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A SYSTEM FOR THE DETECTION OF NUCLEAR EXPLOSIONS AT LONG RANGE BY MEASUREMENT OF RADIOACTIVE DEBRIS AT GROUND LEVEL

Luther B. Lockhart, Jr.

Physical Chemistry Branch
Chemistry Division

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[redacted]

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT

An evaluation is made of the method of detecting nuclear explosions through the measurement of radioactive debris collected by air filtration.

A network of stations for monitoring the radioactivity of the air at ground level for radioactive particulate matter resulting from a nuclear explosion offers a relatively inexpensive, realistically reliable method for detecting those explosions which release radioactive debris into the troposphere.

It is concluded that such a monitor technique should be an integral part of any system that is organized to detect the occurrence of nuclear explosions.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

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A SYSTEM FOR THE DETECTION OF NUCLEAR EXPLOSIONS AT LONG RANGE BY MEASUREMENT OF RADIOACTIVE DEBRIS AT GROUND LEVEL

INTRODUCTION

Information releases pertaining to the Geneva Conference (August 1958) on methods of detecting nuclear explosions—that is, on means of detecting unauthorized nuclear tests following an agreement to ban such tests and of assessing the responsibility for such acts—indicated that little consideration was being given to the long-range detection of airborne fission products at ground level. This was perhaps due to the fact that no one actively engaged in such work took part in the proceedings. It is the sole purpose of this report to point out that such a system is effective, as shown through past experience; it is not contemplated that the U.S. Naval Research Laboratory would participate actively in such a program if this method were adopted.

As is generally well known, during the explosion of any nuclear device a large amount of radioactive material is produced through fission of uranium or plutonium and by interaction of neutrons with materials in the environment. These radioactive materials rise in the air with the fireball and later fall out onto the ground near the point of detonation or are spread and dissipated by the winds to eventually come to earth at locations which may be far distant from the point of detonation. The detection and identification of such radioactive materials in the air or on the ground is a positive indication that an atomic explosion, either planned or accidental, has occurred.

METHODS OF DETECTION OF RADIOACTIVE FISSION PRODUCTS

The ideal method of detection of airborne fission products is to collect material from the air by the use of efficient filters which effectively concentrate the particles dispersed in a large volume of air onto a small area of filter paper. The NRL atmospheric radioactivity monitor equipment is designed to collect such activity over a 24-hour period from 900 to 1200 cubic meters of air at ground level and then to follow its rate of decay over a 16-hour period. From this decay information, a reliable estimate of the gross long-lived activity in the air can be obtained even in the presence of considerably larger amounts of the natural radioactive products. Thus, within 24 hours following the end of each daily collection, information on the gross fission-product contamination in the air is available. A monitor system based on this technique has been in operation by NRL for nearly nine years.

A simpler method involves the collection of such material by an efficient air filter and,rather than following the rate of decay, counting the residual long-lived activity after decay of the natural radioactive components. As performed by the U.S. Public Health Service network, this involves a delay of 5 days; in the IGY program operated by NRL, a delay of 14 days is employed. This method is particularly useful where a central, well-equipped counting station is available to serve a number of collection stations. However, for detection purposes this delay is a distinct disadvantage in that no followup collections for radiochemical analysis will be started at the opportune time.

A third method, and one which can be used to collect gross amounts of radioactive materials, is the use of rain collectors. Rain serves to scavenge a large volume of air in its fall to the ground, so that the collection of rainfall on a 1000-square-foot surface may represent the equivalent of 5 to 10 million cubic feet of air. This method serves to give useful samples for radiochemical analysis but is not particularly adaptable to a simple detection scheme. It is, further, limited by the requirement that rain fall at the right time. This cannot always be arranged.

A final method is the collection of dry fallout on gummed films or in steep-walled pots. This method generally does not collect large amounts of activity and is subject to a number of serious limitations.

It should be emphasized that any method of collection of material from the lower atmosphere will collect quantities of natural radioactive products (RaB-C complex, 26-minute half-life; ThB-C complex, 10.6-hour half-life) whose radioactivity greatly exceeds that of the fission products being collected.

CONFIRMATION OF DETECTION

To check on the validity of the data given by such simple detection systems, it would always be advisable (perhaps after sounding the alarm!) to secure enough material for radiochemical analysis. This could be effectively done by the use of large filter systems having air-flow capacities of 1000 to 2000 cubic feet per minute. A 24-hour collection initiated as soon as the presence of new fission products is suspected or indicated will gather sufficient radioactive material to give positive confirmation of the event. However, provisions must be made for immediate analysis to take advantage of the presence of the fission products of short half-life, which are most definitive of nuclear debris of recent origin.

DISCUSSION OF DETECTION AND IDENTIFICATION PROBLEM

At present, simple detection systems such as those described do not have the sensitivity they once had because of the large quantities of radioactive bomb debris in the air. If a moratorium on testing is maintained for a while to allow some of this material to dissipate through decay or deposition, the method will increase in sensitivity. Eventually, measured increases in the gross long-lived activity will be conclusive proof of a nuclear detonation (or a nuclear incident). Presently, however, a small shot might go unnoticed in the general fission-product background or might give indications that are not sufficiently definite to sound an alarm. Therefore, at the present time, radiochemical analyses for some short-lived activity which could exist only from a new shot would be required for absolute confirmation. This measurement together with another of an isotope of different half-life could be used to determine the date of the burst and also whether this was a result of a nuclear explosion or a reactor incident. (In a reactor incident there would generally be a large excess of long-lived fission products which would have been accumulating during reactor operation. It would be unlikely, too, that debris from such a source would spread any great distance, because of their release at ground level and the generally low magnitude of the explosion.)

Activity levels of gross fission products in the air at several sites in the Northern Hemisphere during 1957 are shown in Fig. 1. This information was obtained from the NRL atmospheric radioactivity monitor equipment. Similar data obtained from air-filter collections which are made at sites along the 80th meridian (west) and forwarded to NRL for assay are shown in Table 1. The present activity level is grossly greater than the ultimate sensitivity of the two methods (approx. 5×10^{-3} $\mu\mu c/m^3$ for the complete monitor and 5×10^{-2} $\mu\mu c/m^3$ for the simple collections, as presently operated). Indeed, no greater sensitivity would be required since at a distance of several thousand miles the activity from a given shot may cause increases to 10 to 50 $\mu\mu c/m^3$—an increase of some 10^3 to 10^4, or 100,000 to 1,000,000 percent greater than the sensitivity of the equipment.

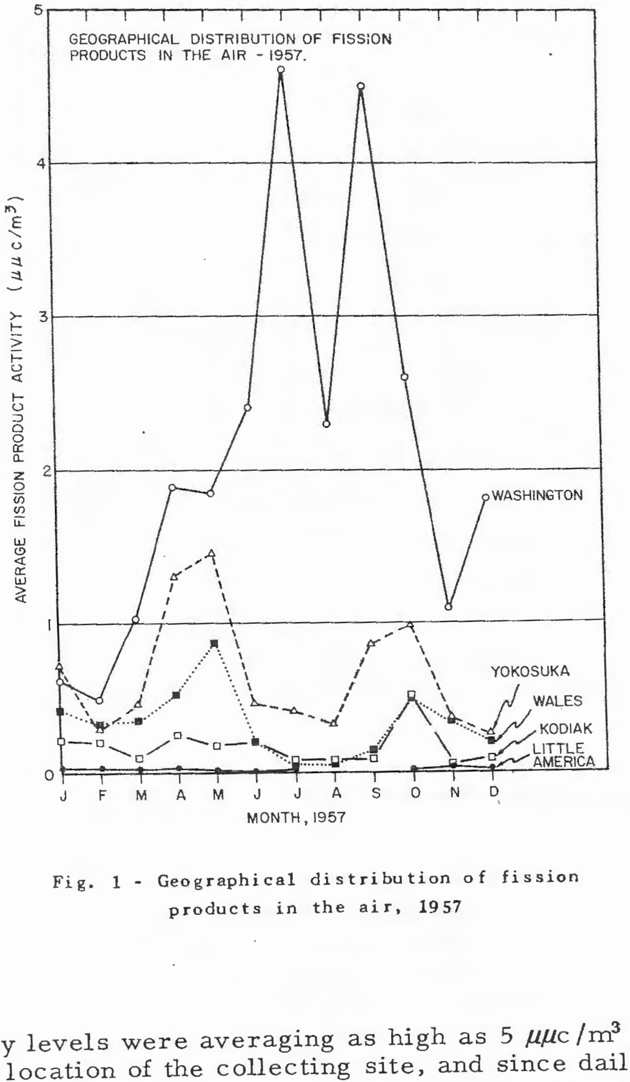

Fig. 1 - Geographical distribution of fission products in the air, 1957

Since activity levels were averaging as high as 5 $\mu\mu c/m^3$ in August 1958 depending on the location of the collecting site, and since daily variations, predominantly in the downward direction, of a factor of 5 are not uncommon due to varying meteorological conditions (rain, etc.), only a very intense peak (say 2 to 5 $\mu\mu c/m^3$ above the average) could be directly related to a fresh explosion with 100-percent certainty.

Table 1
Average Monthly Fission Product Levels along the 80th Meridian During 1958

Collecting Site	Activity (disintegrations/minute/cubic meter of air[*])							
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Thule, Greenland	-	-	-	11.1	6.7	6.4	3.5	2.7
Coral Harbor, N.W.T.[†]	-	-	2.7	5.9	3.7	2.7	1.8	1.6
Moosonee, Ontario	2.2	2.2	4.3	9.3	5.4	6.6	3.4	1.6
Bedford, Mass.	1.7	2.3	4.4	10.0	6.9	7.1	4.6	3.5
Washington, D.C.	3.1	3.4	4.8	12.5	11.3	8.6	7.2	4.8
Columbia, S.C.	3.6	4.8	6.2	12.0	11.4	7.5	7.4	6.0
Miami, Florida	4.8	5.4	9.3	12.6	8.7	5.1	5.0	6.0
San Juan, P.R.	3.7	4.4	4.9	5.9	3.3	3.7	4.4	5.2
Miraflores, P.C.Z.	1.7	1.5	2.7	4.9	0.75	0.47	1.3	1.8
Bogota, Colombia	0.76	0.52	0.65	0.65	0.42	0.82	2.9	1.8
Quito, Ecuador	0.11	0.11	0.09	0.08	0.31	0.53	1.2	1.7
Guayaquil, Ecuador	0.20	0.13	0.13	0.17	0.20	0.67	1.6	1.0
Iquitos, Peru	0.19	0.18	0.13	0.07	0.09	0.49	1.2	1.4
Lima, Peru	0.14	0.16	0.10	0.10	0.23	0.40	2.7	1.5
Huancayo, Peru	0.13	0.06	0.06	0.06	1.5	1.3	8.9	7.8
Chacaltaya, Bolivia	0.15	0.08	0.05	0.07	1.5	2.0	13.0	10.8
Antofagasta, Chile	0.29	0.30	0.25	0.21	0.51	1.3	6.2	2.6
Porto Alegre, Brazil	0.34	0.31	0.21	0.20	0.19	0.28	1.5	1.6
Santiago, Chile	0.34	0.28	0.21	0.19	0.19	0.30	2.3	0.85
Puerto Montt, Chile	0.20	0.17	0.21	0.08	0.09	0.16	0.22	0.26
Punta Arenas, Chile	0.09	0.12	0.12	0.09	0.05	0.06	0.04	-

[*] 1 d/min/m^3 = 0.45 μμc/m^3.

[†] Samples counted after longer decay times than those from other sites; therefore the actual value should be somewhat higher.

With a cessation of test explosions for a relatively long period (6 months or more), most activity present at that time in the lower atmosphere should wash out or fall out, and the only fission-product background would consist of long-lived debris from the stratosphere. Presently, there is no exact information as to the magnitude of this contribution, but it might be expected that this would be not over 10 percent of the present level. Actually, more than half the Sr^{90} being deposited at the present time seems to come from the stratosphere, but the gross fission products associated with it have decayed to low levels because of the relatively long residence time in the stratosphere.

In any case, to make certain a fresh explosion was being detected and to pinpoint the date of explosion, it would be necessary to run radiochemical analyses. An analysis for Mo^{99} with a 67-hour half-life and a life expectancy (for practical purposes) of one month would determine conclusively whether freshly fissioned material was in the area. The ratio of Mo^{99} activity to Ba^{140} (12.8-day half-life) or to Ce^{141} (28-day half-life) activity would define within very close limits the time of detonation of the fissionable material (Table 2). Further, neither of these ratios would be particularly sensitive to the type of fission that occurred; they are all formed in about the same yield (5 to 6 percent), and they would be unaffected by the gross residual activity from past explosions. If more information about the type of explosion is desired, other analyses could be performed. Unfortunately, the site of the explosion is not pinpointed by this method; however, from the age of the debris at the time of collection and with the use of available meteorological data, the general area of the detonation could be indicated.

Table 2
Relation Between Age of Fission Debris and the Activity Ratios of Certain Fission Products*

Age of Debris (days)	Activity Ratio	
	Mo^{99}/Ba^{140}	Mo^{99}/Ce^{141}
0	4.40	10.14
1	3.62	8.11
2	2.98	6.48
3	2.46	5.18
4	2,02	4.14
6	1.37	2.65
8	0.93	1.69
10	0.63	1.08
14	0.29	0.44
20	0.091	0.12
28	0.019	0.019

*Based on yields from fission of U^{235} by thermal neutrons.

The radiochemical separation and purification of these could take place in any chemistry laboratory equipped to do ordinary quantitative chemical analysis. The determination of the counting rates of the first two would require relatively simple β-counters capable of counting accurately (±5 percent) at a level of 50 c/m above background (at 10-percent geometry). The estimation of Ce^{141} would require counting through an absorber in order to estimate the contribution of the long-lived Ce^{144} (275-day half-life) to the total cerium count. The energies of the β's from the isotopes of interest are Mo^{99}, 1.1 Mev; Ba^{140}, 0.48 Mev (40%) and 1.02 Mev (60%); Ce^{141}, 0.41 Mev and 0.56 Mev; and Ce^{144} (Pr^{144}), 0.3(3.0) Mev. Calibration of the β-counters could be readily done with a RaD standard (1.05-Mev

β's from the Bi^{210} daughter), a UX_2 standard (U_3O_8, with shield to remove α's and low-energy β's, will give 2.8-Mev β's), and a Co^{60} standard (0.3-Mev β's). A Ce^{144} (Pr^{144}) standard could be readily supplied for calibration purposes, also.

SUGGESTED NETWORK OF MONITOR STATIONS FOR GLOBAL COVERAGE

For minimum but adequate coverage of nuclear explosions occurring anywhere on the surface of the earth (or in the lower atmosphere), it is felt that three series of six complete monitor stations each, near the 140°E, 40°E, and 80°W meridians at approximately 10°, 30°, and 50° both north and south of the Equator would be required, with perhaps other such stations located in the Arctic, Antarctic, and mid-Pacific areas. Each of these monitor stations should be equipped with minimum facilities for performing simple radiochemical analyses and for making large air-filter collections. Further, each of them could serve as a center where air-filter collections made by more primitive means could be forwarded for assay. A series of such substations could be responsible to the central station.

A list of proposed sites for radioactivity stations is given in Table 3. These were selected arbitrarily on the basis that they are situated to the west of possible test areas (without precise information as to the prevailing wind direction at each site), that they give a reasonable global coverage, and that they are important cities or towns in their areas and can be expected to have reasonable facilties (electric power, housing, etc.). Each would serve as a measuring station for collections made at intermediate sites. This list should be reviewed, certainly, by competent meteorologists to determine the suitability of these sites.

The above coverage gives an excellent possibility of detection of any atomic explosions of reasonable size (5 kilotons fission yield) taking place on the earth's surface or in the lower atmosphere. As examples, the Washington station has picked up activity from a great many Nevada, USA, test shots, while other shots in a given series may have been hidden by activity from the first shot. Also, every reported test series held in the USSR or in Nevada has been detected at one or more of the NRL sites. In a detection system, the first shot is the one of most importance. Most Russian tests from central Siberia have been detected by the NRL ground level air monitors at Kodiak, Alaska; Tokyo, Japan; and Washington, USA. Shots from Nevada and Siberia have been detected in great strength in French Morocco. Present networks in Italy and in France have recorded high activity from both the Nevada tests of 1957 and the Russian tests of early 1958. Because of the prevalent high fission-product activity it has been impractical in recent years to try to make assignments of debris to any particular shot.

The outlined network would give adequate coverage to those areas where tests have been held: Nevada, the mid-Pacific area, Siberia, the Arctic region, and Australia. Coverage would also be excellent for other areas such as the Amazon jungle and the Sahara Desert. Ocean areas are covered, too, but not to so great an extent. Here, it is felt that a test at sea or on small islands without obvious movements of men and material would be of insufficient value to be worth the risk. Further, in many areas, the North Atlantic for instance, visual sightings would result.

In summary, it is felt that such a system would be at least 90-percent effective for explosions on the surface or in the lower atmosphere and having a fission yield of 5 kilotons or greater. Explosions under these conditions with a yield of 20 kilotons or more would be detected in better than 95 percent of the cases, while smaller explosions (1 kiloton) might be detected in only 50 percent of the tests. This effectiveness would be applicable without routine chemical analyses after a cooling-off period of 6 to 12 months. The above sensitivity could be maintained under present conditions of high fission-product background by routine analysis of collections for short-lived fission products. The question of the required effectiveness of a system—whether 50, 90, or 99 percent—is a political rather than a scientific problem.

Table 3
Suggested Location of Radioactivity Monitor Stations

Western Pacific			Western Atlantic		
Okhotsk, Siberia	59°N	140°E	Montreal, Canada	46°N	73°W
Tokyo, Japan	36°N	140°E	Miami, USA	25°N	80°W
Manila, Philippines	15°N	122°E	Caracas, Venezuela	10°N	68°W
Darwin, Australia	12°S	153°E	Rio de Janeiro, Brazil	22°S	42°W
Brisbane, Australia	27°S	153°E	Montevideo, Uruguay	30°S	51°W
Hobart, Tasmania	42°S	147°E	Punta Arenas, Chile	53°S	71°W
Antarctic			Arctic		
Any accessible location			Nome, Alaska	65°N	165°W
			Thule, Greenland	76°N	68°W
Eastern Europe and Africa			Miscellaneous		
Narvik, Norway	65°N	15°E			
Kiev, USSR	50°N	30°E	Dakar, Fr. W. Africa	15°N	15°W
Baghdad, Iraq	34°N	44°E	Lima, Peru	12°S	77°W
Addis Ababa, Ethiopia	10°N	40°E	San Francisco, USA	37°N	120°W
Moçambique, Mozambique	12°S	40°E	Hawaii	20°N	160°W
Durban, U.S. Africa	30°S	30°E	Tahiti	18°S	150°W

COMPARISON WITH OTHER TECHNIQUES

An air monitor system such as outlined above should be supplemented by other detection methods (seismic, acoustic, electromagnetic radiation, etc.). In terms of reliability, it is as good as any (to the author's knowledge) and in addition gives some substantial evidence of an explosion; that is, a part of the actual bomb is collected and identified. This is the only method under consideration that does so. In terms of cost, both in material and manpower, it is relatively inexpensive, particularly if radiochemical analyses can be provided at centrally located laboratories. Under any conditions, such radioactivity measurements should be made at all stations set up to monitor nuclear explosions.

The success of this method depends on the detection of radioactive particles in the air at ground level. Thus, atomic explosions which are contained, whether underground or deep in the ocean, or which take place in the stratosphere could not be detected. In such cases, the use of the other techniques would be required.

OTHER INFORMATION

Such a monitor network would serve to give useful and needed information on the natural radioactive constituents in the atmosphere. The monitor equipment would give directly the radon, thoron, and gross fission-product components in the air, while radiochemical analyses could give valuable information on long-lived fission products (Sr^{90}, Cs^{137}, Ce^{144}) and the long-lived natural RaD (Pb^{210}) in the air. In many respects this would serve as a continuation of the present IGY program on atmospheric nuclear radiation and would also fit into the present AEC Sunshine program.

The change in the air concentration of Sr^{90} and Cs^{137} with time would help define the size and the rate of depletion of the stratospheric reservoir of old fission products.

COST OF MONITOR PROGRAM

Some rough estimates of the cost of the component parts of a complete air monitor station are given in Appendix A. The cost is not excessive and the manpower requirement modest, particularly if the air monitor equipment is run in conjunction with other types of monitor equipment. The only "specialists" required, other than those who can operate and maintain electronic and mechanical equipment, are the chemists with a knowledge of radiochemical techniques and principles. A good analytical chemist should be able to make the transition with a month's indoctrination.

The estimated cost of the entire program (less salaries of technical personnel and transportation charges) is given in Appendix B. These costs are the maximum that would be required for the job. Sufficient radiochemical work could be performed to demonstrate clearly the presence of fresh fission products and to give a reasonable estimate of the time of explosion. If more elaborate analyses are desired, it would be more economical to have well-equipped and better-staffed central laboratories capable of handling samples from a number of these stations.

CONCLUSIONS

A network of stations for monitoring the air at ground level for radioactive particulate matter offers a relatively inexpensive, realistically reliable method for detecting atomic explosions greater than 5 kilotons fission energy occurring anywhere on the surface of the earth or in the lower atmosphere. However, it is of no value if the explosion occurs under conditions which permit little or no radioactive debris to be introduced into the air mass contained below the tropopause.

The monitoring of the air for radioactive products should be an integral part of any system that is organized to detect the occurrence of nuclear explosions.

ACKNOWLEDGMENT

This report is based on previous work carried out at this Laboratory by personnel of the Chemistry and Optics Divisions and with the support of field personnel at a number of naval bases. Prior work at this Laboratory is indicated in the extensive bibliography at the back of the report.

* * *

Appendix A

ITEMIZED COST OF A COMPLETE AIR MONITOR STATION

I. Radioactivity detection system (air monitor)

(a) Initial cost:

Air filter, motor, etc.	$ 500
Geiger counter, scaler, recorder	2,500
Duplicates of above	3,000
Spare parts (tubes, etc.)	2,000
Large blower (7-1/2 hp.)	2,000
	10,000

(b) Yearly cost:

Replacement parts, filters, etc.	$2,000
Electric power	5 kw (15 kw when large blower is operated)
Manpower	1 hr/day (plus maintenance)

II. Simple radioactivity collection system

(a) Initial cost:

Blower, complete	$ 500 (max.)

(b) Yearly cost:

Supplies (filters, envelopes)	$ 200 (max.)
Electric power	1 kw (max.)
Manpower	10 min/day

III. Facilities to convert an ordinary quantitative chemistry laboratory to a radiochemical laboratory at monitor site*

(a) Initial cost:

Equipment assumed to be on hand:

Desks, balances, hoods, working space, some muffle furnaces, hot plates, etc.

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*A larger central setup to serve several such stations would probably be more economical and better equipped.

Auxiliary equipment needed*

β-counting setup (Geiger counter, absorbers, shield, scaler, recorder)	$2,500
Duplicate of above	2,500
Spare parts (tubes, etc.)	2,000
Chemicals and glassware	2,000

(b) Yearly cost:

Chemicals and glassware	$1,000
Spare parts for electronic equipment	1,000
Electric power	10 kw
Manpower	1/2 man-year†

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* Units can be interchangable with I(a).

† An analytical chemist with knowledge of counting techniques can handle the entire program on a routine basis. He would need help with confirmation of positive tests

* * *

Appendix B

ESTIMATED COST OF PROPOSED AIR MONITOR PROGRAM

Complete Air Monitor Station:	Initial Cost	Yearly Cost
Detection system, plus large collector	$10,000	$2,000
Simple collecting systems (3)	1,500	600
Radiochemical laboratory (Use of available chem. laboratory)	9,000	2,000
Total cost	20,500	4,600
Manpower*	1 full-time chemist plus 4 part-time technicians	
Complete Air Monitor Program: (26 complete stations)		
Total cost	$533,000	$120,000
Manpower*	26 full-time chemists plus 104 part-time technicians	

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* Manpower cost will depend on quality of personnel desired, previous training, nationality, and location of monitor station.

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