Data Centres (NDC) operated by States Parties. The primary stations would forward continuous, real-time waveform data from all sensors at the primary facilities to the IDC. Experience has clearly demonstrated the need for continuous data transmission as the most reliable and cost-effective mode of data acquisition.

- As the data are received at the IDC, they would be checked for quality and authenticity, and placed in a long-term archive.

- The waveform data at the IDC would be processed automatically as they are received to detect signals and to provide initial locations of events on a worldwide basis. This initial processing would be completed generally within one hour.

- If necessary, the IDC could automatically or interactively retrieve additional data from auxiliary stations to improve event location and provide additional event identification parameters.

- The data would be reviewed and the automated computer solutions corrected (when necessary) by the technical personnel at the IDC. This review improves the quality of the event location estimates and other information on the events, and could be completed within 6 to 72 hours after the event occurrence. All of these products would be available to the States Parties during this time.

- At some later time, supplementary data may be acquired on an as-available basis from National Data Centres.

Fusion of the seismic data with the data available from other IMS techniques would further improve the monitoring capability of the entire IMS system beyond that provided by the techniques individually. This fusion process might include correlation of data from multiple techniques, or cuing the search for and acquisition of data from one technique based on an input from another technique.

Data Analysis at the IDC

An example of the possible products of the analysis which could be available includes objective event identification parameters beyond event location (e.g., event magnitudes, spectral measurements, etc.). The IDC could provide States Parties with rapid, open and customized (if desired) access to any or all of the data and the products in the IDC archive.

One delegation, representing the views of some others, proposed that in order to meet the requirements of most delegations for a product which provides some further probabilistic characterization of significant events, there is the option of the IDC performing preliminary and probabilistic source characterization without making a final or definitive decision on the origin of the event. This provisional event characterization would use agreed, objective procedures and region-specific knowledge (as it became available) and would include input from other monitoring technologies, such as hydroacoustic.

Some delegations are of the view that final and definitive identification on events should be carried out by the IDC.

The seismic expert group believes that decisions on the role and the operations to be carried out by the IDC should be determined by the Conference on Disarmament.

V. Network Design

The FOC working paper (CD/NTB/WP.181) discussed the structure of a seismic monitoring system composed of a primary network of stations for event detection which would be supplemented by an auxiliary network of stations to improve the location precision and source identification. The group has considered and evaluated specific proposals for the size and geographical distribution of the primary network of stations.

Options for the Primary Network

The networks which were considered by the experts draw on the foundations of the seismic systems which have been developed by the GSE. The extensive documentation on the stations' characteristics and network components, as well as the wealth of experience already emerging from GSETT-3, have enabled the experts to develop the network options below and to define their capabilities and costs with some confidence.

Three national working papers, by the united States (CD/NTB/WP.184), the Russian Federation (CD/NTB/WP.187) and China (CD/NTB/WP.219) have proposed specific global networks of primary seismic stations. Together with Options 2 and 3 of the Friend of the Chair (FOC) working paper (CD/NTB/WP.181), there were five proposed networks considered by the experts. These networks range from a minimum of 40 stations to a maximum of 53 stations. Each network proposal includes arrays as well as single three-component stations.

For the purpose of the evaluation by the seismic expert group, three options are considered. The first option (40 stations) is the minimum-sized network proposed based on CD/NTB/WP.187. The second option (46 stations) is an intermediate network developed jointly by the experts, which takes into account the three national proposals as well as the FOC options. The third option (53 stations) is the maximum-sized network proposed based on CD/NTB/WP.184.

The locations of the stations in Options 1 and 3 are shown in Figure 1. The locations of the stations in Option 2 are shown in Figure 2. Specific locations of the stations in each of the network options are given in Table 2.

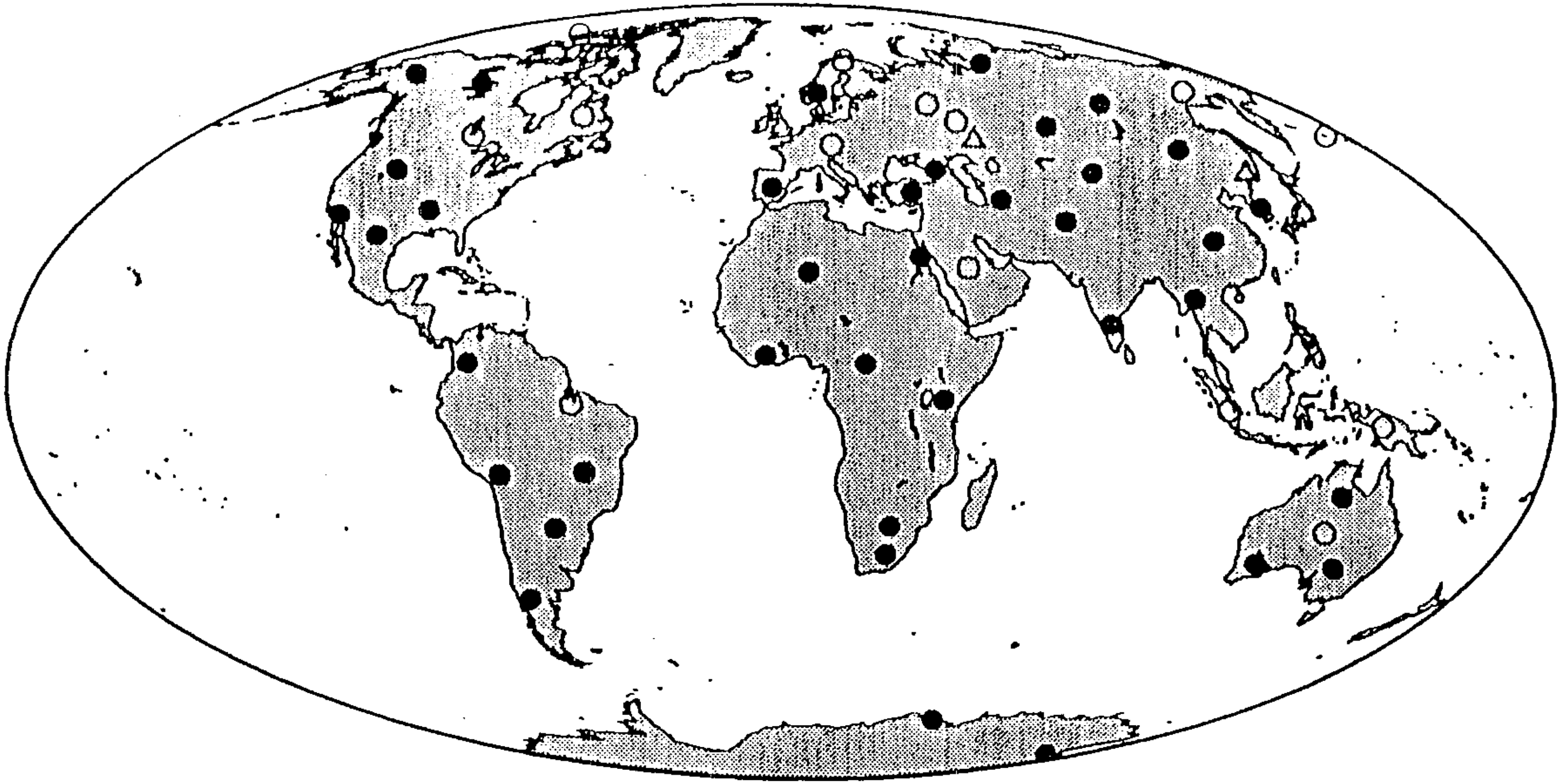


Figure 1. Locations of stations proposed in Option 1 (40 Stations) and Option 3 (53 Stations). The filled in black circles are the sites (38 in all) which are common to both networks. The open triangles are the 2 additional sites for Option 1. The open circles are the 15 additional sites for Option 3.

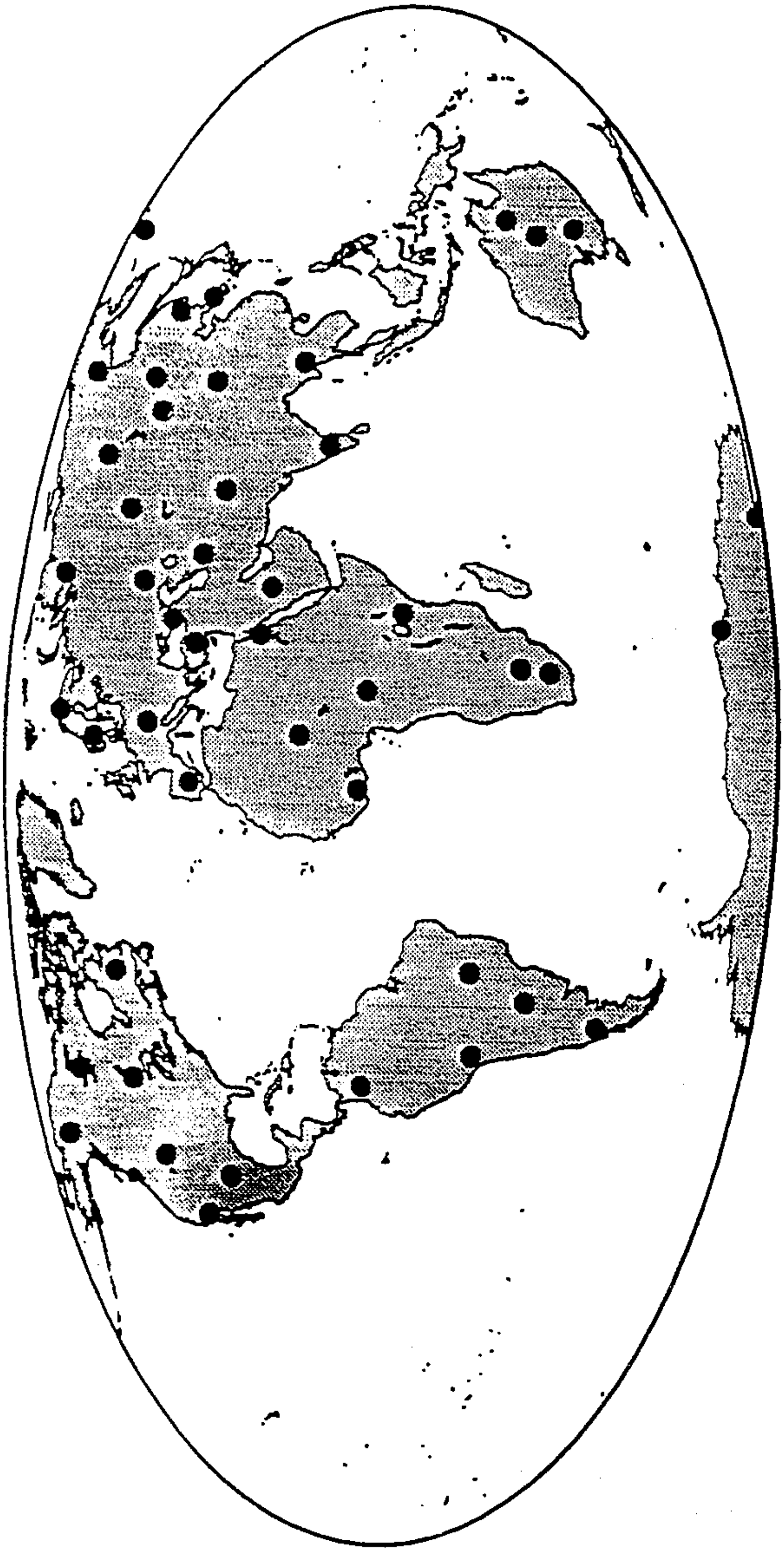


Figure 2. Locations of stations in proposed Option 2 (46 Stations).

Table 2
Comparison of Specific Seismic Networks

Location	Station	Intermediate Network		Network In WP.187	Network In WP.219	Network In WP.184
Argentina	PLCA Paso Flores	3-C		3-C	3-C	3-C
Paraguay	CPUP Villa Florida	3-C		3-C	3-C	3-C
Brazil	BDFB Brasilia	3-C		3-C	array	array
Brazil	New Site northeast Brazil	not in network		not in network	not in network	3-C
Bolivia	LPAZ La Paz	3-C		3-C	3-C	3-C
Colombia	BOCO Bogota	3-C		not in network XSA	3-C	3-C
Mexico	IGUM Mexico City	not in network		not in network	3-C	not in network
USA	LJTX Lajitas, TX	array		array	array	array
USA	PFCA Pinon Flat, CA	3-C		3-C	3-C	3-C
USA	MIAR Mt Ida, AR	not in network		3-C	not in network	3-C
USA	PIWY Pinedale, WY	array		array	array	array
USA	ELAK Elison, AK	array		3-C NPO	array	array
USA	ATAK Attu, AK	3-C		not in network	not in network	3-C
USA	New Site US 07	not in network		not in network	3-C	not in network
Canada	ULMC Lac du Bonnet	3-C		not in network	not in network	3-C
Canada	YKAC Yellow Knife	array		array	array	array
Canada	MBC Mould Bay	not in network		not in network	not in network	3-C
Canada	SCH Schefferville	3-C		not in network	3-C	3-C
Canada	New Site CA 04	not in network		not in network	3-C	not in network
Antarctica	VNDA Vanda	3-C		3-C	3-C	3-C
Antarctica	MAW Mawson	3-C		3-C	3-C	3-C
South Africa	BOSA Boshof	3-C		3-C	array	array
Botswana*	LBTB Lotatse	3-C		3-C	not in network	3-C
Kenya	KMBO Kilima Mbogo	3-C		3-C	3-C	3-C
Ivory Coast	DBIC Dimbroko	3-C		3-C	3-C	3-C
Central Afr Rep	BGCA Bangui	3-C		3-C	3-C	3-C
Algeria	TAM Tamanrasset	not in network		not in network	3-C	not in network
Niger	New Site	3-C > array		3-C	not in network	3-C > array
Egypt	LXEG Luxor	array		array	array	array

Table 2 (Continued)

Location	Station	Intermediate Network		Network In WP.187	Network In WP.219	Network In WP.184
Saudi Arabia	New Site	array		not in network	array	array
Spain	ESDC Sonseca	array		array	array	array
Germany	GECO Freyung	array		not in network	array	array
Norway	NAO Hamar	array		array	array	array
Norway	ARAO Karasjok	array		not in network	array	array
Turkey	BRTR Belbashi	array		array	array	array
Russia	KBZ Khabaz	3-C		3-C	not in network	3-C
Russia	KIRR Kirov	not in network		not in network	not in network	array
Russia	KLMR Zilim	not in network		not in network	not in network	array
Kazakhstan	AKTO Aktubinsk	3-C > array		3-C	array	not in network
Turkmenistan	GEYT Alibeck	array		array	array	3-C > array
Pakistan	PRPK Pari	array		array	array	array
India	GBAO Gauribidanur	array		array	array	array
Russia	ZALR Zalesovo	3-C > array		3-C	array	array
Russia	NRIL Norilsk	3-C		3-C	not in network	array
Russia	PDYO Peleduy	array		3-C	array	array
Russia	SEYO Seymchan	3-C		not in network	not in network	array
Russia	USU Ussuriysk	3-C > array		3-C	not in network	not in network
Mongolia	IVG Ivgelt	3-C > array		not in network	not in network	not in network
China	HAI Hailar	3-C > array		array	3-C	array
China	ENH Enshi	not in network		array	not in network	array
China	LZH Lanzhou	3-C > array		not in network	3-C	not in network
China	WMQ Urumchi	not in network		array	not in network	array
Rep Korea	KSRS Wonju	array		array	array	array
Japan	MATO Matsushiro	not in network		not in network	array	array
Thailand	CMTO Chiang Mai	array		array	array	array
Indonesia	New Site	not in network		not in network	not in network	3-C
Papua New Guinea	New Site	not in network		not in network	3-C	3-C
Cook Islands	New Site Rarotonga	not in network		not in network	array	not in network

Table 2 (Continued)

Location	Station	Intermediate Network		Network In WP.187	Network In WP.219	Network In WP.184
Australia	WRAO Warramunga	array		array	array	array
Australia	ASAO Alice Springs	array		not in network	not in network	array
Australia	STKA Stephens Crk	3-C		3-C	3-C	3-C
Australia	YERD Yerdanie Rock	not in network		3-C	3-C	3-C
	TOTAL	46		40	44	53

3C > array: Indicates that the site could start operations in the IMS as a three component stations and be upgraded to an array

* Consideration could be given to moving this station to a site farther north

In addition to the number of sites in the networks, the network options vary as to the number of seismic arrays to be incorporated at the designated IMS sites. Both the number of sites and the number of arrays influence the capabilities of the networks.

The three networks have been evaluated on the basis of the initial experience gained with the existing stations of the network in GSETT-3 and on computer simulations for those facilities that are not yet installed or fully operational. The networks are compared as follows:

Option 1	Ability to detect and locate explosions at the magnitude 3 3/4 level, equivalent to an explosion of the order of 1 to 2 kilotons
Option 2	Ability to detect and locate explosions at the magnitude 3 1/2 level, equivalent to an explosion of the order of 0.5 to 1 kiloton
Option 3	Ability to detect and locate explosions at slightly less than the magnitude 3 1/2 level, equivalent to explosion of the order of 0.5 to 1 kiloton.

The network in Option 2, developed by the expert group, has essentially the same detection capability as the larger network in Option 3 because of the optimization of the station locations. Each of the networks has approximately uniform geographical coverage of the land masses although the detection capability varies as indicated above.

The networks in options 2 and 3 provide a higher capability for detection in oceanic areas than the Option 1 network. Also, Option 3 provides some redundancy.

With careful calibration the desired location accuracy of 10-20 km can be achieved in the northern hemisphere with each of the primary network options. This is achieved only for events more than one-half magnitude unit above the detection levels above. In the southern hemisphere, the uncertainties will be larger. It must however be understood that this calibration process can only be accomplished after the network is fully installed and operated for several years.

By incorporating data from even a modest hydroacoustic network, the location accuracy can be improved in oceanic areas.

Synergy with other IMS Components

The experts met with the hydroacoustic expert group and discussed ways to improve the synergy between the two networks. The number of stations in the primary network has been reduced, especially stations in oceanic areas, because of the expected capability of the hydroacoustic network to detect and locate explosions in these areas. In general, the networks are highly complementary since in those areas where the seismic capability is least, the hydroacoustic capability is best.

There does remain some capability to detect explosions in oceanic areas with the seismic network, but establishing accurate locations would require data from the hydroacoustic network. The capabilities provided by each of the network options suggest that a moderate density hydroacoustic network might be required, e.g., 2-3 stations per ocean basin. For example, the Option 2 seismic network provides a detection level of about 3 3/4 in the broad ocean areas. This would allow the detection of a one kiloton explosion near the ocean surface.

If stations of the other monitoring networks are co-located with the seismic stations, the communications channels could be shared.

Inclusion of an Auxiliary Network

For the purpose of enhancing the location accuracy for OSI purposes and for the acquisition of data that could prove useful for the identification of events, it has been recommended in some national proposals, as well as in the FOC report, that a network of auxiliary stations be used. A definitive auxiliary network can not be identified at this time, but experience gained in the GSETT-3 will help with this definition.

The network currently being tested in GSETT-3 is such a two-tiered system. Annex 2 lists the stations participating in GSETT-3.

VI. Costs of Network Options

The networks which are discussed in this document each draw on, in varying degrees, the investments which have been made over the years in high quality seismic monitoring systems and the investments which are planned and being implemented for GSETT-3.

The annual operating costs of the networks for the three options can be compared as follows:

Option 1	$US 7 million
Option 2	$US 9 million
Option 3	$US 10 million

The network communications costs have been discussed in CD/NTB/WP.184, CD/NTB/WP.187 and CD/NTB/WP.192 in the context of the International Data Centre. CD/NTB/WP.187 provided an estimate of $US 4 million for the overall communications costs and CD/NTB/WP.184 estimated the communications costs at $US 8 million based on current operational experience and international rates. In general, international communications are rapidly declining and some savings will result from new developments in the telecommunications field. Thus, the communications cost in CD/NTB/WP.184 should be considered an upper limit. Within the range of uncertainty in international tariffs and new developments in international telecommunications, the communications cost differences between the three options are insignificant.

Investments of over $100 million have been made to develop the facilities which are considered in the three options. Each network option has a number of seismic stations that are participating currently in the GSETT-3 experiment or have plans to participate in GSETT-3. There are significant ongoing activities to install new facilities and to upgrade existing facilities for GSETT-3.

The capital investments which would be needed to place the networks into operation for each of the options is as follows:

	Total	Planned Investment	Remaining Investment Needed
Option 1	$US 9	$US 4	$US 5
Option 2	$US 15	$US 9	$US 6
Option 3	$US 20	$US 9	$US 11

The planned investments are those which are being carried out over the next 1-2 years at the national level or in bilateral cooperation, primarily for development of facilities for GSETT-3. The funds indicated in the column under "Remaining Investment Needed" indicate that either the plans for this support is not available in the 1-2 year time frame or decision on these funds is unknown at this time.

For all the options, there are additional new sites to be installed or upgraded. The remaining percentages of the networks could be completed within two years from the time a decision is made to proceed and funds are made available.

Consideration will also need to be given to a long-term provision for eventual replacement of the equipment. This consideration applies to all monitoring components of the IMS.

Many of the facilities called for in the three proposed options are available today. In some cases, the facilities which are incomplete involve upgrades to existing facilities, for instance, a three component station being upgraded to an array. The following table indicates the approximate percentage of the facilities in the three proposed networks that exist today and are planned or will be completed in the near future.

Percentage of Facilities Completed

	March 1995	December 1995	December 1996
Option 1	65%	80%	90%
Option 2	65%	80%	90%
Option 3	65%	75%	85%

VII. Experimental Activities and Financial Requirements Needed before Entry into Force

In contrast to the radionuclide, hydroacoustic, and infrasound networks, there are globally coordinated seismic monitoring facilities in operation today in many parts of the globe. As is seen in the preceding section, each of the three network options presented for consideration has approximately two-thirds of the monitoring components available today and this percentage is rising primarily because of the investments and preparations being made for the GSETT-3 experiment.

The following are suggestions for practical steps which could be taken to assist in putting the seismic monitoring network into operation.

- The GSETT-3 experiment has started and is building up to its recommended network for evaluation. Results from this test are now becoming available and these results should be evaluated for their applicability to the proposed seismic options for the IMS.

- Evaluate, using the GSETT-3 resources, the number and geographical distribution of auxiliary seismic stations which would be needed to enhance the location and identification capacity of the primary network.

- As decisions are made by the CD on the components and structure of the seismic IMS, plans should be made and carried out to modify the GSETT-3 to reflect these changes as soon as practicable and continue its operations.

- In order to develop the synergy between the seismic and hydroacoustic networks, small-scale experiments could be planned and carried out.

- Training of technical personnel from a number of countries in seismic data processing and analysis should be expanded at the GSETT-3 IDC.

- The GSE has begun the task of preparing detailed documentation covering all technical aspects of the operation of the stations and the IDC in connection with GSETT-3. As decisions are made concerning the seismic monitoring system, work should immediately begin on preparing the technical operation manuals for the seismic monitoring system using the documentation already developed by the GSE as a basis.

If a decision is taken to implement a provisional IMS seismic network at some point in the future, the GSETT-3 system could be progressively modified to meet the agreed IMS design.

The implementation of a provisional IMS seismic network in the future would require that adequate funding be obtained in terms of national and/or international resources.

Annex 1

Technical Characteristics of the IMS Seismic Equipment

A three-component station in the seismic IMS would consist of the following elements:

- Three-component broadband seismometers
- A data acquisition system with digitizers to convert the seismometer output signals into digital form and modules for placing authentication signatures into the data stream
- Electronics for very accurate synchronization to Universal Time
- A system for transmitting data continuously (Primary stations only) or making data available for automatic retrieval (Auxiliary stations) by the IDC, as well as managing the flow, calibration and archival of the data
- Devices for data archiving
- Communication interfaces for data transmission to National Data Centres and the International Data Centre
- Data channels for additional input signals (e.g., wind indicators, temperature, and other environmental data) and status indicators.

Some of the data handling facilities may be at the National Data Centre rather than at the station itself.

An array in the seismic IMS would consist of all of the elements above plus additional vertical component short-period sensors distributed to enhance the signal-to-noise ratio and to provide azimuth and phase identification information.

Annex 2

Status of GSETT-3 Station and Gamma Data Commitments as of 1 March 1995

COUNTRY	Alpha Stations Envisaged by GSE	Beta Stations Offered	Station commit-ment Status	Data Available to IDC	Gamma Data Committed
Argentina	1	1	committed	1994/ July 1995	yes
Australia	5	11	committed	1994	yes
Austria	0	1	lacking	unknown	-
Belgium	0	0	not applicable	not applicable	yes
Bolivia	1	-	lacking	unknown	-
Botswana	1	-	lacking	unknown	-
Brazil	1	2	committed/ lacking	1994/1995	-
Bulgaria	0	1	committed	July 1995	yes
Canada	6	18	committed	1994	yes
Cen. Afr. Republic	1	-	committed	1994	-
Chile	0	1	committed	-	-
China	3	0	committed	unknown	-
Cook Islands	0	1	committed	1994	-
Colombia	1	0	committed	mid-1995	-
Costa Rica	0	1	committed	-	-
Czech Republic	0	1	committed	1994	yes
Denmark	1	-	lacking	July 1995	yes
Egypt	1	0	lacking	unknown	-
Ethiopia	0	1	committed	-	-
Finland	1	2	committed	1994	yes
France	1	0	committed	Jan.1995	yes
Germany	1	9	committed	1994	-
Hungary	0	1	committed	1994	yes

Iceland	0	1	committed	-	-
India	1	0	committed	May 1995	-
Indonesia	1	-	lacking	unknown	-
Iran	1	1	lacking	June 1995	yes
Israel	0	1	committed	March 1995	yes
Italy	0	2	committed	1994	yes
Ivory Coast	1	-	committed	March 1995	-
Japan	1	7	committed	1994	yes
Kazakhstan	1	-	lacking	unknown	-
Kenya	1	-	lacking	unknown	-
Rep. of Korea	1	-	lacking	unknown	-
Mexico	1	2	lacking	unknown	-
Mongolia	1	1	committed	unknown	-
Netherlands	0	1	committed	1994	yes
N.Africa (XAF)	1	-	lacking	unknown	-
New Zealand	0	1	committed	1994	yes
Norway	3	1	committed	1994	yes
Pakistan	1	1	committed	1995	-
Papua New Guinea	1	-	committed[1]	Jan. 1995	-
Paraguay	1	-	committed	1994	-
Peru	0	1	committed	1995	yes
Philippines	0	1	committed	-	-
Poland	0	1	lacking	unknown	yes
Portugal	0	1	committed	-	-
Romania	0	1	committed	1995	yes
Russian Federation	5	5	committed	1994	-
Seychelles	0	1	committed	-	-
South Africa	1	1	committed	1994/1995	yes
Spain	1	2	committed	Jan. 1995	yes
Sweden	1	0	committed	Jan. 1995	yes
Switzerland	0	1	committed	Jan. 1995	yes
Thailand	1	-	committed	Feb. 1995	-
Turkey	1	-	committed	unknown	-

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[1] *Envisaged Alpha Station currently used as Beta station*

Turkmenistan	1	-	committed	unknown	-
Ukraine	0	1	committed	-	-
United Kingdom	0	2	committed	1994	yes
United States	7	12	committed	1994	yes
Western Samoa	0	1	committed	1994	-
Zambia	0	1	committed	Jan. 1995	-
TOTAL (Committed)	60(49)	102(95)			26

GSETT-3 Stations

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Argentina						
Paso Flores	PLCA	α	3-C	-40.7306	-70.5500	yes
Coronel Fontana	CFA	β	3-C	-31.6070	-68.2393	no
Australia						
Alice Springs	ASAR	α	array	-23.6664	133.9044	yes
Mawson, Antarctica	MAW	α	3-C	-67.6039	62.8706	yes
Stephens Creek	STKA	α	3-C	-31.8817	141.5917	yes
Warramunga	WRA	α	array	-19.9426	134.3394	yes
Woolibar	WOOL	α	3-C	-31.073	121.678	yes
Armidale	ARMA	β	3-C	-30.4198	151.6280	yes
Casey	CSY	β	1-C	-66.2894	110.5289	yes
Charters Towers	CTA	β	3-C	-20.088	146.254	yes
Fitzroy Crossing	FITZ	β	3-C	-18.103	125.643	yes
Forrest	FORT	β	1-C	-30.7790	128.0590	yes
Meekatharra	MEEK	β	1-C	-26.6142	118.5361	yes
Mount Isa	QIS	β	1-C	-20.5577	139.6052	yes
Narrogin	NWAO	β	3-C	-32.93	117.23	yes
Roma	RMQ	β	1-C	-26.489	148.755	no
Toolangi	TOO	β	3-C	-37.5714	145.4906	yes
Warburtan	WARB	β	3-C	-26.1838	126.6430	yes
Young	YOU	β	1-C	-34.2783	148.3817	no
Austria						
Molln	MOA	β	3-C	47.849529	14.26594	no
Bolivia						
La Paz	LPAZ	α	3-C	-16.2880	-68.1306	no
Botswana						
Lobatse	LBTB	α	3-C	-25.0150	25.5966	no
Brazil						
Brasilia	BDFB	α	3-C	-15.6418	-48.0148	yes

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
To be defined		β	3-C			no
To be defined		β	3-C			no
Bulgaria						
Vitosha	VTS	β	3-C	42.6180	23.2378	no
Canada						
Lac du Bonnet	ULM	α	3-C	50.2497	-95.8750	yes
Mould Bay	MBC	α	3-C	76.2420	-119.3600	yes
Schefferville	SCH	α	3-C	54.8167	-66.7833	yes
Waterton Lakes	WALA	α	3-C	49.0586	-113.9115	yes
Whitehorse	WHY	α	3-C	60.6597	-134.8806	yes
Yellowknife	YKA	α	array	62.4932	-114.6053	yes
Bella Bella	BBB	β	3-C	52.1847	-128.1133	no
Caledonia Mtn.	LMN	β	3-C	45.8520	-64.8060	yes
Campbell	CBB	β	3-C	50.0328	-125.3653	no
Dawson City	DAWY	β	3-C	64.0655	-139.3909	no
Deer Lake	DRLN	β	3-C	49.2560	-57.5042	yes
Edmonton	EDM	β	3-C	53.22	-113.35	no
Eldee	EEO	β	3-C	46.6411	-79.0733	no
Fort Churchill	FCC	β	3-C	58.7610	-94.0870	yes
Glen Almond	GAC	β	3-C	45.7030	-75.4780	no
Inuvik	INK	β	3-C	68.3070	-133.5200	yes
Iqaluit	FRB	β	3-C	63.7467	-68.5467	yes
La Malbaie	LMQ	β	3-C	47.5483	-70.3267	no
Pac. Geoscience	PGC	β	3-C	48.65	-123.45	yes
Pemberton	PMB	β	3-C	50.5202	-123.0732	no
Penticton	PNT	β	3-C	49.31	-119.61	no
Resolute Bay	RES	β	3-C	74.6870	-94.9000	yes
Sadowa	SADO	β	3-C	44.7694	-79.1417	no
Thunder Bay	TBO	β	3-C	48.6473	-89.4083	no
Central African Republic						
Bangui	BGCA	α	3-C	5.1761	18.4242	yes

Station Name (In alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Chile						
To be defined		β	3-C			no
China, Peoples Republic of						
Beijing	BJT	α	3-C	40.04	116.18	no
Hailar	HIA	α	3-C	49.27	119.74	no
Lanzhou	LHZ	α	3-C	36.09	103.84	no
Colombia						
To be defined		α	3-C			no
Cook Islands						
Rarotonga	RAR	β	3-C	-21.2125	-159.7733	yes
Costa Rica						
To be defined		β	3-C			no
Czech Republic						
Vranov	VRAC	β	3-C	49.3110	16.5960	yes
Denmark						
Danmarkshavn	DAG	α	3-C	76.77	-18.65	no
Egypt						
LUXESS	LXAR	α	array	26.00	33.00	no
Ethiopia						
Furi	FURI	β	3-C	8.90	38.68	no
Finland						
FINESS	FINES	α	array	61.4436	26.0771	yes
Kangasniemi	KAF	β	3-C	62.1127	26.3062	yes
Ylistaro	VAF	β	3-C	63.042194	22.671499	yes
France						
Lormes	LOR	α	3-C	47.26	3.86	yes
Germany						
GERESS	GERES	α	array	48.8451	13.7016	yes
Berggiesshübel	BRG	β	3-C	50.8748	13.9469	yes
Black Forest	BFO	β	3-C	48.3311	8.3303	yes
Bochum	BUG	β	3-C	51.4455	7.2643	yes
Clausthal-Zellerfeld	CLZ	β	3-C	51.8429	10.3741	yes

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Collm	CLL	β	3-C	51.31	13.00	no
Fürstenfeldbruck	FUR	β	3-C	48.1639	11.2768	no
Gräfenberg	GRFO	β	3-C	49.691944	11.205000	no
Moxa	MOX	β	3-C	50.6461	11.6161	yes
Taunus	TNS	β	3-C	50.2236	8.4489	yes
Hungary						
Piszkes	PSZ	β	3-C	47.9184	19.8945	yes
Iceland						
Borgames	BORG	β	3-C	64.50	-21.50	no
India						
Gauribidanur	GBA	α	array	13.6042	77.4361	no
Indonesia						
To be defined	XIN	α	3-C			no
Iran						
To be defined	XIRN	α	3-C			no
To be defined		β	3-C			no
Israel						
Bar Giyora	BGIO	β	3-C	31.72	35.09	no
Italy						
L'Aquila	AQU	β	3-C	42.3540	13.4050	yes
Villasalto	VSL	β	3-C	39.4960	9.3780	yes
Ivory Coast						
Dimbroko	DBIC	α	3-C	6.6701	-4.8563	no
Japan						
Matsushiro	MJAR	α	array	36.54	138.21	yes
Aobayama	AOB	β	3-C	38.25	140.85	no
Chichijima	OGS	β	3-C	27.06	142.20	no
Hachijojima	HCH	β	3-C	33.12	139.80	no
Ishigakijima	ISG	β	3-C	24.38	124.23	no
Kaminokuni	KKJ	β	3-C	41.78	140.18	no
Shiraki	SHK	β	3-C	34.53	132.68	no
Tsukuba	TSK	β	3-C	36.21	140.11	no

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Kazakhstan						
Aktubinsk	AKT0	α	array	50.4340	58.0180	no
Kenya						
Nairobi	KMBO	α	3-C	-1.2740	36.8040	no
Korea, Republic of						
To be defined	XKO0	α	array	37.00	128.00	no
Mexico						
To be defined	XMEX	α	3-C	18.00	-96.00	no
Chilapa	CHAM	β	3-C	17.00	-99.00	no
Iguala	IGUM	β	3-C	19.00	-100.00	no
Mongolia						
To be defined		α	3-C			no
Ulaan-Baatar	ULN	β	3-C	47.52	107.03	no
Netherlands						
Heimansgroave	HGN	β	3-C	50.7640	5.9317	yes
New Zealand						
South Karori	SNZ0	β	3-C	-41.310	174.705	yes
North Africa						
To be defined	XAF	α	3-C			no
Norway						
ARCESS	ARCES	α	array	69.5349	25.5058	yes
NORSAR	NAO	α	array	60.8237	10.8324	no
Spitsbergen	SPITS	α	array	78.1777	16.3700	yes
NORESS	NORES	β	array	60.7353	11.5414	yes, as α station
Pakistan						
Pari	PKAR	α	array	33.6500	73.2520	no
Nilore	NIL	β	3-C	33.60	73.10	no
Papua New Guinea						
Port Moresby	PMG	α	3-C	-9.41	147.15	yes, as β station

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Paraguay						
Villa Florida	CPUP	α	3-C	-26.3306	-57.3292	yes
Peru						
Nana	NNA	β	3-C	-11.99	-76.84	no
Philippines						
To be defined		β	3-C			no
Poland						
To be defined		β	3-C			no
Portugal						
To be defined		β	3-C			no
Romania						
Muntele Rosu	MLR	β	3-C	45.4917	25.9437	no
Russian Federation						
Khabaz	KBZ	α	3-C	43.7286	42.8975	no
Norilsk	NRI	α	3-C	69.40	88.10	no
Peleduy	PDY	α	array	59.6333	112.7003	yes
Zalesovo	ZAL	α	array	53.9400	84.8050	no
Zilim	UFA	α	array	53.85	57.05	no
Arti	ARU	β	3-C	56.4302	58.5625	yes
Kislovodsk	KIV0	β	3-C	43.9557	42.6952	yes
Obninsk	OBN	β	3-C	55.1167	36.6000	yes
Urgal	URG	β	3-C	51.0986	132.3639	no
Ussuriisk	USK	β	3-C	44.2833	132.0831	no
Seychelles						
Mahe	MSEY	β	3-C	-4.61	55.49	no
South Africa						
Boshof	BOSA	α	3-C	-28.6140	25.5555	yes
Silverton	SLR	β	3-C	-25.74	28.28	no
Spain						
Sonseca	ESDC	α	array	39.6772	-3.9617	yes

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
San Pablo de los Montes	PAB	β	3-C	39.5458	-4.3483	yes
Taburiente	TBT	β	3-C	28.679	-17.9127	yes
Sweden						
Hagfors	HFS	α	array	60.1344	13.6968	yes
Switzerland						
Alpnach	APL	β	3-C	46.9496	8.2428	yes
Thailand						
Chiang Mai	CMAR	α	array	19.00	99.00	yes
Turkey						
To be defined	XTUR	α	array	39.00	34.00	no
Turkmenistan						
Alibek	ABK0	α	array	37.93	58.12	no
Ukraine						
To be defined		β	3-C			no
United Kingdom						
Eskdalemuir	EKA	β	array	55.3332	-3.1588	yes
Wolverton	WOL	β	3-C	51.312721	-1.222806	no
United States						
Lajitas	TXAR	α	array	29.33	-103.67	yes
Lisbon	LBNH	α	3-C	44.2401	-71.9259	yes
Mount Ida	MIAR	α	3-C	34.5457	-93.5730	yes
North Pole	NPO	α	3-C	64.7714	-146.8865	no
Pinedale	PDAR	α	array	42.7667	-109.5583	yes
Pinon Flats	PFO	α	3-C	33.6092	-116.4550	no
Vanda, Antarctica	VNDA	α	3-C	-77.5139	161.8456	yes
Albuquerque	ALQ	β	3-C	34.9462	-106.4567	no
Black Hills	RSSD	β	3-C	44.1200	-104.0360	no
Blacksburg	BLA	β	3-C	37.2113	-80.4205	no
Dugway	DUG	β	3-C	40.1950	-112.8164	no
Elko	ELK	β	3-C	40.74	-115.24	no
Ely	EYMN	β	3-C	47.9470	-91.5080	no

Station Name (in alphabetical order)	Code	Type	Station Type	Latitude	Longitude	Data used by IDC as of 1 March 1995
Kanab	KNB	β	3-C	37.02	-112.82	no
Mina	MNV	β	3-C	38.43	-118.15	no
Newport	NEW	β	3-C	48.2630	-117.1200	no
Tucson	TUC	β	3-C	32.3096	-110.7846	yes
Tuckaleechee Caverns	TKL	β	3-C	35.658	-83.77	no
Tulsa	TUL	β	3-C	35.91	-95.79	yes
Western Samoa						
Afiamalu	AFI	β	3-C	-13.9093	-171.7793	yes
Zambia						
Lusaka	LSZ	β	3-C	-15.276611	28.188194	yes

SUMMARY

During the meeting of experts held between 6 February and 3 March 1995 it was not possible for the experts to agree on a single integrated international monitoring network of seismological, radionuclide, hydroacoustic and infrasound stations to verify compliance with a comprehensive test ban treaty. The options discussed by the expert groups are summarized in the attached table. The table does not include all of the options tabled in national working papers presented during the experts meetings or the intersessional meetings of last year. The table includes details of the options, initial and operating costs and an indication of the effectiveness of the option. The experts agreed that there was, in their view, a need for further expert work on the design of a single IMS. They believe that such a meeting could take place in the third part of the CD session.

SUMMARY

Technique	Option	Network	Initial Cost ($M)	Annual Cost ($M)	Effectiveness
Infrasound	1	60 Stations	10.8	3.6	Full capability over land areas and most oceans.
	2	70 Stations	12.6	4.2	Additional coverage in oceans.
Radionuclide	1A	50 Particle Samplers	11.3	2.8	Non-evasive atmospheric test detection within 20 to 30 days.
	1B	50 Particle & 50 Gas Samplers	19	3.7	Adds some detection and identification of underwater and underground nuclear tests (if venting occurs).[1]
	2A	75 Particle Samplers	16.9	4.1	Non-evasive atmospheric test detection and identification within 10 to 16 days.
	2B	75 Particle & 75 Gas Samplers	28.5	5.6	Adds some detection and idenfication of underwater and underground nuclear tests (if venting occurs).[1]
	3A	100 Particle Samplers	22.5	5.5	Non-evasive atmospheric test detection, idenfication and location within 3 to 10 days.
	3B	100 Particle & 100 Gas Samplers	38	7.5	Adds detection, identification and location of underwater and underground nuclear tests (if venting occurs).[1]
	4	10 Particle 10 Particle & Gas Samplers & 3 Airplanes	7.6[2]	4.4-13.4	Detection within 30 days. Idenfication of events detected by other techniques within 7 days (assuming immediate permission to fly and sample upon detection).
Hydroacoustic	1	2 MILS & 19 autonomous moored buoys	8.5	6.9	Global detection, discrimination and location coverage of broad ocean areas.
	2	2 MILS & 8-9 fixed cable stations	35	0.5	Detection, discrimination and location coverage in Southern Hemisphere. Discrimination in Northern Hemisphere. Relies on seismic in Northern Hemisphere for lcoation.
	3	2 MILS & 4 fixed cable stations	22	0.25	Discrimination in most oceans. Relies on seismic in Northern and Southern Hemispheres for location.
Seismic[3]	1	40 Primary Stations	5	7	Detection 1-2 KT. Location uncertainty greater than 20 Km for magnitude 4. Requires high density hydroacoustic (Options 1 or 2).
	2	46 Primary Stations	6	9	Detection 0.5-1 KT. Location within 10-20 KM for magnitude 4. Requires moderate density hydroacoustic (Option 3).
	3	53 Primary Stations	11	10	Detection 0.5-1 KT. Location within 10-20 Km for magnitude 4. This Option provides slightly better coverage in Southern Hemisphere than does Option 2. Requires moderate density hydroacoustic network (Option 3).

[1] Detection probabilities for gas samplers are estimated conservatively. Further studies on gas samplers' capabilities are on-going.

[2] The initial cost of $7.6M for the sampler and aircraft combination assumes that the aircaraft exist and can be obtained on a lease basis (it does include some modification and equipment costs). Purchase cost of aircraft would increase value by approximately $30M (according to a previous Russian Federation estimate).

[3] Options 1&2: 90% of facilities will be ready by December 1996 with on-going national investments.
Option 3: 85% will be ready.