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Working Group 1 - Verification

International Monitoring System

Report of the Expert Group

based on Technical Discussions held from 4 through 15 December 1995

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Executive Summary by Chairman of the Expert Group

As a result of the Expert Group's work a list of stations and their location for four International Monitoring System (IMS) technologies is presented as a recommendation of the Group of Experts. In addition to the 50 primary seismic stations already recommended (CD/NTB/WP.269) the Experts reached consensus on the following elements of the IMS:

1	Seismic auxiliary stations	111 Continental stations 8 Island locations
2	Hydroacoustic	2 MILS plus 4 hydrophone stations plus 5 T-phase stations
3	Infrasound	60 stations
4	Radionuclide	75 stations + 5 International Radionuclide Laboratories (IRLs) equipped with particulate samplers.

The Expert Group also discussed the role of satellites and electromagnetic pulse (EMP) stations as part of an IMS. The Russian Federation delegation stated that they would, in the very near future, make some new proposals which could result in minor changes to the consensus network. The US delegation stated that in its view a radionuclide network should be capable of detecting all radioisotopes from a nuclear explosion and should therefore comprise both particulate and noble gas detector stations. The latest estimate of costs for the IMS are similar to those presented to WG1 in earlier Expert Group working papers.

Introduction

1 The AHCNTB Working Group 1 Chairman, Ambassador Norberg issued, with the approval of WG1, a mandate for expert work on the IMS to take place between 4-15 December 1995. Scientific experts and representatives from the following Member States participated in the discussions: Argentina, Australia, Belgium, Canada, China, France, Germany, Hungary, India, the Islamic Republic of Iran, Italy, Japan, Mongolia, Netherlands, Pakistan, Romania, the Russian Federation, Sweden, United Kingdom, United States of America. The non-member States represented were: Austria, Czech Republic, Denmark, Finland, Israel, New Zealand, Norway, Republic of Korea and Switzerland. In all 82 representatives from 29 States participated.

2 The main task of the Expert Group was to determine the location of stations for an auxiliary network of seismic stations, a hydroacoustic network, an infrasound network and a radionuclide parteulate network. Consideration was also to be given to the role of noble gases and their potential contribution to the IMS. Discussions were also held on the role of satellites and EMP systems. During the 2 week period 20 meetings with interpretation were held and 20 without. Numerous informal meetings and discussions were held in addition to the formal chaired sessions.

3 Four groups were established to expedite the tasks:

Seismology	Chairman	Dr H Haak (Netherlands)
Hydroacoustic		Dr M Lawrence (Australia)
Infrasound		Dr T Murphy (USA)
Radionuclide		Dr M Matthews (New Zealand)

The seismology and hydroacoustic sessions were held between 4-8 December and infrasound and radionuclides between 11-15 December 1995.

4 The success of the Expert Group's work is due to the professionalism, enthusiasm and dedication of the participants and the excellent Chairmen who guided their work. The US and French delegations did much of the modelling and simulation work overnight and were tireless in their efforts to serve the different groups. Their work was a major contribution to achieving consensus and is gratefully acknowledged. Each Chairman was assisted by a drafting group and the contribution of Dr M Cooper (Australia) to the radionuclide group was particularly significant.

5 Many delegations presented informal papers (some of which will appear as AHCNTB working papers) to provide advice, information and clarification. Much use was made of this input in the preparation of each group's report. The final technical consensus reports of the individual groups are presented here. The results are summarised in the Table below with revised estimates of costs which are similar to those already reported in CD/NTB/WP.224 and CD/NTB/WP.269.

6 The location of stations recommended by the Expert Group is determined only on technical requirements to construct a network of stations to detect, locate and identify nuclear explosions of 1 kt or less in the atmosphere, underwater and underground. The Expert Group recognised that the proposed locations are dependent upon the willingness of the host State to participate in the IMS. It is also possible that some locations may prove logistically difficult but the Experts believe that this could only be determined during a site selection survey. It was, however, not regarded as a serious problem as slight adjustments of precise locations would, in general, not have a major effect on the capability of the IMS.

7 The delegation of the Russian Federation announced during the discussions that they would, at the earliest opportunity, table some new proposals directed to the improvements of the capabilities of the IMS. Details of the proposal were not available for Expert assessment which was regretted by a number of delegations. It is possible that acceptance of the new proposals by the AHCNTB may result in some adjustment to the Expert recommendations concerning the seismic, radionuclide and hydroacoustic networks.

8 In the preparation of their reports, the Expert Group addressed the synergy of the various systems and this is clearly seen in the way in which the primary and auxiliary seismic network works in synergy with the hydroacoustic network. The hydroacoustic network has a vital role to play in the IMS but has no redundancy built into the system and the failure of one element could have a serious effect on the performance of the IMS. Consideration should, in the view of the Experts, be given to the availability of autonomous floating-buoy systems to fill gaps caused by a catastrophic failure of one or more elements of the hydroacoustic system.

9 During the discussions the question of supplementary data was raised. The Expert Group recognised that there are numerous nationally operated monitoring systems such as seismic or radionuclide networks which could assist in the identification or location of an event detected by elements of the IMS. Not every State Party would have an IMS station on their territory but it was thought that many would like to contribute to source location and identification to minimise the number of On-Site-Inspections (OSIs) and to enhance transparency. The Experts believed that arrangements could be made to make such data available to the International Data Center (IDC) should it wish to make use of it to improve the determination of source parameters. This could be achieved by the use of the 'open-station' concept first described some time ago by the German delegation during GSE discussions on data transfer.

10 Technical discussions led by the Chairman of the Expert Group were also held on nuclear electromagnetic pulse (NEMP) monitoring and a view was expressed that, based on empirical experience the technique is capable of effectively identifying atmospheric nuclear explosions against a background of EMP signals from lightning and providing accurate location and timing of nuclear explosions. A paper was distributed by the Chinese delegation for consideration by Experts.

11 The Chinese delegation also distributed a paper which gave further explanation to their proposed satellite monitoring system. They presented three options and expressed the belief that such a system would become the only effective and reliable monitoring means in the IMS to detect nuclear explosions in space, an environment not monitored by the ground-based IMS. One option includes a proposal to use the US GPS detection system from which the data would be transmitted to a US ground-station, decoded to remove non-nuclear detection data and then transmitted to the IDC for integration with data from the IMS.

12 Finally, the Chairman of the Expert Group would like to thank all the participants of the expert meetings for their determination to succeed in providing the AHCNTB with the locations and number of stations to comprise the IMS networks. The discussions were conducted in a business-like manner, with a willingness by all participants to listen to all technical arguments and national views and to seek solutions to achieve a consensus on the technical aspects of defining an IMS. All participants agree there is much work still to be done in establishing the IMS and defining in more detail the technical details. They expressed their willingness to assist the AHCNTB at any time and in any forum to complete the work and to bring the IMS to fruition.

13 The report should be regarded as an addition to the earlier reports of the Expert Group: CD/NTB/WP.224 and CD/NTB/WP.269 which are cross referenced in the four technology reports produced by the Experts during their meetings between 4-15 December 1995.

14 The Group of Experts would like to express their appreciation and to acknowledge the help provided by the UN Secretariat, in particular Ms J Mackby, and the Interpreters who coped so well with the difficult technical terms used by the Experts.

Summary

Costs are quoted in millions of US$.

	Technique	Network	Initial Cost	Annual Cost	Effectiveness
1	Radionuclides				
	(a) particulates	75+5	16	4.5	Non-evasive atmospheric test detection and identification within 10-16 days.
	(b) noble gases*	75+5	12	1.2	Some detection and identification of nuclear tests conducted underwater or underground should any venting occur.
2	Infrasound	60	11	3.6	Full capability over land and ocean areas. Sub-kiloton location.
3	Seismic				
	(a) Primary	50	16	10	Use of primary and auxiliary data provides good global coverage of underground and underwater explosions when used synergistically with hydroacoustics.
	(b) Auxiliary	119	10	1	
4	Hydroacoustic				
	(a) hydrophones	6	16±4	0.3	Detection, location and identification in southern oceans, some identification in northern ocean areas. Relies on seismic network for detection, location and identification in the northern seas.
	(b) T-phase	5	1	0.1	

* Included without prejudice to the question of whether or not noble gases should be part of the IMS.

Report by Expert Group on Auxiliary Seismic Stations to the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification

8 December 1995

Introduction

A working group of experts (the Group) met from 4 through 8 December 1995, under the direction of Dr. Peter Marshall to consider the definition of a list of auxiliary seismic stations that would be recommended for inclusion in an International Monitoring System (IMS).

The Group believes that the primary network, which provides for the detection and initial location of seismic events throughout the world, should be supplemented by a number of auxiliary seismic stations. In its consideration of the list of auxiliary stations, the Group took into account available and planned seismic stations of suitable quality world-wide which would best complement the 50-station primary network listed in CD/1364, pp. 92-94.

The Group considered all views expressed on the overall number of auxiliary seismic stations that might be required and the geographical location of specific auxiliary stations.

The Group found invaluable the work completed by the Ad Hoc Group of Scientific Experts (GSE) in their forty-second session, 27 November-1 December 1995. The GSE considered and evaluated networks containing 30, 75, 100, 130 and 150 auxiliary stations for inclusion in the IMS. The GSE recommended a list of 111 auxiliary seismic stations to cover primarily the continents, and an additional list of 17 stations on small islands to provide for improved coverage of ocean areas. The GSE recommended that the 17 small island sites be considered by the Expert Group in conjunction with a hydroacoustic network. The GSETT-3 has provided most useful information and experience on the use of auxiliary seismic stations that has been utilized in preparing the Group's recommendation for the list of IMS auxiliary stations.

The Group benefitted from joint meetings and discussions with the group of hydroacoustic experts. The resulting recommendation by the Group reflects a selection of auxiliary stations that results in an optimum synergistic effect between the seismic and hydroacoustic networks.

Recommended Number and Location of Auxiliary Seismic Stations

As part of the mandate given by the Chairman of the Ad Hoc Committee on a Nuclear Test Ban, Working Group on Verification, the Group considered a number of factors for the selection of auxiliary stations, including:

- Optimal use of existing seismic facilities;
- Synergistic effects with the hydroacoustic network;
- Localization of events of magnitude 4 or larger with an uncertainty of less than 1,000 square kilometres;
- Coverage of the active seismic areas of the world, with emphasis on regions where earthquakes look explosion-like;
- Coverage in regions where there is extensive mining activity that produces large seismic signals;

-- Coverage of the areas where the azimuthal coverage of the primary station network is inadequate.

The Group recommends 119 auxiliary seismic stations for the IMS with locations provided in Table 1. The list includes 111 stations to cover primarily the continents and 8 additional stations to provide improved coverage of ocean areas acting in conjunction with the hydroacoustic stations. The recommended auxiliary seismic stations are located in 57 countries.

The Group made two changes to the list of 111 stations on the continents which were recommended by the GSE based on new technical information provided to the Group.

The Group examined in detail the synergy aspects of the stations on small islands with respect to the recommended hydroacoustic network. The Group therefore included 8 such stations in the network.

In the recommended list of stations, 79 are located in active seismic areas (this number includes 11 sites in areas of both seismic activity and mining activity). Eighteen additional sites are located in areas of large mining activity. Twenty-two are located at sites selected primarily to increase the azimuthal coverage of the primary network. The purposes of each of the stations were provided in Table 1 and Table 2 of the report by the GSE to the Conference on Disarmament on their forty-second session.

The Group recognizes that the availability of some of the stations in Table 1 will depend on consideration of the costs of upgrading existing installations and on the willingness of the host countries to provide these facilities.

The Group recommends that there be a provision for adding or deleting auxiliary stations in the IMS. Such flexibility is needed because with time, new stations will become available which offer improved capability, and some existing auxiliary stations may need to be eliminated for various reasons (e.g., non-performance, lack of host country support).

The Group agreed on the general characteristics and requirements of the auxiliary stations. These are provided in Appendix 1.

Operational Status of the Auxiliary Seismic Stations

The recommended list of auxiliary stations is composed of:

-- Stations that are already available and can be adopted with a minimum of new investment, including the addition of communications links;
-- Stations that currently exist, but require an upgrade to their present equipment, including improved seismographic equipment and communications links;
-- New stations which would need to be installed specifically for treaty monitoring purposes, e.g., in remote areas or in some developing countries.

The status of the individual recommended auxiliary seismic stations is summarized in Table 2. This table is based on the best information available to the Group at this time. A mark in the "Now" column under "Operational Status" indicates that the station is currently operational with equipment that meets, or nearly meets, the expected specifications. A mark in the "Now" column under "Communications to the IDC" indicates that a communications link exists today to the International Data Centre (IDC). A mark under the "1996" column indicates that there are definite plans and programs underway to complete these facilities by the end of 1996. A mark under the "New" column indicates that there are not now definite plans or programs to complete these facilities.

Eighty-seven of the stations are currently operational with modern digital equipment, although 43 of these require the addition of communications links to the IDC. There are ongoing plans and programs by individual States to upgrade the seismic and communications equipment at a number of sites within the next year. If these programs are completed on schedule, by the end of 1996 a total of about 86 auxiliary seismic stations will be operational with communications links to the IDC.

Beyond the current plans and ongoing programs, there are an additional 17 sites that must be installed with new or significantly upgraded equipment. New plans and resources must be made available for these sites. Upgraded communications equipment must be added at 16 other sites.

Required Investment Costs and Overall Annual Operating Costs

The Group estimates that approximately 10 million ($US) in new capital investment will be required to bring the full recommended list of auxiliary stations to operational capability with communications links to the IDC. This estimation could change as updated information on the sites requiring new facilities becomes available.

The annual cost for communications from the recommended sites to the International Data Centre is estimated to be 1-2 million ($US).

The annual operational costs for the recommended stations vary significantly depending on a wide variety of conditions, including:

- Locations of the sites (sites in harsh environmental conditions or remote locations will incur higher operational costs);
- National purposes for the station existence (stations which have been installed for other purposes, such as earthquake hazard analysis, may reduce the operational costs due to sharing);
- Personnel costs (salaries for personnel operating and maintaining stations may vary considerably from site to site).

Based on these considerations, the Group can make only a preliminary estimate of the range for the annual operational and maintenance costs of the recommended auxiliary stations. The cost range is about 5-10 million ($US).

Improvements in Overall IMS Capability Provided by the Addition of the Recommended Auxiliary Stations

The main improvement will be in the location and identification capabilities in the most active seismic zones of the world. The resulting combined primary-auxiliary network should, in the view of the Group, be capable of locating seismic events in continental areas and coastal regions of magnitude 4 or higher with an uncertainty of less than 1,000 square kilometres, and of providing sufficient azimuthal coverage to allow source characterization criteria to be applied to such events. Calibration of the combined network, as described in Appendix 2, is required to achieve this capability. Calibration is an elaborate ongoing process, but one which, if done carefully, will result in significant improvements in the precision of event locations within the first few years of network operation.

Auxiliary stations located on small islands may, in selected cases, be capable of recording signals from explosions ("T-Phases") propagating through the oceanic sound channel. When used in conjunction with seismic and hydroacoustic stations, they have the potential of significantly reducing location errors in the broad ocean areas. This is more useful in the southern hemisphere Pacific Ocean, where seismic locations can have errors much larger than 1,000 square kilometres.

Next Steps

The Group recommends that the calibration process, which is beginning with GSETT-3, be established immediately for the recommended primary/auxiliary seismic stations of the IMS system. This requires a systematic analysis of suitable events as they occur and results in a gradual improvement of the accuracy of the system. The need for calibration is one reason why the Group recommends continued development and testing of the IMS.

The Group recommends that extensive use be made of additional regional and local seismic stations and networks to help in the calibration of the primary/auxiliary IMS seismic network. All countries are encouraged to submit the results of their local network analyses to assist in this calibration process.

The Group notes that a number of States are prepared to make supplementary data available from seismic stations not included in the recommended list of auxiliary stations for distribution by the IDC. These data might provide State Parties with a capability for event location and characterization which could even be beyond the capability of the primary/auxiliary IMS network. Such supplementary seismic data, put at the disposal of the CTBT Organization by the State Parties, could provide an effective means for the resolution of ambiguous events. The Group recommends that the IDC maintain a current list of such stations.

The Group recommends that steps be taken to allow for the authentication of such supplementary data if requested by the contributing State Party. For this purpose, it has been recommended that whenever a State Party designates a national facility as a source of supplementary data, the IDC shall test and validate that facility at the expense of the relevant State Party. Following validation, the IDC may call upon data from that facility in a manner similar to that used with auxiliary facilities. The State Party may also voluntarily transmit data from supplementary facilities to the IDC. Such data shall be archived at the IDC and processed in the standard manner, whenever a specific need arises.

The Group expects that the question of data processing and event characterization will be dealt with comprehensively in discussions on synergy and in reporting on the future function of the IDC. The Group encourages seismic experts to participate and contribute in the future relevant discussions.

Reservation

The delegation of the Russian Federation intends to submit in the near future proposals directed to the improvement of the capabilities of the network. In this connection, the network which is presented in this paper is not final.

Table 1
List of Seismological Stations Comprising the Auxiliary Network

Location	Station	Code		Latitude	Longitude
Canada	Mould Bay, N.W.T.	MBC	1	76.24 N	119.36 W
Canada	Iqaluit, N.W.T.	FRB	2	63.75 N	68.55 W
Canada	Bella Bella, B.C.	BBB	3	52.18 N	128.11 W
Canada	Sadowa, Ont.	SADO	4	44.75 N	79.14 W
Canada	Dease Lake, B.C.	DLBC	5	58.42 N	130.06 W
Canada	Inuvik, N.W.T.	INK	6	68.31 N	133.52 W
Denmark	Sondre Stromfjord, Greenland	SFJ	7	67.05 N	50.30 W
United States	Kodiak Island, AK	KDC	8	57.75 N	152.49 W
United States	Attu Island, AK	ATTU	9	52.80 N	172.70 E
United States	Newport, WA	NEW	10	48.26 N	117.12 W
United States	Yreka, CA	YBH	11	41.73 N	122.71 W
United States	Elko, NV	ELK	12	40.74 N	115.24 W
United States	Albuquerque, NM	ALQ	13	34.95 N	106.46 W
United States	Tuckaleechee Caverns, TN	TKL	14	35.66 N	83.77 W
Mexico	La Paz, Baja	LPBM	15	24.17 N	110.21 W
Mexico	Tepich, Yucatan	TEYM	16	20.21 N	88.34 W
Mexico	Tuzandepeti, Veracruz	TUVM	17	18.03 N	94.42 W
Costa Rica	Las Juntas de Abangares	JTS	18	10.29 N	84.95 W
Guatemala	Rabir	RDG	19	15.01 N	90.47 W
United States	San Juan, PR	SJG	20	18.11 N	66.15 W
Venezuela	Santo Domingo	SDV	21	8.89 N	70.63 W
Venezuela	Puerto la Cruz	PCRV	22	10.18 N	64.64 W
France	Kourou, Guiana	KOG	23	5.21 N	52.73 W
Brazil	Pitinga	PTGA	24	0.73 S	59.97 W
Brazil	Rio Grande do Norte	RGNB	25	6.91 S	36.95 W
Peru	Cajamarca	CAJP	26	7.00 S	78.00 W
Peru	Nana	NNA	27	11.99 S	76.84 W
Chile	Limon Verde	LVC	28	22.59 S	68.93 W
Argentina	Coronel Fontana	CFA	29	31.61 S	68.24 W
Bolivia	San Ignacio	SIV	30	15.99 S	61.07 W
Iceland	Borgarnes	BORG	31	64.75 N	21.33 W
Norway	Spitsbergen Array	SPITS	32	78.18 N	16.37 E
Sweden	Hagfors Array	HFS	33	60.13 N	13.70 E
United Kingdom	Eskdalemuir Array	EKA	34	55.33 N	3.16 W
Switzerland	Davos	DAVOS	35	46.84 N	9.79 E
Czech Republic	Vranov	VRAC	36	49.31 N	16.60 E
Russian Federation	Kislovodsk Array	KIV0	37	43.96 N	42.70 E
Russian Federation	Obninsk	OBN	38	55.12 N	36.60 E
Russian Federation	Kirov	KIRR	39	58.43 N	50.02 E
Russian Federation	Arti	ARU	40	56.43 N	58.56 E
Romania	Muntele Rosu	MLR	41	45.50 N	25.90 E
Italy	Enna, Sicily	ENAS	42	37.50 N	14.30 E
Greece	Anogia, Crete	IDI	43	35.28 N	24.89 E
Morocco	Midelt	MDT	44	32.82 N	4.61 W
Egypt	Kottamya	KEG	45	29.93 N	31.83 E

Table 1
List of Seismological Stations Comprising the Auxiliary Network

Location	Station	Code		Latitude	Longitude
Ethiopia	Furi	FURI	46	8.90 N	38.68 E
Djibouti	Arta Tunnel	ATD	47	11.53 N	42.85 E
Uganda	M'Barara	MBRU	48	0.36 N	30.40 E
Zambia	Lusaka	LSZ	49	15.28 S	28.19 E
Namibia	Tsumeb	TSUM	50	19.13 S	17.42 E
Botswana	Lobatse	LBTB	51	25.01 S	25.60 E
Zimbabwe	Bulawayo	BUL	52		
Rep South Africa	Sutherland	SUR	53	32.38 S	20.81 E
Madagascar	Antananarivo	TAN	54	18.92 S	47.55 E
Gabon	Bambay	BAMB	55	1.66 S	13.61 E
Mali	Kowa	KOWA	56	14.50 N	4.02 W
Senegal	M'Bour	MBO	57	14.39 N	16.96 W
Armenia	Gami	GNI	58	40.05 N	44.72 E
Israel	Eilath	MBH	59	29.79 N	34.91 E
Israel	Parod Array	PARD	60	32.55 N	35.26 E
Oman	Wadi Sarin	WSAR	61	23.00 N	58.00 E
Islamic Rep of Iran	Kerman	KRM	62	30.28 N	57.07 E
Islamic Rep of Iran	Masjed-e-Solayman	MSN	63	31.93 N	49.30 E
Saudi Arabia	Ar Rayn	RAYN	64	23.60 N	45.60 E
Kyrghyzstan	Ala-Archa	AAK	65	42.64 N	74.49 E
Kazakhstan	Kurchatov Array	KURK	66	50.72 N	78.62 E
Kazakhstan	Borovoye	BRVK	67	53.06 N	70.28 E
Kazakhstan	Makanchi	MAK	68	46.81 N	81.98 E
India	To Be Recommended by India	#1	69		
India	To Be Recommended by India	#2	70		
India	To Be Recommended by India	#3	71		
India	To Be Recommended by India		72		
China	Baijiatuan	BJT	73	40.02 N	116.17 E
China	Kunming	KMI	74	25.15 N	102.75 E
China	To Be Recommended by China		75		
China	To Be Recommended by China		76		
Nepal	Everest	EVN	77	27.96 N	86.82 E
Russian Federation	Zilim	UFA	78	53.85 N	57.05 E
Russian Federation	Magadan	MA2	79	59.58 N	150.78 E
Russian Federation	Seymchan	SEY	80	62.93 N	152.37 E
Russian Federation	Yuzhno-Sakhalinsk	YSSK	81	46.95 N	142.75 E
Russian Federation	Tiksi	TIXI	82	71.66 N	128.87 E
Russian Federation	Talaya	TLY	83	51.68 N	103.64 E
Russian Federation	Urgal	URG	84	51.10 N	132.36 E
Russian Federation	Bilibino	BIL	85	68.04 N	166.37 E
Russian Federation	Yakutsk	YAK	86	62.01 N	129.43 E
Japan	Kamikawa-asahi, Hokkaido	JKA	87	44.12 N	142.50 E
Japan	Kumigami, Okinawa	JOW	88	26.83 N	128.29 E
Japan	Hachijojima, Izu Island	JHJ	89	33.12 N	139.82 E
Japan	Ohita, Kyushu	JNU	90	33.12 N	130.88 E

Table 1
List of Seismological Stations Comprising the Auxiliary Network

Location	Station	Code		Latitude	Longitude
Philippines	Tagaytay, Luzon	TGY	91	14.10 N	120.94 E
Philippines	Davao, Mindanao	DAV	92	7.09 N	125.57 E
Indonesia	Sulawesi	SULW	93	4.00 S	120.00 E
Indonesia	Parapat, Sumatra	PSI	94	2.70 N	98.92 E
Indonesia	Jayapura, New Guinea	JAY	95	2.52 S	140.70 E
Indonesia	Kupang, Timor	KUG	96	10.16 S	123.59 E
Indonesia	Jakarta, Java	PACI	97	6.50 S	107.00 E
Indonesia	Sarong, Jazirah Doberai	SWI	98	0.86 S	131.26 E
Antarctica	Palmer Station	PMSA	99	64.77 S	64.07 W
Antarctica	Georg Neumayer Base	VNA	100	70.61 S	8.37 W
Antarctica	South Pole	SPA	101	90.00 S	115.00 E
Papua New Guinea	Port Moresby	PMG	102	9.41S	147.15 E
Papua New Guinea	Bialla	BIAL	103	5.31 S	151.05 E
Australia	Narrogin, WA	NWAO	104	32.93 S	117.23 E
Australia	Fitzroy Crossing, WA	FITZ	105	18.1 S	125.64 E
Australia	Charters Towers, QLD	CTA	106	20.09 S	146.25 E
Solomon Islands	Honiara, Guadalcanal	HNR	107	9.43 S	159.95 E
France	Port Laguerre, New Caledonia	NOUC	108	22.10 S	166.30 E
Viti Levu Fiji	Monasavu	MSVF	109	17.75 S	178.05 E
New Zealand	Urewera, North Island	URZ	110	38.26 S	177.11 E
New Zealand	Erewhon, South Island	EWZ	111	43.51 S	170.85 E
Chile	Rapa Nui, Easter Island	RPN	112	27.16 S	109.43 W
Argentina	Ushuaia	USHA	113	55.00 S	68.00 W
Japan	Chichijima, Ogasawara	JCJ	114	27.10 N	142.18 E
United States	Guam, Marianias Islands	GUMO	115	13.59 N	144.87 E
New Zealand	Raoul Island	RAO	116	29.15 S	177.52 W
Western Samoa	Afiamalu	AFI	117	13.91 S	171.78 W
Cook Islands	Rarotonga	RAR	118	21.21 S	159.77 W
Norway	Jan Mayen Island	JMI	119	70.92 N	8.72 W

Footnotes:				
#1 Group Recommends: New Delhi	NDI	69	26.68 N	77.22 E
#2 Group Recommends: Hyderabad	HYB	70	17.42 N	78.55 E
#3 Group Recommends: Kodaikanal	KOD	71	10.20 N	77.50 E

Table 2
Operational Status of the Auxiliary Seismic Stations

	Location	Station	Code	Operational Status			Communications to IDC		
				Now	1996	New	Now	1996	New
1	Canada	Mould Bay, N.W.T.	MBC	x			x		
2	Canada	Iqaluit, N.W.T.	FRB	x			x		
3	Canada	Bella Bella, B.C.	BBB	x			x		
4	Canada	Sadowa, Ont.	SADO	x			x		
5	Canada	Dease Lake, B.C.	DLBC	x			x		
6	Canada	Inuvik, N.W.T.	INK	x			x		
7	Denmark	Sondre Stromfjord	SFJ		x			x	
8	United States	Kodiak Island, AK	KDC		x			x	
9	United States	Attu, AK	ATTU	x			x		
10	United States	Newport, WA	NEW	x			x		
11	United States	Yreka, CA	YBH	x				x	
12	United States	Elko, NV	ELK	x				x	
13	United States	Albuquerque, NM	ALQ	x			x		
14	United States	Tuckaleechee Caverns, TN	TKL	x			x		
15	Mexico	La Paz, Baja	LPBM			x			x
16	Mexico	Tepich, Yucatan	TEYM		x			x	
17	Mexico	Tuzandepeti, Veracruz	TUVM			x			x
18	Costa Rica	Las Juntas de Abangares	JTS	x				x	
19	Guatemala	Rabir	RDG			x			x
20	United States	San Juan, PR	SJG	x			x		
21	Venezuela	Santo Domingo	SDV	x				x	
22	Venezuela	Puerto la Cruz	PRCV			x			x
23	France	Kourou, Guiana	KOG	x			x		
24	Brazil	Pitinga	PTGA		x			x	
25	Brazil	Rio Grande do Norte	RGNB		x			x	
26	Peru	Cajamarca	CAJP		x				x
27	Peru	Nana	NNA	x				x	
28	Chile	Limon Verde	LVC	x				x	
29	Argentina	Coronel Fontana	CFA	x				x	
30	Bolivia	San Ingnacio	SIV			x			x
31	Iceland	Borgarnes	BORG	x			x		
32	Norway	Spitsbergen Array	SPITS	x			x		
33	Sweden	Hagfors Array	HFS	x			x		
34	United Kingdom	Eskdalemuir Array	EKA	x			x		
35	Switzerland	Davos	DAVOS	x			x		
36	Czech Republic	Vranov	VRAC	x			x		
37	Russian Federation	Kislovodsk Array	KIVO	x			x		
38	Russian Federation	Obninsk	OBN	x			x		
39	Russian Federation	Kirov	KIRR	x					x
40	Russian Federation	Arti	ARU	x			x		
41	Romania	Muntele Rosu	MLR	x					x
42	Italy	Enna, Sicily	ENAS	x				x	
43	Greece	Anogia, Crete	IDI	x					x
44	Morocco	Midelt	MDT	x					x
45	Egypt	Kottamya	KEG	x					x

Table 2
Operational Status of the Auxiliary Seismic Stations

	Location	Station	Code	Operational Status			Communications to IDC		
				Now	1996	New	Now	1996	New
46	Ethiopia	Furi	FURI		x			x	
47	Djibouti	Arta Tunnel	ATD	x			x		
48	Uganda	M'Barara	MBRU		x			x	
49	Zambia	Lusaka	LSZ	x			x		
50	Namibia	Tsumeb	TSUM	x			x		
51	Botswana	Lobatse	LBTB	x			x		
52	Zimbabwe	Bulawayo	BUL		x				x
53	South Africa	Sutherland	SUR	x				x	
54	Madagascar	Antananarivo	TAN			x			x
55	Gabon	Bambay	BAMB		x			x	
56	Mali	Kowa	KOWA		x			x	
57	Senegal	M'Bour	MBO		x				x
58	Armenia	Garni	GNI	x				x	
59	Israel	Eilath	MBH	x				x	
60	Israel	Parod Array	PARD	x				x	
61	Oman	Wadi Sarin	WSAR		x			x	
62	Islamic Rep of Iran	Kerman	KRM	x					x
63	Islamic Rep of Iran	Masjed-e-Solayman	MSN	x					x
64	Saudi Arabia	Ar Rayn	RAYN		x			x	
65	Kyrghyzstan	Ala-Archa	AAK	x				x	
66	Kazakhstan	Kurchatov Array	KURK	x				x	
67	Kazakhstan	Borovoye	BRVK	x				x	
68	Kazakhstan	Makanchi	MAK	x				x	
69	India	To Be Recommended by India	#						
70	India	To Be Recommended by India	#						
71	India	To Be Recommended by India	#						
72	India	To Be Recommended by India	?						
73	China	Baijiatuan	BJT	x			x		
74	China	Kunming	KMI	x				x	
75	China	To Be Recommended by China							
76	China	To Be Recommended by China							
77	Nepal	Everest	EVN	x					x
78	Russian Federation	Zilim	UFA	x				x	
79	Russian Federation	Magadan	MA2	x				x	
80	Russian Federation	Seymchan	SEY	x				x	
81	Russian Federation	Yuzhno-Sakhalinsk	YSSK	x				x	
82	Russian Federation	Tiksi	TIXI	x				x	
83	Russian Federation	Talaya	TLY	x				x	
84	Russian Federation	Urgal	URG	x				x	
85	Russian Federation	Bilibino	BIL	x				x	
86	Russian Federation	Yakutsk	YAK	x				x	
87	Japan	Kamikawa-asahi, Hokkaido	JKA	x				x	
88	Japan	Kumigami, Okinawa	JOW	x				x	
89	Japan	Hachijojima, Izu Island	JHJ	x				x	
90	Japan	Ohita, Kyushu	JNU	x				x	

Table 2
Operational Status of the Auxiliary Seismic Stations

	Location	Station	Code	Operational Status			Communications to IDC		
				Now	1996	New	Now	1996	New
91	Philippines	Tagaytay, Luzon	TGY	x					x
92	Philippines	Davao, Mindanao	DAV	x			x		
93	Indonesia	Sulawesi	SULW			x			x
94	Indonesia	Parapat, Sumatra	PSI	x					x
95	Indonesia	Jayapura, New Guinea	JAY			x			x
96	Indonesia	Kupang, Timor	KUG			x			x
97	Indonesia	Jakarta, Java	PACI		x				x
98	Indonesia	Sarong, Jaziraj Doberai	SWI			x			x
99	Antarctica	Palmer Station	PMSA	x				x	
100	Antarctica	Georg Neumayer Base	VNA	x				x	
101	Antarctica	South Pole	SPA	x				x	
102	Papua New Guinea	Port Moresby	PMG	x			x		
103	Papua New Guinea	Bialla	BIAL			x			x
104	Australia	Narrogin, WA	NWAO	x			x		
105	Australia	Fitzroy Crossing, WA	FITZ	x			x		
106	Australia	Charters Towers, QLD	CTA	x			x		
107	Solomon Islands	Honiara, Guadalcanal	HNR	x			x		
108	France	Port Laguerre, New Cal.	NOUC	x					x
109	Viti Levu Fiji	Monasavu	MSVF	x				x	
110	New Zealand	Urewera, North Island	URZ			x			x
111	New Zealand	Erewhon, South Island	EWZ			x			x
112	Chile	Rapa Nui, Easter Island	RPN	x			x		
113	Argentina	Ushuaia	USHA			x			x
114	Japan	Chichijima, Ogasawara	JCJ	x				x	
115	United States	Guam, Marianias Islands	GUMO	x			x		
116	New Zealand	Raoul Island	RAO		x			x	
117	Western Samoa	Afiamalu	AFI	x			x		
118	Cook Islands	Rarotonga	RAR	x			x		
119	Norway	Jan Mayen Island	JMI	x				x	

Footnote # :
The Group recommends New Delhi (NDI), Hyderabad (HYB) and Kodaikanal (KOD) for these sites

Appendix 1

General Characteristics and Requirements of the Auxiliary Stations

The Group agreed to the following items on the general technical characteristics and requirements of the auxiliary stations:

- The equipment at the auxiliary stations should meet defined minimum technical specifications. These minimum technical requirements should follow as closely as possible those requirements developed and adopted for the primary stations in terms of instrumentation and operational characteristics (CD/NTB/WP.224). These specifications should be modified as new knowledge or technologies become available.

- Ideally, the auxiliary stations should operate with a reliability as close as practical to that expected for stations in the primary network. However, because of operational considerations, this may not be possible.

- All auxiliary stations must be provided with communications equipment that allow the International Data Centre to have immediate and automatic access to data which has been recorded at the site. The type of communications equipment needed at most auxiliary stations should not be as expensive to acquire and operate as that required for the primary stations.

- Some auxiliary stations should be able to act as a partial backup to stations in the primary network should an extended problem with a primary station arise.

- Even though most auxiliary stations were established for national purposes, i.e., contributing in a larger sense to a national scientific goal, priority must be given to the CTBT monitoring role in the operation of the stations and provision of data to the IDC. Such a priority of purpose should be firmly established and maintained by the national authorities in cooperation with the CTBT Organization.

Appendix 2

Calibration of the Primary/Auxiliary Network

To locate events with an uncertainty of less than 1,000 square kilometres requires some calibration of the recommended primary/auxiliary seismic-hydroacoustic network. The procedure for locating seismic events depends on a knowledge of the velocity of seismic waves within the Earth. This velocity, however, varies from one region to another, and even within regions, because of variations in geological structure. This introduces uncertainties into the seismic location of events.

If the net effect of the velocity variations along the entire path from the source to the seismic station can be estimated, a correction can be made and the precision of the seismic location improved. This calibration process depends on the use of events for which the locations are known very precisely. This is an elaborate ongoing process, but one which, if done carefully, will result in significant improvements in the precision of event locations within the first few years of network operation.

The events used in the calibration process may be explosions (non-nuclear) or earthquakes which are recorded by local networks and subjected to detailed analysis. In GSETT-3, participating National Data Centres have been encouraged to submit the results of their local network analysis in order to begin the network calibration process.

Report of Hydroacoustic Expert Group to the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification

8 December 1995

Introduction

The hydroacoustic expert group was asked to provide a proposal for the hydroacoustic component of the International Monitoring System (IMS). This proposal was to address such issues as the locations of the hydroacoustic stations, synergy with other technologies and various technical aspects. This report, developed over the week 4 through 8 December, constitutes that requested proposal.

This report builds upon the previous reports of this expert group, in particular the substantial report from February 1995 (CD/NTB/WP.224) together with the supplementary report of August 1995 (CD/NTB/WP.269).

Hydroacoustic Component of the IMS

The hydroacoustic component of the IMS is intended to provide detection, location and identification of events in the wide ocean areas in conjunction with the other IMS systems. Hydroacoustic stations are of two types: hydrophone stations and T-phase (island seismic) stations. Hydrophone stations are sufficiently sensitive to detect explosions below and above the ocean surface, as well as within islands or coastal regions, at great range. T-phase stations are less sensitive, though fully capable of observing underwater explosions, as well as explosions on islands, at great range. The hydroacoustic network is sparse and small (11 stations) compared to the other networks because of very favourable propagation conditions in the oceans (in the Sound Fixing and Ranging, i.e. SOFAR, waveguide). The proposed hydroacoustic network makes use of synergy with the seismic system to reduce costs, especially in the northern hemisphere where the seismic network density is greatest.

This document sets out the locations and types of stations in the proposed network. The network consists of 6 hydrophone stations, including the 2 MILS stations, and 5 T-phase stations, as displayed in Figure 1. The hydrophone stations are located predominantly in the southern hemisphere where inter-station distances are greatest and the higher sensitivity of these stations is used to best advantage. The T-phase stations supplement the hydrophone stations, enhancing location capability in the southern hemisphere, and extending coverage of all types into the northern hemisphere.

Locations in the proposed network were chosen after consideration of bathymetric shadowing, network configuration for location by triangulation, availability of power and communications. Sites were chosen for advantageous coverage, such as the capacity to observe two major oceans from a single site, or to cover regions with complex bathymetry that are blocked to other hydroacoustic stations. As far as possible, the major oceans are covered by triangular subnetworks for good location capability. The hydrophone station sites were chosen for short cable runs to the local axis of the SOFAR channel. T-phase sites were chosen for efficient conversion from ocean-borne acoustic waves to seismic waves; in practice this has meant finding islands with underwater slopes that drop steeply to the SOFAR axis.

Locations

The proposed hydrophone stations are listed in Table 1.

Table 1. Hydrophone stations

Station	Ocean	Latitude	Longitude	Existing
Wake Island	NE Pacific	19.3	166.6	yes
Ascension Island	mid Atlantic	-8.0	-14.4	yes
Cape Leeuwin	SE Indian	-34.4	115.1	no
BIOT/Chagos Arch. *	NW Indian	-7.3	72.4	no
Crozet Island	SW Indian	-46.5	52.2	no
Juan Fernandez Island	SE Pacific	-33.7	-78.8	no

Preliminary suggestions for hydrophone locations are given in Table 2. These locations, which are the nearest suitable positions at the SOFAR depth, will need to be refined by detailed survey prior to installation. The approximate cable length to the hydrophone is also given (for those stations which do not yet exist). It is useful to work with these (approximate) hydrophone locations here because they can be used to determine the approximate cable length required for each station. The cable length affects the cost of the installation of each hydrophone station.

Table 2. Hydrophone locations and cable lengths

Hydrophone	Latitude	Longitude	Cable length (km)
Wake	19.3	162.6	existing
Ascension 1	-7.8	-14.6	existing
Ascension 2	-8.9	-14.6	existing
Ascension 3	-7.9	-14.3	existing
Cape Leeuwin	-35.0	114.2	120
BIOT/Chagos Arch. 1 *	-6.3	71.0	150
BIOT/Chagos Arch. 2 *	-7.6	72.5	30
Crozet 1	-46.3	52.2	30
Crozet 2	-46.7	51.7	50
Juan Fernandez 1	-33.3	-78.8	30
Juan Fernandez 2	-33.9	-78.8	30

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* Appears without prejudice to the question of sovereignty.

Two hydrophones are specified for three of the four new stations. For each of these stations the two hydrophones lie on opposite sides of the island. This is in order to achieve coverage of the ocean without blockage by the island. The exception, Cape Leeuwin on the southwest corner of Australia, covers both the Indian and Southern Oceans. The longest cable run, at the BIOT/Chagos Archipelago* station, is required to avoid blocking of signals by the archipelago, which is a large feature in the northern Indian Ocean.

Note that there are two hydrophones at the same location at Wake Island. These hydrophones are arranged vertically with a separation of 90 m. The advantage of having a pair of hydrophones is to achieve some redundancy and robustness.

The proposed T-phase stations are listed in Table 3. The number of elements is the number of seismic detectors to be established at the location. Where there are two elements, they are generally placed on opposite sides of the island. None of these stations exist at present.

Table 3. T-phase stations

Station	Latitude	Longitude	Existing	Seismometers
Flores Is.	39.3	-31.3	no	2
Guadeloupe	16.3	-61.1	no	1
Queen Charlotte Is.	52.1	-131.5	no	1
Clarion Is.	18.2	-114.6	no	2
Tristan da Cunha	-37.2	-12.5	no	2

The Revillagigedo Island group contains a number of islands, including Clarion Island. Further investigation may reveal that one of the other islands of this archipelago may be more suitable for the current purpose. However, this would not change the network in any substantial way.

The group noted that the availability of some of the stations in Tables 1 and 3 will depend on the willingness of countries to host these facilities.

Synergy with other components of the IMS

The hydroacoustic component of the IMS was introduced to provide accurate event characterization (identification), and good localisation capability over the ocean areas (in particular over the southern hemisphere) where less coverage is provided by the seismic network.

Some 60 to 70% of seismic events occur in ocean areas. The hydroacoustic network proposed will have exceptional capability to characterize events in the ocean. Thus the combination of the hydroacoustic component with the seismic component will allow the IDC to issue improved event characterizations.

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* Appears without prejudice to the question of sovereignty.

Seismic stations within the proposed seismic component of the IMS network which have known T-phase capability for receiving undersea explosions are Rarotonga and Tahiti. There are technical grounds to believe that Jan Mayen in northern waters and Easter Island in the South Pacific will also receive T-phases from such explosions.

Simulations for a 1 kiloton, well-coupled, underwater explosion detected and located by the hydroacoustic network in synergy with the seismic network (primary and auxiliary) indicate a location capacity of the order of 1000 square kilometres. However, this localization performance within the South Pacific is achieved for these explosions within the simulations only by including the T-phase component of a further 3 seismic stations from within the proposed IMS seismic networks (Easter Island, Tahiti, and Rarotonga). The additional T-phase signals from these explosions may be used in the same way as the signals from T-phase stations that form part of the hydroacoustic network. The additional synergy gained from the inclusion of T-phase data from these three stations is believed to provide the lowest cost, practical means to achieve this performance. However, the effectiveness of this additional synergy should be reviewed as test results become available. Similarly, the T-phase capability available from the Jan Mayen station provides an additional synergy to further improve the identification capability of the network in northern waters. The effectiveness of this synergy should be reviewed following an evaluation of the suitability of Jan Mayen T-phase capability.

The synergy with atmospheric IMS techniques can also enable an above water blast to be more reliably and accurately reported. The atmospheric IMS component can be expected to give the initial detection and location for such an event. However, by using the hydroacoustic data it may be expected that the location estimation can be considerably improved.

Technical Characteristics

The technical characteristics of the stations were discussed and agreement was reached on the following issues.

Table 4. Hydroacoustic Station Technical Characteristics

Parameter	Hydrophone Stations	T-Phase Stations
Frequency Band	1-100 Hz	1-20 Hz
Sampling Rate	240 samples/second	50 samples/second
Response Type	Flat to pressure	Flat to velocity
Sensitivity	62 dB re 1 microPascal in a one Hertz band (spectral level), approximately 82 dB re 1 microPascal wideband (flat spectrum)	1 nanometre/sec wideband
Sensor Type	Hydrophone (with spares); only one hydrophone per cable active at a time	Vertical seismometer - borehole or vault emplacement.

Parameter	Hydrophone Stations	T-Phase Stations
Other deployment notes	Two cables allowed at island sites; one each at opposite sides of the island to prevent blockage by the island	Up to 3 seismometer sites allowed at each island T-phase station, to prevent attenuation of the signal by the island mass.
Quantization	24 bit analog-to-digital conversion	24 bit analog-to-digital conversion
Dynamic Range	144 decibels	144 decibels
Data Transmission Mode	Continuous	Undecided (push-pull at minimum)

The experts agree that the hydrophone stations should consist of fixed cable systems. However, autonomous moored-buoy hydroacoustic stations, though not considered to be an alternative to long-lived fixed-cable stations, are important to provide flexible, low-cost (relative to fixed-cable) test capability to optimise the position of fixed-cable stations in partially-shadowed areas, to replace fixed-cable stations temporarily in cases of delayed implementation, or while making major repairs.

Costs

Costs for the fixed-cable hydrophone stations are estimated to be $3-$5 million ($US) for procurement, site preparation and deployment. The annual (recurring) costs are estimated to be $50 thousand ($US), including communication and minimal maintenance. This annual estimate assumes the availability of existing communication facilities.

Costs for the T-phase stations are estimated to be at least $160 thousand ($US) for procurement and installation per seismometer (up to 3 may be used), assuming local infrastructure is present that includes a drill rig and local power. Initial costs could increase significantly for installations in remote areas. The annual costs are estimated to be $24 thousand ($US) using push-pull communication.

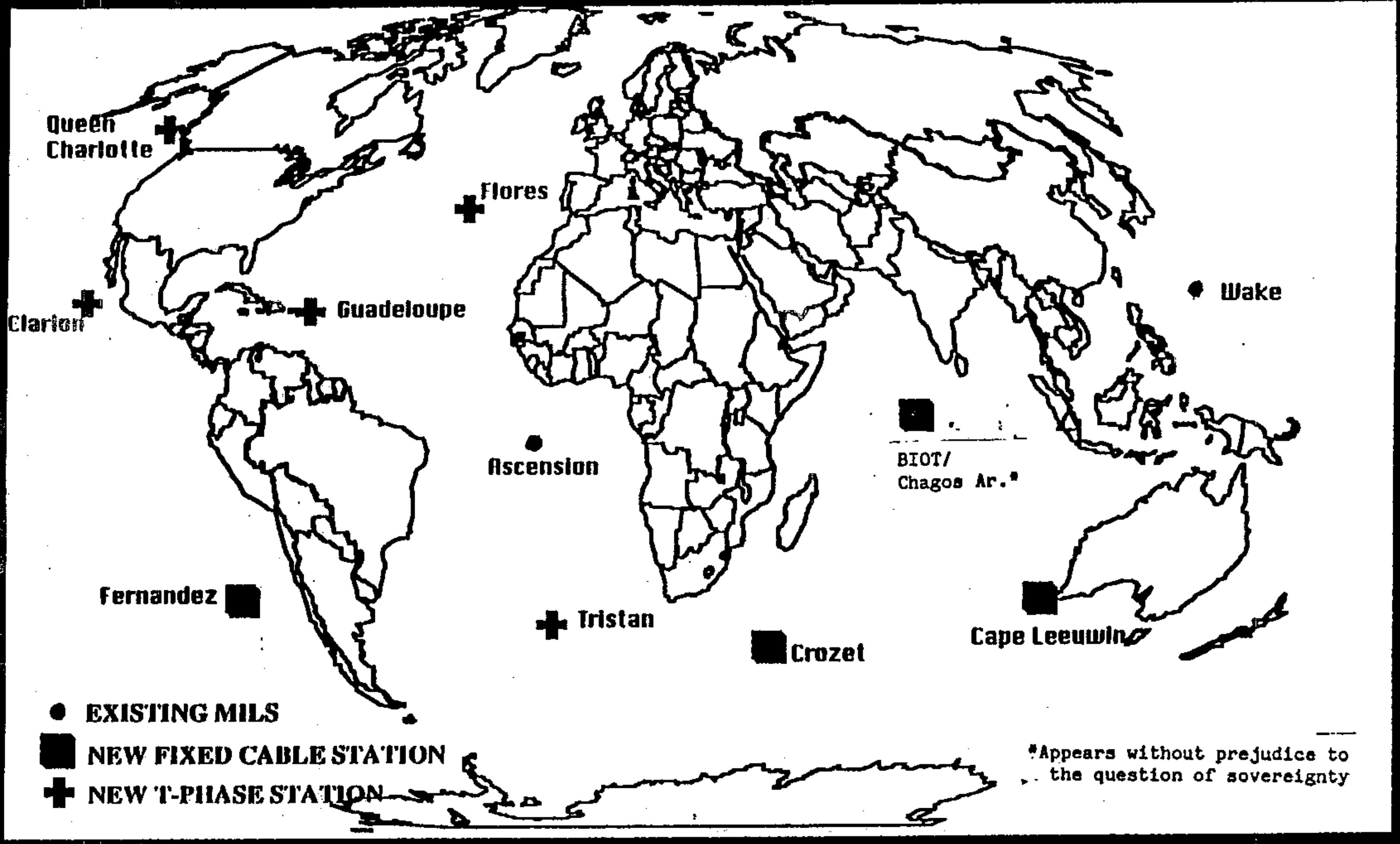
Summary

The hydroacoustic expert group recommends locations for each of the 6 hydrophone and 5 T-phase stations. In order to achieve the required IMS performance it is necessary to perform T-phase processing on four of the stations from within the seismic network. The latest recommendations on a number of technical issues are presented together with the latest estimate of the costs.

Reservation

The Russian delegation intends to submit in the near future proposals directed to the improvement of the capabilities of the network. In this connection, the network which is presented in this paper is not final.

Figure 1. Proposed Hydroacoustic Network for International Monitoring System. Circles are existing Missile Impact Location Stations (MILS), squares are new fixed-cable stations, and crosses are new T-phase stations.



*Appears without prejudice to the question of sovereignty

Report of the Infrasound Expert Group to the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification

15 December 1995

Introduction

The infrasound expert group was given a mandate by Working Group One of the Conference on Disarmament's Ad Hoc Committee on a Nuclear Test Ban to develop a proposal for an infrasound monitoring network, to consist of 48 to 60 stations. The mandate also requested the experts to co-locate the stations with seismic stations where practical. Supplementary instructions from the Friend of the Chair for the International Monitoring System directed the experts to design a system to detect approximately one kiloton explosions at a range of 2000 to 2500 km and to provide global coverage. The experts were also asked to provide information on the station design and cost estimates if possible. In this report the experts propose an infrasound network consisting of 60 stations, provide estimates of the detection and location capability of the network, and provide some minor modifications to the equipment specifications given in CD/NTB/WP.224. We have not attempted to repeat the entire discussion given in WP.224, as much of it remains unchanged, and we refer the reader to that document for a fuller discussion of this technology.

Network Design Considerations

Considerable development in our understanding of the performance of infrasound systems has occurred since our last meeting in August 1995. Much more actual performance data from previously deployed systems has been made available, and more sophisticated modelling tools have been developed. Two groups have developed modelling tools which attempt to take the same physical effects into account, although the details of how this is done are somewhat different. A comparison of the models shows that when given the same inputs they produce similar results, giving us confidence in the modelling process itself. There was a range of opinions on the estimates for the level of background noise, however, and to a lesser extent on the relationship between signal amplitude as a function of propagation distance, which resulted in a range of estimates for the detection capability for a given network design. These differences arose due to the fact that the groups operated in the past in different areas and with different types of equipment, and due to differences in assumptions about the conditions under which the network will be required to operate.

The operational experience of the United States research group showed that in their view a judicious choice of sites can give substantially lower average wind noise backgrounds than previously anticipated, particularly over continental land masses. In the view of this group these average values are the appropriate measure of performance, taking due account of the variations about the average in a statistical sense, which results in a longer effective detection range than previously considered. This in turn means that it is possible to achieve a specified level of detection with fewer stations than previously thought. In the view of this group, it is feasible to obtain global 1 kt detection with 50 stations composed of four element arrays.

The experience of the French research group indicated somewhat higher average background levels and showed that there can be extended periods in which the noise at a given site is far higher than the average. In the view of this group the network must be designed to operate satisfactorily under these more stressful conditions, which naturally leads to a requirement for a larger network or to the use of detecting arrays with a larger number of elements than the standard four-element design.

It was found that the estimates of location capability by the two research groups were not particularly sensitive to the background noise estimates, so the experts decided to proceed by optimizing the network for location accuracy, within the constraints of total network size given us by the Ad Hoc Committee. The detection capability of this network is then described as a range of values obtained by using the background noise assumptions of the various research groups.

The overall IMS will be composed of a number of sub-networks utilizing different monitoring technologies. The total performance of the system will be determined not only by the capabilities of each sub-network but also by the synergy between the various technologies. For example, infrasound can identify explosions from other types of low-frequency sounds, but cannot uniquely identify an explosion as being nuclear. Other atmospheric monitoring techniques, however, can resolve this issue. Another example is that the sparseness of a 48 to 60 station infrasound network introduces some difficulties with location accuracy, particularly over remote ocean areas, but this can be remedied by making use of information from other monitoring technologies.

One opinion expressed in the experts' discussions is that there would be considerable synergy between infrasound and EMP monitoring, should both technologies be used. In this view, the inadequacy of infrasound in both event identification and location accuracy, and also event identification at high altitude, can be effectively remedied by EMP monitoring.

Network Proposal

The principal charge for the infrasound experts in this session was to produce a network design with a list of potential station locations. The choice of sites is driven primarily by four factors : geometry, geography, local wind noise, and co-location with other facilities. In a world without oceans the station locations would simply be determined by geometry and local noise, and we would attempt to position them such that the distance between stations was uniform and the network would therefore provide the same location capability everywhere. This is clearly not possible, but our goal of optimum location capability still leads us to attempt to distribute the stations as evenly as we can. The degree to which this can be achieved is determined by geography - in some cases, particularly in ocean areas, there are only a few islands in the region and the choice of sites is therefore quite constrained. These choices are further constrained by the fact that some islands pose severe logistical problems, making them unacceptably difficult or expensive for use in the IMS. If a variety of sites are available to cover a certain geographical area the remaining two factors come into play. Low surface wind noise is the next most important criterion because of the tremendous improvement in station performance if a suitable site can be found. This effect often varies dramatically on a very local scale, so it must be kept in mind that the site locations as given in this document are approximate and can be expected to move, perhaps as much as 100 km, once detailed site surveying begins. Finally, practical considerations of shared maintenance, data transmission, and infrastructure make it cost-effective to co-locate the infrasound stations with other IMS stations or with existing scientific or meteorological stations whenever possible.

Taking all of these factors into account, the experts have come up with a proposed IMS infrasound network. It must be kept in mind that this network was designed with scant regard to political considerations and only limited knowledge of the details of local conditions. The experts recognize that practical considerations may mean that some sites in our proposed network may ultimately turn out to be unsuitable for IMS purposes. The proposed stations are of course subject to agreement of the host states for their acceptance and location.

The proposed network is comprised of 60 stations, which are listed in Table 1. The table also indicates whether the site is co-located with another facility. This network has 53 sites co-located with sites already selected or proposed for other IMS or meteorological stations, including 24 primary seismic stations.

The use of more elements in the detecting arrays results in an increase in the signal-to-noise ratio which can be obtained at a given site, and also improves the redundancy of the station, making it less sensitive to the failure of an individual sensor. The improvement in signal to noise can be used to improve the detection range from a site with good noise conditions or to enable the use of a site with high noise conditions. Because we do not have precise noise characterization data for all of the proposed sites in the infrasound network and because some of the sites in the southern oceans are somewhat remote and will have to cover large areas, the experts recommend that the option to use larger arrays be retained for those sites where they may prove necessary. In particular, we recommend the use of a large array for the proposed station at the South Pole because of reliability considerations.

The performance goal of the network is to detect approximately one kiloton explosions anywhere in the world, and to locate them to within a radius of 100 km or better. The location capability is meant to be as good and as uniform as possible, given the constraints of geography. The degree to which these goals are met depends on the model used to evaluate network performance, as discussed previously. Using the United States group's model, the estimated network performance easily meets the goals, with detection levels well below 1 kt worldwide and location uncertainty of less than 50 km radius over most of the world. Maps showing the estimated detection thresholds and location capability are shown in figures 1 and 3 respectively.

When evaluated using the French group's model the performance goals are approached but not met with a maximum network size of 60 stations. The detection threshold is estimated to be between 1 and 2 kt over most of the earth, with an increase up to as much as 5 kt at high latitudes. The estimated detection thresholds are shown in figure 2. The location accuracy at 1 kt is shown in figure 4. The large location errors in some regions shown in this figure are due to the fact that the estimated probability of detecting the event in these regions is low in this model. To get a better idea of the location capacity for events which are readily detected, the location accuracy for a 5 kt explosion is shown in figure 5. In this case we see the location accuracy is within 100 km over most of the earth.

Equipment Specifications

Technical specifications for the equipment were given previously in CD/NTB/WP.224, and are largely correct as given in that paper. As in that paper, the sensor the experts recommend is a wideband microbaragraph. Based upon the experience of many research groups, the experts recommend the use of noise-reducing pipes or porous hoses, although the experts recognize that quantitative characterization of the gains from such pipes is still under review. The configuration of the standard four-element station remains the same as given in WP.224.

Upon consideration of the larger data set which has been made available since WP.224 was written, the experts now recommend that the frequency band should be 0.02 Hz to 5.0 Hz, reduced from the previous range of 0.01 to 10 Hz. This will allow the sampling rate to be reduced from 20 samples per second to 10 samples per second. The specifications for sensitivity (0.01 Pa) and dynamic range (80 dB) are unchanged from before.

Data Handling

Upon further reflection, the experts now recommend that data from the infrasound stations be sent continuously to the IDC, rather than using the scheme with reduced rate continuous data flow and triggered event data considered previously. The trigger criteria will be different for each site, depending on local noise conditions, and will also vary seasonally. It will be easier and more cost-effective to gain experience with the system by learning to operate it optimally, using complete data at the IDC, than to attempt to do it on-site at the station locations. Having continuous data will be more useful for developing improved event characterization techniques.

Cost

The experts consider that the previous cost estimates given in WP.224 are still correct, with an average cost of 180 thousand US$ per four-element station. The total cost for a 60 station network of such stations is estimated at 10.8 million US$, and the operating cost is approximately 3.6 million US$ per year. The use of larger arrays at selected stations will result in a modest increase in the station cost. The total additional cost for the construction of larger arrays is estimated to be 0.4 million US$.

Directions for Further Work :

The experts believe that this report completes the conceptual phase of the IMS infrasound network design. In order to make further progress, it will be necessary to perform detailed technical work in some areas. The most important issue is to try to develop a commonly accepted method for estimating the network performance. Other issues 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;

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.

Time for Deployment :

As discussed above, there are a number of issues which need to be resolved to move from a conceptual network to 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 the financial and administrative arrangements have been made. This 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	

Proposed Infrasound Station List

#	Latitude	Longitude	Location	Country	Co-location*
1	-40.73	-70.55	Paso Flores	Argentina	P
2	-67.60	62.87	Mawson Base, Ant.	Australia	P
3	-32.93	117.23	Narrogin	Australia	A
4	-42.07	147.21	Hobart	Australia	
5	-12.30	97.00	Cocos Is.	Australia	R?
6	-19.93	134.33	Warramunga	Australia	P
7	7.50	134.50	Palau Is.	Rep. of Belau	
8	-16.29	-68.13	La Paz	Bolivia	P
9	-15.64	-48.01	Brasilia	Brazil	P
10	50.25	-95.88	Lac du Bonnet	Canada	P
11	16.00	-24.00	Cape Verde Is.	Rep.of Cape Verde	R?
12	5.18	18.42	Bangui	Cen. African Rep.	P
13	-27.00	-109.20	Easter Is.	Chile	A, R?
14	-33.80	-80.70	Juan Fernandez Isl.	Chile	H
15	40.00	116.00	Beijing	China	A
16	25.0	102.8	Kunming	China	A
17	76.53	-68.67	Dundas, Greenland	Denmark	M
18	11.3	43.5	Djibouti	Djibouti	A
19.	0.00	-91.70	Galapagos Islands	Ecuador	R?
20	-10.00	-140.00	Marquesas Island	France	
21	-22.10	166.30	Port LaGuerre	France (New Cal.)	A
22	-49.15	69.10	Kerguelen	France	R?
23	-17.57	-149.57	Tahiti Is.	France	P
24	5.21	-52.73	Kourou, Fr. Guiana	France	A
25	48.85	13.70	Freyung	Germany	P
26	-70.60	-8.37	Georg von Neumayer	Germany (Ant.)	A
27	13.59	77.43	Gauribidanur	India	P
28	35.74	51.39	Tehran	Iran	
29	6.67	-4.86	Dimbokro	Ivory Coast	P
30	36.00	140.00	Tsukuba	Japan	M
31	50.43	58.02	Aktubinsk	Kazakhstan	P
32	-1.27	36.80	Kilima Mbogo	Kenya	P
33	-18.80	47.48	Antananarivo	Madagascar	M
34	47.99	106.77	Javhklant	Mongolia	P
35	-19.13	17.42	Tsumeb	Namibia	A
36	-44.00	-176.00	Chatham Island	New Zealand	R?
37	69.58	25.51	Karasjok	Norway	P
38	-26.33	-57.33	Villa Florida	Paraguay	P

39	33.65	73.25	Pari	Pakistan	P
40	-4.13	152.11	Rabaul	Papua New Guinea	
41	38.30	-28.00	Azores Is.	Portugal	H, R?
42	56.76	37.05	Dubna	Russian Fed.	NDC
43	53.00	158.00	Petropavlovsk	Russian Fed.	P
44	44.00	132.00	Ussuriysk	Russian Fed.	P
45	53.94	84.81	Zalesovo	Russian Fed.	P, R?
46	-28.60	25.42	Boshof	South Africa	P
47	35.56	8.70	Thala	Tunisia	P
48	-37.00	-12.30	Tristan da Cunha Is.	UK	H, R?
49	-8.00	-14.30	Ascension Is.	UK	H, R?
50	32.00	-64.50	Bermuda Is.	UK	R?
51	64.77	-146.89	Eilson, Alaska	USA	P
52	-75.50	-83.55	Siple Base, Ant.	USA	
53	-77.50	161.84	Windless Bight, Ant.	USA	
54	48.26	-117.12	Newport, Wa.	USA	A
55	33.60	-116.45	Pinon Flats, Ca.	USA	P
56	28.13	-177.22	Midway Is.	USA	H, R?
57	19.59	-155.28	Central Puna, Hawaii	USA	R?
58	19.16	166.38	Wake Is.	USA	R?
59	-90.0	115.0	South Pole, Ant.	USA	A
0	-5.00	72.00	BIOT/Chagos Archipelago	UK**	H,M

* P = IMS primary seismic station
H = proposed IMS hydroacoustic station
M = existing meteorological station
A = proposed IMS auxiliary seismic station
R? = possible IMS radionuclide station
NDC = National Data Centre

** appears without prejudice to the question of sovereignty

Report of Radionuclide Expert Group to the Ad Hoc Committee on a Nuclear Test Ban Working Group on Verification

15 December 1995

Executive Summary

The experts considered both components of the radionuclide monitoring system - particulate and noble-gas monitoring - but were unable to reach consensus on the inclusion of noble gases. Operational parameters pertaining to particulate monitoring were agreed and locations for monitoring stations were identified. While experts from most countries represented in the group considered that, in order for the radionuclide network to be acceptable, both noble-gas and particulate monitoring would be required, doubts were expressed by some about the practicability of including noble-gas monitoring at this stage.

1. Introduction

Following on from earlier expert work in May and August of 1994 (CD/NTB/WP.171) and in February (CD/NTB/WP.224) and August 1995, (CD/NTB/WP.269), the radionuclide expert group was requested to provide a proposal for a radionuclide network of the International Monitoring System (IMS). The group was given the task to consider the detection, identification and location in so far as possible, of a 1 kiloton nuclear explosion carried out underground, underwater or in the atmosphere.

The mandate for the group is summarized as follows:

- to develop a single optimised network for particulate monitoring, making every effort to make maximum possible use of existing facilities and infrastructures;
- to consider the selection of equipment for radionuclide monitoring and sample analysis at certified laboratories;
- if possible, to consider the contribution that noble gas monitoring could make to the IMS;
- consider triggering by specific radionuclides;
- consider synergy and cost effectiveness.

2. Particulate Monitoring

2.1 Network design

The primary criterion used to establish the number of particulate monitoring stations within the radionuclide network is a 90% probability of detection by at least one station for radionuclides from a 1 kt nuclear explosion conducted in the atmosphere, within a period of approximately 14 days, including the reporting time of up to 3 days. The source term for particulate radionuclides was discussed in CD/NTB/WP.224.

The experts agreed that the particulate monitoring system should contain a network of stations, which has been optimized in accordance with modelling procedures described in working documents CD/NTB/WP.224 and CD/NTB/WP.274. Discussion focused on a proposed network of 75 stations, with another 5 stations located at International Radionuclide Laboratories (IRL), previously named 'Certified Laboratories'. It is anticipated that such a baseline network of at least 80 stations would achieve a level of performance which closely meets the above criterion.

A list of proposed stations and their locations is attached (Annex), together with an example of a global coverage map.

Although the US experts preferred a radionuclide network of 100 stations, they are willing to accept an optimised network of 80 - 100 stations with the understanding that at least 80 stations would have noble gas capability. The Russian experts considered that 50 stations would have been sufficient, and the network of 75 stations with another 5 stations at IRLs is, in their view, a consensus compromise.

The group recognised that the availability of some of the stations in the Annex will depend on consideration of the costs of upgrading existing installations and on the willingness of the host countries to provide these facilities.

2.2 Technical specifications

Based on the technical parameters of the stations and the analysis modes which have been agreed in previous meetings (CD/NTB/WP.171 and CD/NTB/WP.224), the network design and operation have been based on the following specifications:

- air sampling rate - 500 m^3/h, with >80% collection efficiency ($0.2\mu m$ diameter);

- sampling period - 24 hours;
- reporting time - up to 3 days;
- transport / decay time - up to 24 hours;
- place of analysis - preferably on-site, however, if transit within 24 hours, analysis at a supporting laboratory is acceptable;
- mode of operation - automatic where possible, manual where required;
- detector specification - high resolution, high purity germanium detector with relative efficiency of greater than, or equal to, 40 %;
- network down time - less than 5%;
- station down time - less than one week on a continuous basis and less than 15 days total per year.

With respect to the sampling rate of 500 m^3/h, the experts accept that this flow rate is higher than required for the simple detection of a 1 kt non-evasive atmospheric test, and may even allow the detection of a test with a yield of perhaps one hundred times lower. The higher flow rate is recommended to allow for sufficient material to be collected to assure the certainty of radionuclide identification, event timing, localization, and ultimately attribution through further in-depth analysis at more than one IRL.

One delegation was of the view that only minimum detectable concentrations need to be specified, with other parameters left to States Parties.

2.3 Operational Aspects

In addition to the technical parameters of the stations, key aspects of the network operation were discussed, with conclusions as follows.

(a) Use of existing stations

It is accepted that suitably located, existing stations which already meet, or could be readily upgraded to meet, the IMS requirements, would be integrated into the IMS.

(b) Triggering

A maximum of one day sampling is necessary for adequate meteorological backtracking. Opinions were expressed that a longer sampling period could be adopted for routine operations, or single measurements of aggregated filters, with an operational change to one day sampling and analyses when triggered by other technologies, or some means within the radionuclide system. While, in principle, there are merits in the triggering proposal, operational difficulties exist, such as the costs and complexity of supporting a triggering infrastructure.

Overall, there was a final consensus that any triggering would not be practicable or cost effective. The option of triggering was therefore withdrawn from further consideration, with continuous one day sampling at all stations being considered as the most practical means of operation, ensuring operational consistency across the network.

(c) Alarm criteria

The group recognized that alarm criteria need to be established. The group understands that such criteria will be discussed in the framework of the forthcoming review of the draft Friend of the Chair/IDC working paper.

(d) International Radionuclide Laboratories (IRLs)

To perform detailed analysis of samples suspected of containing fission products originating in a recent nuclear explosion, as defined in agreed alarm criteria, and to assure the analytical quality of the IMS, the experts recommend the establishment of between five and ten IRLs. These laboratories would comprise existing facilities under contract to the Technical Secretariat. The certification criteria for an IRL should be established by the Technical Secretariat. A minimum specification for an IRL would be the capability to conduct high resolution gamma spectrometric analyses and radiochemistry with alpha and beta counting/spectrometry. Experts indicated laboratories in their respective countries which might be considered as potential IRLs, as listed in the Annex.

In addition to the IRLs, there is a need for 'Supporting Laboratories' which would be existing national facilities supporting sampling stations within each country. These Supporting Laboratories may have an additional regional role of providing technical support for monitoring stations in neighbouring countries which lack the necessary infrastructure. This support includes system maintenance, analysis of samples from manual samplers, and quality assurance of on-site analysis. It is conceivable that some IRLs may also function as a supporting laboratory.

It is envisaged that each IRL would be responsible for the oversight of quality control of analysis carried out at two or more supporting laboratories.

3. Noble Gas Monitoring

The detailed mandate given to the expert group for its consideration of noble-gas monitoring was as follows:

a. Provide a detailed report on the contribution noble-gas radionuclide detection could make to the detection and identification of nuclear explosions as part of an IMS.

b. Consider the role of noble gases in a system specifically targeted against clandestine nuclear tests both above and below ground.

c. Indicate whether or not particulate and noble-gas detectors should be co-located.

d. Document the cost and availability of noble-gas detection equipment.

e. Provide a clear indication of experts' views.

Unlike the particulate monitoring case, relatively few experts had direct experience of noble-gas monitoring, and the group relied heavily on comments from those with relevant experience in addressing the points in this mandate, as described below.

3.1 The contribution noble-gas monitoring could make

There was consensus agreement within the expert group that the following three basic facts are relevant in consideration of noble-gas systems:

- Nuclear explosions produce the xenon isotopes;

- The total production of Xe-133 is of the order of 10^{16} Bq per kilotonne (kt) fission;

- Xenon can be detected in the atmosphere, and its concentration

In view of the above facts, the Expert Group considered that under certain circumstances, it would be useful to undertake the monitoring of noble gases, particularly in the following three categories:

- a nuclear test conducted evasively in the atmosphere under conditions in which particulates were removed by rain-out;
- a test conducted underwater, with partial venting of gases;
- a test conducted underground, with partial venting of gases.

It was suggested that any potential treaty violater would deliberately try to conduct any test in an evasive manner, making the inclusion of noble-gas monitoring in the IMS very important. There was a range of opinions within the group concerning whether or not evasive test scenarios were realistic, however. Doubts were expressed about the possibility or practicability of conducting successful evasive tests above ground, and about the degree of venting from an underground test.

3.2 Technical aspects of noble-gas monitoring

Drawing heavily on the knowledge of the few experts present with experience in noble-gas monitoring, the group considered the following technical aspects of network design: source-term design criterion; detection probabilities; modelling; backgrounds; reactor/test discrimination; and equipment, as described below.

(a) Source term

The independent fission yield of Xe-133m and Xe-133 from a 1 kt detonation is about 10^{13} Bq, and this would therefore be the minimum source term from any evasive atmospheric or underwater test. It is expected, however, that the volatility of the I-133 precursor would lead to a higher source term in these cases, with a figure of 10^{15} being accepted as the amount of Xe produced within 12 hours of detonation. This was the figure adopted in CD/NTB/WP.224.

With underground tests, the situation is more complex as the degree of venting may vary from zero to the maximum of 10^{16} Bq. A level of 10% of the Xe-133 produced within 12 hours of detonation, or 10^{14} Bq, had previously been adopted (CD/NTB/WP.224) as an appropriate source term in this scenario. This is equivalent to 1% of the cumulative fission yield. A view was expressed that this might be unrealistically high, and that perhaps less than 0.01% would be more realistic, with a resulting source term of 10^{12} Bq. This is 10% of the independent fission yield. There was no final consensus on this point, although the modeling results considered were based on the 10^{14} Bq source term.

(b) Detection probability

The results of modeling studies, which were presented at the meeting, indicated that an optimised network of 80 stations would have a detection probability greater than 80% for underwater and atmospheric tests (assuming a Xe-133 sensitivity of 1 mBq/m^3) after 10 days.

In the case of underground tests, there was an apparent discrepancy between US and Canadian predictions, with a 70% detection probability estimated by the former with 1mBq/m^3 sensitivity, while the Canadian modelling indicated a sensitivity of about 20 μBq/m^3 would be required to achieve global coverage. A venting scenario of 10% of the xenon produced within 12 hours of detonation (10^{14} Bq) was adopted in both cases. The atmospheric transport models used by both countries are similar and have been verified against observations of particulate releases from volcanic eruptions and tracer gas releases. The apparent differences arise from different presentation methods. The US approach considers uniform global coverage with tests on an equal-area grid. The Canadian approach considered individual test sites.

Both models showed, however, that a global network could be designed, using currently available equipment, to give a high probability (70 - 80%) of detection of xenon from a 1 kt test. A lower underground venting rate would reduce this detection probability, possibly to less than 20% for 0.01% venting.

(c) Xenon backgrounds

Noble-gas measurements have indicated that the xenon background is variable, particularly in areas where there are nuclear reactors, with backgrounds up to 20 mBq/m^3 being normal (depending on location and meteorological conditions). In most regions of the world, however, the xenon background is very low, particularly in the southern hemisphere. It was considered that information on background levels would be important in any monitoring network in order to avoid false alarms, supporting the view that daily sampling would be advantageous as a monitoring practice, as in the particulate monitoring network.

(d) Discrimination between reactors and tests

The two isomers of Xe-133 (Xe-133 and its metastable state Xe-133m) can be used to aid discrimination between routine nuclear reactor emissions and nuclear explosions. The Xe-133m : Xe-133 ratio provides source information, with burn-up in a reactor resulting in a much lower ratio than that arising from nuclear explosions.

(e) Equipment for noble-gas monitoring

Presentations by three delegations with direct experience in noble-gas monitoring indicated that it is feasible and practicable to measure low levels of Xe isotopes in the atmosphere. One particular system, currently under development in the USA, is expected to be ready for field evaluations within 2 years. It is a fully automated system with an expected detection capability of about 20 μBq/m^3, and a projected capital cost of $150,000, with an annual running cost of about $15,000, assuming co-location, with particulate systems. Another system developed in Sweden has been operational for 5 years with detection capability of 1 mBq/m^3.

3.3 Network design

If a global noble-gas network was to be established, the experts agreed that many of the considerations applying to the particulate network would apply to the noble gas network as well.

Accordingly, an optimised 80 station network could involve co-location of xenon monitoring equipment with the particulate system in order to reduce infrastructure and communication costs.

The technical parameters involved in the particulate network would also apply in the noble-gas network, with details as follows:

- Sampling rate: 10 m^3/d;
- Sample processing: within 24 hours;
- Sample analysis: on-site unless transfer to laboratory possible within 24 h;
- Automatic/manual: ideally, samples would be automatically analyzed;

- Detection mode: beta-gamma coincidence or high resolution gamma spectrometry;
- Existing stations: should be used;
- Downtime: the network should be 95% operational at any time.

As an alternative to a global network, one delegation suggested the possibility of using existing nationally funded noble-gas stations, with the international organisation purchasing data from these stations, and perhaps incorporating them into the IMS later when their value had been proven.

3.4 Expert views

Based on the facts pertaining to noble-gas production in nuclear explosions, there was consensus agreement that noble gas monitoring had the potential to make a valuable contribution to the IMS, with the majority of experts present supporting its inclusion. In particular, the deterrence function of the noble-gas monitoring was highlighted, with any evader either having to test deeper underground in order to avoid venting, and hence with increased potential for seismic detection; or deeper underwater, with increased potential for hydroacoustic detection.

In view of the lack of experience of noble-gas monitoring, however, some experts questioned the practicability of including it in the IMS at this stage, with uncertainties in evasion scenarios, venting levels, background levels, modelling accuracy, equipment performance and the feasibility of its operation, and the general lack of noble-gas data, being cited as reasons for this view.

So while the majority of experts present supported the inclusion of noble-gas monitoring in the IMS, and the technical parameters of a global network could have been agreed upon if such a network were to be adopted, there remained a range of opinions concerning the necessity for noble-gas monitoring to be part of the IMS, and it was not possible to achieve consensus on the issue at this stage.

4. Network Costs

4.1 Particulate monitoring

The Expert Group reconsidered the network cost estimates given previously in CD/NTB/WP.171 and CD/NTB/WP.224. Following experience gained subsequent to those working documents, the experts agreed the following estimates were more appropriate for monitoring stations.

Capital costs - manual analysis $150,000 ; fully automatic stations - $200,000

Annual operating costs - manually operated - $55,000; automatic - $25,000

4.2 Noble-gas monitoring

The estimated capital cost of the xenon sampler is $150,000 and the annual operating cost is $15,000.

4.3 Total network

The experts considered proposed station locations in their respective countries and assessed the types of equipment which would be required there, and the extent of any upgrading required for existing stations. This allowed a more realistic estimate to be made of the total cost of a network including both particulate and noble-gas monitoring, as follows:

Total capital costs -

- Facility up-grade costs: $1M
- Particulate monitoring: $14.9M
- Noble-gas monitoring: $12.0M

Annual operating/maintenance costs -

- Particulate monitoring: $4.5M
- Noble-gas monitoring: $1.2M

For remote stations or under extreme environmental conditions, operating costs could double.

5. Network establishment time

In the working paper, CD/NTB/WP.171, a network establishment time of 3-5 years has been estimated assuming that only a few existing stations could be included in the radionuclide monitoring system. The proposed locations of stations, as given in Table 1, indicate that existing stations can be used in more than 50% of the sites, subject to upgrading equipment or facilities. In view of this, an establishment time of 3 years is considered realistic and a substantial part of the network could go into operation in a shorter period of time.

6. Other Issues

6.1 Supplementary Airborne Monitoring Stations

The Russian Federation proposed that the use of aircraft could be of benefit as a supplementary means for the collection of radionuclides, both particulate and noble gas. The Russian Federation agreed to provide further information on a proposal in a forthcoming working paper. Essentially, under this proposal, aircraft would be based at defined locations, world-wide, and would be deployed following a trigger from another technology of the IMS. Aircraft would be nationally owned and not part of the IMS. Their deployment would be confined to areas over international oceans. The State Party operating an aircraft would be responsible for its provision, and for equipping and maintaining the aircraft. Financial reimbursement of the State Party would only occur when the aircraft had been deployed.

6.2 Reservation

The Russian delegation intends to submit in the near future proposals directed to the improvement of the capabilities of the network. In this connection, the network which is presented in this paper is not final.

Annex

Proposed locations for International Radionuclide Monitoring Stations

Proposed International Radionuclide Laboratories

Figures

Figure 1. Proposed International Radionuclide Monitoring Network

Figure 2. Contour map for the proposed International Radionuclide Monitoring Network

Annex . Proposed Locations for International Radionuclide Monitoring Stations.

n	Station	Region	Country	Location	Lat. (+/-)	Long (-/+)	Existing Station
1	AR001	S.America	Argentina	Buenos Aries - (IRL Station)	-34.00	-58.00	X
2	AR002		Argentina	Bariloche	-41.10	-71.25	
3	AR003		Argentina	Salta	-24.00	-65.00	
4	BR001		Brazil	Rio de Janeiro	-22.54	-43.10	X
5	BR002		Brazil	Recife	-8.00	-35.00	
6	CL001		Chile	Punta Arenas	-53.08	-70.55	X
7	GF001		French Guyana	Cayenne	5.00	-52.00	
8	CA002	N.America	Canada	Vancouver	49.25	-123.17	X
9	CA003		Canada	Resolute	74.70	-94.90	X
10	CA004		Canada	Yellowknife	62.45	-114.48	X
11	CA005		Canada	St. John's	47.00	-53.00	X
12	MX001		Mexico	Baja	28.00	-113.00	
13	PA001		Panama	Panama City	8.92	-79.60	X
14	US001		USA	Sacramento, CA	38.70	-121.40	X
15	US002		USA	Melbourne, FL	28.25	-80.60	X
16	US003		USA	Ashland, KS	37.19	-99.77	
17	US004		USA	Charlottesville, VA	38.00	-78.00	X
18	US005		USA	Salchaket, AK	64.40	-147.06	X
19	US006		USA	Sand Point, AK	55.00	-160.00	
20	AQ001	Antarctica	Antarctica	Dumont d'Urville	-66.00	140.00	
21	AQ002		Antarctica	Mawson	-67.60	62.50	
22	AQ003		Antarctica	Halley	-76.00	-28.00	
23	AQ004		Antarctica	Palmer	-64.46	-64.04	X
24	CM001	Africa	Cameroon	Douala	4.20	9.90	
25	ET001		Ethiopia	Filtu	5.50	42.70	
26	LY001		Libya	Misratah	32.50	15.00	
27	MR001		Mauritania	Nouakchott	18.00	-17.00	
28	NI001		Niger	Bilma	18.00	17.00	
29	TZ001		Tanzania	Dar es Salaam	-6.00	39.00	
30	IS001	Europe	Iceland	Reykjavik	64.40	-21.90	X
31	NO001	——	Norway	Svalbard	78.00	15.00	
32	PT001		Portugal	Vila do Proto (Azores)	37.44	-25.40	X
33	SE001		Sweden	Stockholm	59.39	17.96	X
34	RU001		Russian Fed.	Dubna - (IRL Station)	56.76	37.05	X
35	GE001		Germany	Schauinshland	47.90	7.90	X
36	CN001	Asia	China	Beijing - (IRL Station)	39.75	116.20	X
37	CN002		China	Guangzhou	23.00	113.30	
38	CN003		China	Lanzhou	35.80	103.30	
39	IN001		India	Nagpur	21.20	79.05	X
40	IR001		Iran	Tehran	35.00	52.00	X
41	JP001		Japan	Okinawa	26.18	127.18	
42	JP002		Japan	To be Named > (IRL Station)	36.20	139.00	
43	KW001		Kuwait	Kuwait City	29.00	48.00	X
44	MY001		Malaysia	Kuala Lumpur	2.55	101.47	X
45	MN001		Mongolia	Ulan-Bator (Ulaanbaatar)	47.52	107.03	X
46	PH001		Philippines	Quezon City	14.45	121.03	X
47	RU002		Russian Fed	Petropavlovsk	53.00	158.00	X
48	RU003		Russian Fed	Zalesovo	53.94	84.81	X
49	RU004		Russian Fed	Peleduy	59.63	112.70	X
50	RU005		Russian Fed	Ussuriysk	43.70	131.90	X
51	RU006		Russian Fed	Bilibino	68.02	168.26	X
52	RU007		Russian Fed	Kirov	58.59	49.68	X
53	RU008		Russian Fed	Nordvik - (or equivalent)	74.10	111.50	

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Annex Proposed Locations for International Radionuclide Monitoring Stations (continued).

n	Station	Region	Country	Location	Lat. (+/-)	Long (-/+)	Existing Station
54	TH001	Asia	Thailand	Bangkok	13.75	100.50	
55	AU001	Australia	Australia	Melbourne - (IRL Station)	-37.45	144.58	X
56	AU002		Australia	Perth	-31.96	115.80	X
57	AU003		Australia	Darwin	-12.40	130.70	X
58	AU004		Australia	Townsville	-19.20	146.80	X
59	AU005		Australia	Cocos Is.	-12.00	97.00	
60	AU006		Australia	MacQuerie Is.	-54.00	159.00	
61	CL002	Oceans	Easter Island (Chile)	Hang-Roa (Isla de Pascua)	-27.07	-108.35	X
62	EC001		Galapagos (Ecuador)	I. San Cristobal	-1.00	-89.20	
63	FR002		Reunion Is. (FR)	Reunion Is.	-21.05	55.57	X
64	FR003		Kerguelen Is. (FR)	Port-aux-France	-49.00	70.00	
65	FR004		Lesser Antilles (FR)	Guadeloupe-Pt. a Pitre	17.00	-62.00	
66	FR005		Tahiti (FR)	Papeete	-17.00	-150.00	X
67	KI001		Christmas Is. (Kiribati)	Kiritimati	2.00	-157.00	
68	NZ001		New Zealand	Kaitaia	-35.12	172.27	X
69	NZ002		New Zealand	Rarotonga	-21.25	-159.75	X
70	NZ003		New Zealand	Chatham Is.	-44.00	-176.00	
71	NZ004		Fiji	Nandi	-18.00	177.50	
72	PG001		Papua New Guinea	New Hanover	-3.00	150.00	
73	UK002		BIOT/Chagos Ar.(UK)*	Diego Garcia	-7.00	72.00	
74	UK003		St. Helena (UK)	St. Helena	-16.00	-6.00	
75	UK004		Tristan d Cunh (UK)	Edinburgh	-37.00	-12.33	
76	US007		Wake Is. (USA)	Wake Airfield	19.30	166.60	
77	US008		Guam (USA)	Upi, Guam	13.65	144.86	
78	US009		Midway Is. (USA)	Midway Is.	28.00	-177.00	
79	US010		Hawaii (USA)	Waltiawa, HI	21.47	-158.03	X
80	ZA001		South Africa	Marion Is.	-46.50	37.00	

* Without prejudice to the question of sovereignty.

Annex Proposed International Radionuclide Laboratories, formerly called Certified Laboratories.

n	IRL Station	Region	Country	Location	Lat. (+/-)	Long (-/+)	Existing Lab/Stn
1	IRL01	Australia	Australia	Melbourne - Australian Radiation Laboratory			X
	AU001			Melbourne - IRL Station	-37.45	144.58	X
2	IRL02	N.America	Canada	Ottawa - Health Canada			X
	CA001			Ottawa - IRL Station	45.33	-75.75	X
3	IRL03	Europe	Finland	Helsinki - Center for Rad. and Nuc. Safety			X
	FI001			Rovaniemi - IRL Station	66.48	25.68	X
4	IRL04	Asia	Japan	To be named >			
	JP002			To be named > (IRL Station)	36.33	139.00	
5	IRL05	S.America	Argentina	Buenos Aries - National Board of Nuclear Reg.			X
	AR001			Buenos Aries - IRL Station	-34.00	-58.00	X
6	IRL06	Europe	France	Montlhery - French Atomic Energy Commission			X
	FR001			Montlhery - IRL Station	48.49	2.20	X
7	IRL07	Asia	China	Beijing - COSTIND			X
	CN001			Beijing - IRL Station	39.75	116.20	X
8	IRL08	Europe	Russian Fed	Moscow - MOD Special Verification Services			X
	RU001			Dubna - IRL Station	56.76	37.05	X
9	IRL09	Europe	UK	Brimpton - AWE Blacknest			X
	UK001			Chilton - IRL Station	51.50	-1.50	X
10	IRL010	N.America	USA	Sacremanto - USAF Technical Applications Center (No Station)			X

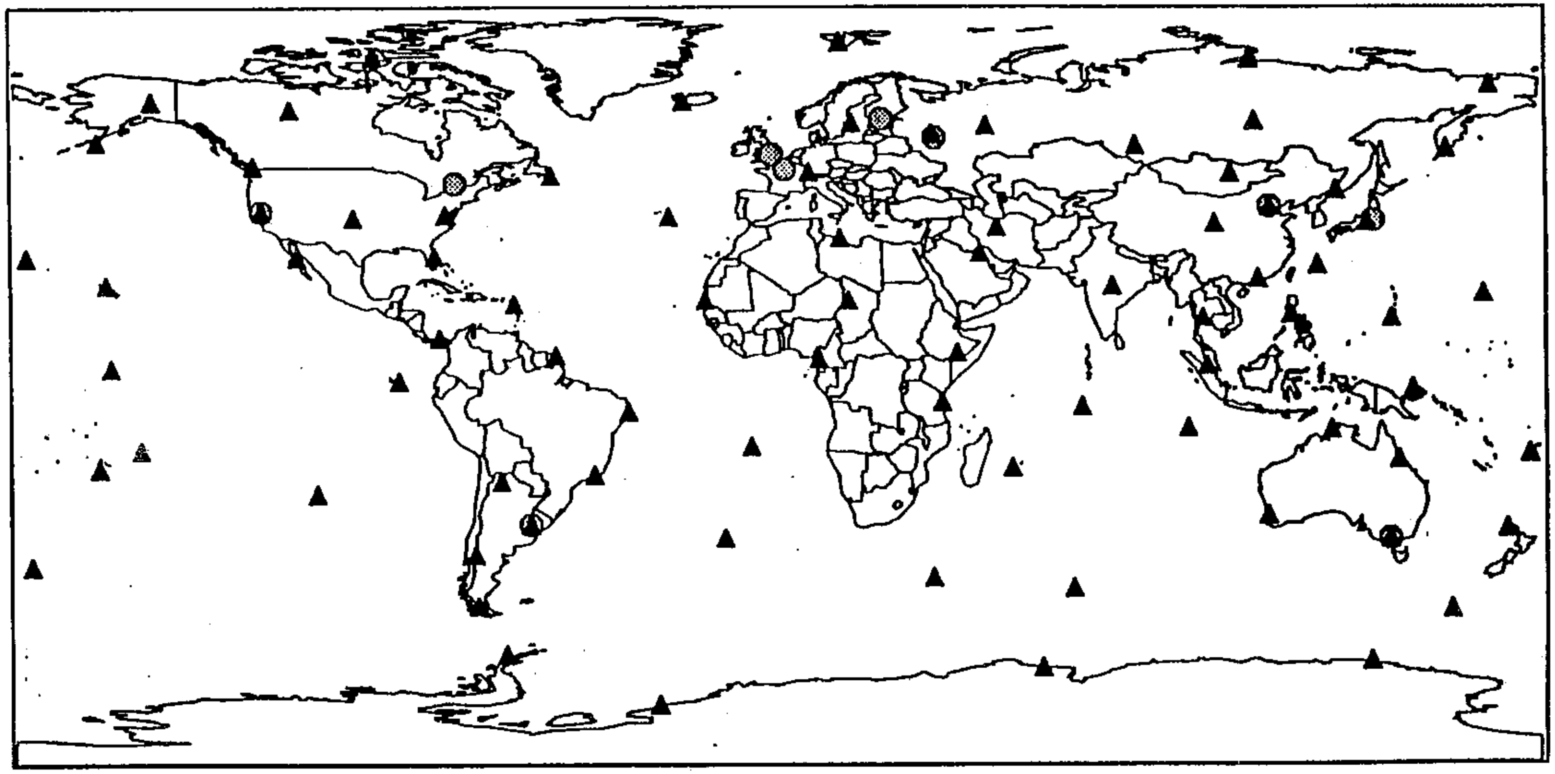

Figure 1. Proposed International Radionuclide Monitoring Network. Triangles indicate monitoring stations, circles, proposed International Radionuclide Labs.

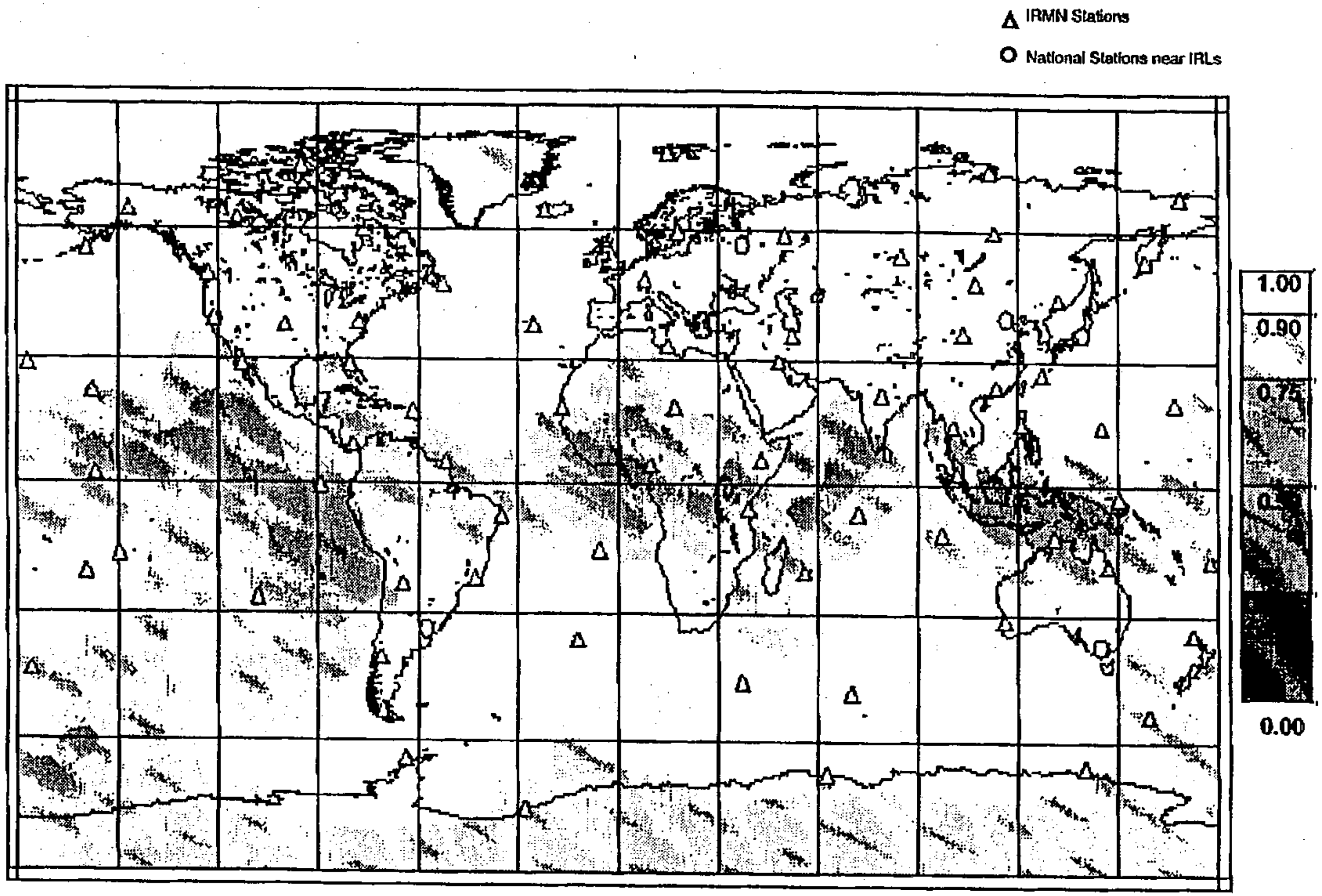

Figure 2. P(D) contour map of the proposed International Radionuclide Monitoring Network at a detection sensitivity of 1uBq m^{-3} for ^{140}Ba from hypothetical 1-kT atmospheric tests after a 10-day transit time.