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WEATHER FOR INDUSTRIAL NUCLEAR EXPLOSIONS

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Philip W. Allen, Air Resources Laboratory, Las Vegas, Nevada
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ABSTRACT

Nuclear explosives are a major energy source and, as man's use of natural resources progresses toward lower-grade minerals and ores, and he engages in larger construction efforts, these large detonations will become a more necessary and more frequent mining and engineering tool. The risk of an accidental release of radioactivity to the atmosphere is very low. Some minor releases may be planned, but the potential impact of any such a release is very great, so that extensive safety precautions will be taken, providing for the protection of people in the path of any such radioactive cloud. An essential part of this capability is the knowledge of such paths well ahead of the detonations, and this involves predictions of winds, trajectories, turbulence, precipitation, and related transport phenomena.

This paper explores the philosophy of weather controls on the scheduling of detonations, outlines the preparations and procedures involved in such a weather service, and describes the meteorological problems encountered in two recent detonations for the stimulation of natural gas wells, near Farmington, New Mexico, and Rulison, Colorado.

Introduction

For a number of years, the federal government has been adapting nuclear explosives to engineering and industrial enterprises for which vast explosive energy is needed. The government's efforts have been contained in the Plowshare program, managed by the U. S. Atomic Energy Commission with assistance by other federal and state agencies and private contractors.

The Nuclear Non-Proliferation Treaty, covering the transfer of nuclear devices to "non-nuclear" nations, emphasizes the need for a more advanced peaceful explosive technology. The treaty provides that the nuclear weapon nations shall make available the potential benefits of peaceful nuclear explosions to the non-nuclear nations who are party to the treaty. The last Congress considered legislation that would authorize the AEC to provide commercial Flowshare services, and the new Congress is expected to continue to work on this problem.

Potential Industrial Uses⁽¹⁾

The vast energy available from nuclear explosives is slowly but surely becoming useful in private industry. The most promising applications are for the recovery of natural gas, shale oil, and other minerals from deep geologic formations of low permeability, where rock crushing and fracturing is needed to provide pathways for gas or leaching chemicals. Other potential applications include the formation of underground reservoirs and crushing or moving large volumes of rock for use in conventional engineering projects.

Natural Gas. When a well is drilled into an underground formation containing methane gas under high pressure, the gas flows through the pores or between the grains into and up the well. In a large part of the intermountain West, gas is contained in rock of such low permeability that the gas flows too slowly to be economically useful. There are non-nuclear ways of fracturing the rock to produce short-lived increases in productivity. Nuclear explosives have been used twice now to fracture much larger volumes of rock in order to attempt to demonstrate the feasibility of producing commercially useful wells. The first experiment, Project GASBUGGY, using a 26-kiloton explosive, occurred near Farmington, New Mexico, in December 1967, and the well, still being tested, is expected ultimately to produce around one billion cubic feet of gas. In the second experiment, Project RULISON, in western Colorado, a 40-kiloton nuclear

explosive was detonated in September 1969. This well is in the process of producing an expected five billion cubic feet of gas. Both wells are producing at from five to ten times the rates that could have been expected from conventional stimulation in the same formations. Several more nuclear stimulation projects are being considered.

The Bureau of Mines has estimated that the use of nuclear explosives to stimulate production could double the Nation's available natural gas reserves by adding up to 300 trillion cubic feet. Figure 1 shows most of the geologic formations where this technique might be applied in the United States. They are in Wyoming, Colorado, Utah, and New Mexico. The use of natural gas is increasing rapidly as a result of its low contribution to air pollution. The demand is rapidly exceeding current availability, thus emphasizing the importance of trying to use nuclear explosives for this purpose.

Oil Shale. Experiments have been proposed wherein the vast oil reserves, locked in the shales of Colorado and elsewhere, might be recovered by in-situ retorting. Nuclear explosion would fracture the shale and provide the initial source of heat^(1,2).

Underground Storage. A problem for the natural gas industry is the storage of gas during low-use seasons. Nuclear explosions in appropriate media provide a relatively inexpensive and easy way to create large underground void space for the storage of gas. Such reservoirs are also being considered for storage of water without loss by evaporation in arid areas, and for the storage of fluid and radioactive wastes⁽²⁾.

Nuclear Mining. While not as near realization as gas well stimulation, projects are being planned that are expected to demonstrate that nuclear

explosives have value in the fracturing, crushing, and leaching phases of underground mining⁽²⁾.

USSR Program. The USSR has used and is planning to continue using nuclear explosives to achieve some of these same industrial goals⁽³⁾. Their program may be developing momentum faster than that of the U. S. They have reported successfully stopping an uncontrolled gas well fire, using an underground nuclear explosion to pinch off the flow of gas. In another project, they created a useful water reservoir in the crater formed by a nuclear detonation. They, too, are considering the use of nuclear explosives in mining and have stimulated the production of hydrocarbon fuels.

The Environmental Effects of Underground Nuclear Explosions

Earth Motion. Nuclear explosions have occurred in a variety of geologic formations. Measurements have been made of seismic energy, ground surface motion, and structural response out to hundreds of miles. The effect on the environment and on human activities are now reasonably well understood and predictable and these effects are considered in the design of future detonations⁽⁴⁾.

Ground Water Contamination. Techniques have been developed for estimating, prior to actual detonation, the transport of radionuclides in underground water. In the underground environments being considered for nuclear detonations the water motion is too slow for contamination to reach consumers before the radiation decays or dilution and other hydrologic processes have removed any hazard⁽⁵⁾.

Atmospheric Contamination. The most promising industrial applications of nuclear detonations involve little or no release of radioactive materials to the atmosphere. The explosions are at such great depths that all explosive debris and vaporized rock should be contained underground. They are much deeper than

most detonations of similar yield at the Nevada Test Site. A prompt venting of radioactive gas to the surface is almost inconceivable⁽⁶⁾, and a delayed seepage is highly unlikely. More than 230 announced underground nuclear explosions that were designed for essentially complete containment have been conducted by the U. S. since the limited test ban treaty was signed in 1963. Of these, 17 leaked radioactivity that was detected offsite. Twelve of the 17 were tunnel experiments and/or experiments involving open lines of sight part way through the sand and gravel filling the emplacement hole. Only five have leaked after being fully buried in vertical shafts. Indications are that these five might not have leaked if they had been buried deeper, as are industrial PLOWSHARE detonations.

No nuclear explosion of sufficient verified yield for industrial application that was emplaced in a deep hole according to current guides for depth and back filling has ever vented radioactive debris promptly to the atmosphere. However, the sudden release of so great an amount of energy does present a risk that is of concern to the public. Any high explosive is dangerous. By taking appropriate precautions, the risk has been made acceptable to most people in comparison with the explosive's importance to man. In an underground nuclear detonation the combination of extremely high pressure with the radioactive residue of the fission process presents an added risk. In this case too, the risk may be accepted by most people when compared with the contribution these detonations can make to the nation's welfare and economy.

Because venting or seeping from a nuclear explosion into the atmosphere might expose people to some radioactivity, meteorological services in the forms of wind and radiation predictions are routinely provided to assist in safety planning before a detonation and in any emergency actions that might be needed after an accident such as relocating people. As long as the detonations are

conceived as primarily government experiments but with industrial partners, the meteorological services may continue to be provided by the government. However, as these explosions become routine industrial tools, the government's role is expected to be reduced to that of a reviewing and controlling agency, with industry providing the safety and services, including meteorology.

One purpose of this paper, then, is to encourage the private meteorology sector to be alert to, and prepare for, this gradually unfolding opportunity. It is not likely to be a gold mine, but it could eventually be another area for service. Several major oil and gas companies are forming nuclear energy subsidiaries for the purpose of managing nuclear stimulation projects. At least one of these has already used private meteorological assistance on a detonation site survey, but with considerable guidance from our laboratory. It seems appropriate to describe for you some of the characteristics of the problem and the probable requirements for meteorological services in connection with contained industrial nuclear detonations. Keep firmly in mind, though, that the industrial sponsor wants a profitable venture, so that the cost of meteorological service must be kept to a level consistent with the scope of the radiological hazard.

Types of Radiation Releases

Figure 2 shows the emplacement hole, detonation cavity, and chimney of broken rock associated with a typical underground nuclear explosion. The depth of the explosive is determined by the depth of the mineral to be extracted, but (excluding crater-forming applications) is never less than the depth at which containment has been demonstrated to be virtually guaranteed. The detonation creates a cavity that is initially full of extremely hot radioactive gas. Initial cooling occurs rapidly and the gas pressure generally drops below that of the overburden within a minute or so. The attendant shock wave has in the meantime crushed or

cracked the rock out several hundred feet in all directions and when the cavity pressure can no longer support the overhead rocks, they fall until a chimney of broken rock extends upward for some distance. Most fallen rocks occupy more space than they did before being broken, so the chimney stops growing when the fallen rocks provide support to those that have not yet fallen. In the Nevada alluvium, which has little structural integrity, chimneys often grow all the way to the surface, leaving a large dimple or subsidence crater.

In a prompt venting, radioactive gases and particles find an unplugged channel to the surface and erupt under considerable driving pressure and high temperature. Such ventings occurred a few times before the physics of containment was generally understood, or under special circumstances when experimental emplacements failed to operate as designed. Such special experiments are not planned in the industrial applications.

Seepage through loose backfill and through bundles of signal cables has occasionally permitted very small amounts of radioactive gases to reach the atmosphere within minutes after a detonation. On other occasions when the detonations were not very deep, very low levels of radiation have been observed after several hours in gases that have seeped up through the chimney of rubble to the surface. Seepage has never been a safety problem on a detonation that was as deeply buried as foreseeable industrial applications are likely to be.

In view of the good safety record, why have meteorological support? This question has been asked over and over, and the answer always returns: because the risk is not known to be absolutely zero, and the consequence of even a small release could be of great concern. The government's objective⁽⁷⁾ is to avoid all releases of radioactivity, if possible, and to minimize effects of accidental releases. The effects of potential releases of radioactivity on the environment

were studied by the government long before the Environmental Quality Act of 1969 made this mandatory. If an accidental release occurs, the environmental effects in the path of the radioactivity are thoroughly studied afterward, both to add information and to prevent further undesirable effects.

After a nuclear detonation occurs deep underground, reentry to the chamber of rubble involves either deep-well drilling techniques or cleaning out the original emplacement pipe. Equipment and techniques are in common use by the oil and gas industry for preventing blow-out of gas wells to the atmosphere. These same techniques are used to control the high gas pressures that might be encountered as the drilling tools approach the chimney of detonation debris, crushed rock, and fracture zone. Their safety record when proper equipment was used has been very good, but not perfect. Natural gas formations are normally under high gas pressure and in the presence of the nuclear debris this gas may be mixed with fission products and contain induced radioactivity. Therefore, precautions are normally taken during the drilling and reentry process to have current information readily available on wind and diffusion conditions, plus the facilities to protect people in downwind areas if a blow-out of radioactive effluent should occur. Such activities normally take place six months or more following detonation and the levels of radioactivity remaining in the gas by that time are well below permissible levels as a result of decay and diffusion. These operations are still carefully controlled in order to avoid exposures to even low levels of radiation.

Still another concern is not related to either the detonation or the reentry, but to the processing of the recovered gas, oil, or minerals. Especially when natural gas is produced, or the production process involves the release of a gas, very low levels of radioactivity may be present in that gas. For example,

low levels of radioactive tritium and krypton were present in the natural gas produced from the GASBUGGY gas well stimulation experiment in northwestern New Mexico and from the RULISON experiment in western Colorado. In both cases, the potential exposures to the public from breathing released gas, before or after burning, were much less than those considered permissible. However, in both cases, this gas was initially released to the atmosphere only when diffusion rates and wind conditions further reduced these low potential human exposures by many orders of magnitude. Such meteorological controls were removed only after hundreds of measurements indicated that no health hazard existed even when adverse atmospheric conditions maximized downwind concentrations.

Requirement for Meteorological Service

The requirements for meteorological services supporting underground nuclear explosions have been developed by the Las Vegas office of the NOAA Air Resources Laboratory over almost 15 years of study and experience. The laboratory has supported a wide variety of underground safety and proof tests totaling approximately 300 nuclear explosive devices. All of the tests since 1963 have been underground. Underground detonations have been conducted safely in such populated areas as Mississippi, New Mexico, Colorado, and northern Nevada. You may recall that the SALMON nuclear detonation near Hattiesburg, Mississippi, in 1964 was postponed daily for 30 days, awaiting a satisfactory weather condition.

The meteorological services needed by the director of a nuclear explosion and reentry operation include (1) estimates of radiation levels possibly resulting from a maximum accidental release of radioactivity, (2) precise knowledge of current local winds and air trajectories to determine the areas that would be affected by a release of radioactivity, and (3) the changes expected in these parameters for the next several hours, at least.

When operations are of long duration, or the schedule sequence involves a series of time consuming preliminary activities, the forecasting requirement may extend 24 hours or longer into the future and include precipitation and storm probabilities. Critical activities in the oil and gas stimulation or production processes, such as the nuclear detonation itself and reentry drilling intercepting the cavity or chimney, are not permitted except in the presence of satisfactory weather conditions.

Customarily, the meteorological service has included the translation of radioactivity release estimates into potential human exposures as a result of atmospheric transport, diffusion, and/or deposition. A number of scaling and diffusion models are available for making these estimates⁽⁸⁾. Conservative assumptions are used that tend to over-predict potential exposures. This results in extra safety preparedness, an expense that the government encourages in its own projects but which may cut company profits from industrial detonations.

The forecasts are used to plan for the relocation of people in the downward area in case of an accident. If it is impractical to move people from some area, the detonation is postponed until the winds shift to an area where emergency actions can be implemented successfully. The government would rather prepare to move too many people, rather than too few. Plans for radiation protection are much more effective and less expensive when they have meteorological guidance than when all sectors must be kept at maximum readiness for extended periods.

For economic reasons and for operational convenience, there may be a temptation for some future users of nuclear explosives to tend to downgrade the scope of meteorological service below the level of adequacy, and to avoid controls based on meteorological conditions. Meteorologists must insist on

sufficient current data to be able to understand the atmospheric processes at work over and around any detonation site.

After a long series of detonations that have been completely and safely contained, there can also be a tendency to downgrade the risk of leakage and for that reason reduce meteorological alertness. Our own experience has indicated that this, too, is a dangerous trap. It will be a long time before nuclear explosions can be permitted without adequate meteorological controls.

Local Meteorology

In mountainous or uneven terrain, where most U. S. industrial applications are likely to take place, large variations often occur in the vertical and horizontal distributions of wind and temperature. Mountain and valley winds are common at the surface and vertical motion from mountain waves or convection are common only short distances above the surface. The ground surface over a nuclear explosion may be dry desert or dense forest, level or sloping, on a ridge or in a valley. Each project site has its own peculiar meteorology.

Figure 3 shows the winds over the detonation area at the time of the RULISON detonation in western Colorado on September 10, 1969(9). This illustrates the vertical and horizontal differences that could be important in the event of an accidental release of radiation. In the Colorado River Valley, surface winds were from the northeast, whereas at the surface over the detonation they were from the northwest, and on the other side of the mountain they were from the southwest. On top of the mesa, they were from the southwest on the upstream side and from west and west-northwest on the downstream side of the mesa.

The mixing depth, in case of a nighttime release of radioactive effluent, might be deep if the site were near a ridge top with little or no thermal inversion, or shallow if it were capped by a strong inversion at the bottom of a broad basin. A daytime release of radioactivity could be injected into a

shallow pool of cold air or into a deep unstable airmass. The path of the effluent is often influenced by the depth of mixing, and also by the height to which buoyancy will take it if it is initially warmer than the ambient temperature.

Measurements

In order to have local meteorological information readily available it is advisable to prepare for the future use of nuclear explosives by making a preliminary study of the meteorology of the detonation area. Information on nocturnal drainage, daytime upslope flow and other mesoscale processes can help to avoid the choice of a site where an accidental release would have a significant probability of unacceptable exposures. Control personnel and equipment must not be placed in a sector that would likely require evacuation if a venting should occur. Figure 4 illustrates how the drainage flow at the Project GASBUGGY site eliminated the area northwest of the detonation site as a control point location.

Table 1 gives in tabular form the measurements needed for planning a typical project. Climatological-type measurements, such as can be made using a small network of mechanical recorders, provide sufficient information on local variations of wind and temperature to indicate the typical diurnal and synoptic transport regimes. Statistical analyses of such data sometimes have great impact on project planning and nearly always are well worth their low cost. These analyses, together with a few cases in which winds are measured above the surface by a network of hourly pibals, enable the project meteorologist to relate the local transport characteristics to predictable large scale synoptic pressure systems and thereby make useful short-period mesoscale predictions of wind and temperature structure. We have insisted on climatological measurements

beginning, if possible, at least a year before the detonation in order to sample that season before plans progress too far to make design changes. The probability of schedule delays makes it desirable to continue to sample the subsequent seasons in order to be sure to have sampled the correct season.

During periods when there is risk of radiation release, it is essential that the meteorologist and the project director have almost "real time" information on winds and diffusion parameters, and that these be displayed in a meaningful format. The final decisions to detonate nuclear explosives have always been based on existing weather conditions and predicted changes, rather than on predictions alone. The potential consequences of a significant radioactivity release are such that immediate, accurate, and intelligent protective actions must be anticipated and available. These actions must be based on current atmospheric conditions. For this reason, radio-telemetry and computer processing of data are now standard practice and a computer-driven display is being developed. Indirect remote wind and temperature measuring devices are being considered, but their suitability so far has not been demonstrated to our satisfaction.

A typical mesometeorological network is outlined in Table 2, covering an area roughly 50 miles across. The basic equipment items are the radar balloon tracker and pibals for winds, the rawinsonde for vertical temperatures, and the radio-telemetered surface winds. We are currently using a portable telemetered surface wind and temperature network and are just placing into service the Portable Automatic Computerized Environmental Radar (PACER) that combines radar balloon or tetraoon tracking with raob reception in a small trailer. This local network supplements use of the complete National Weather Service teletype and facsimile data network and guidance materials. The latter circuits must

in some cases be extended to a remote site using special lines or radio links.

The measurement network for reentry drilling depends on the nature of the project, the scale of possible accident, the operations involved in reentry, the pressure expected in the chimney, and many other factors. In some projects the reentry may be a greater safety problem than the detonation.

The information now being displayed for weather advisors and project management includes (1) nearly continuous recordings of surface winds for key stations in the network, (2) hourly or half-hourly winds to several thousand feet, (3) vertical temperature distribution every 3 hours, (4) streamlines at the surface and one or two levels above the surface updated every hour, and (5) predicted trajectory or cloud path originating at the site and updated hourly.

Predictions

For a number of years useful predictions of low altitude winds and trajectories have been made for nuclear explosion safety. They have been limited to relatively short ranges in time and space. The typical subjective prediction technique involves evaluating the motion and development of large scale pressure systems, their influence on terrain-related circulations, and often the influence of the terrain on the large scale systems. Objective forecasting rules have been developed for the sites at which a sufficiently long period of record could be acquired in the local area around the detonation.

Computer prediction models of mesoscale motion are just now reaching operational usefulness but they require larger computers than are normally available on remote projects. One such model is a wind profile prediction model currently being developed by Cornett in our laboratory for the Nevada Test Site, using the wind data from the NTS network of pibals and raobs. It requires only a few minutes of large computer time and the verification for many situations

is superior to that by the average forecaster. If such a model can be adapted for the terrain at other sites and for use on the telephone terminals of a time-shared computer, then a major improvement in wind prediction accuracy is possible.

Computer models are available now for relating downwind radiation exposures to meteorological conditions for a given accident situation⁽⁸⁾. Radiation exposure predictions can be updated as frequently as new source terms, meteorological data, or radiological data are acquired.

If the worst were to happen and a major release occur or seepage persist for a long time, then trajectory forecasts would be needed for many hours, and the prospects evaluated for precipitation scavenging of the cloud, producing areas of higher radiation exposure. The trajectory information would be used by tracking aircraft. Mobile radiological monitoring teams would proceed to the areas affected by precipitation, measure actual radiation levels, and take whatever actions might be needed to protect the public. 36-hour trajectory forecasts from NTS and specific other places are routinely extracted from the current National Meteorological Center forecast models and transmitted twice daily by TWX to the Site or to any available TWX terminal. A shorter range local trajectory is expected to be obtained from the local wind profile model.

The results of government research and experience with weather technology for industrial nuclear explosions are of course available for private meteorological use.

Summary

The use of nuclear explosives to help extract valuable mineral resources from difficult media is gradually becoming a practical possibility. Meteorological information is needed for efficient implementation of protective actions to

prevent unnecessary radiation exposure in case of an accident either during the detonation phase or the production phase. While producing required atmospheric information involves a large number of measurements and calculations, facilities are rapidly becoming available that will operate reliably in remote areas at relatively low cost to acquire, process, and display the information in a form that will greatly facilitate decisions that provide for public safety and peace of mind.

REFERENCES

1. U. S. Atomic Energy Commission: Annual Report to Congress for 1969, U. S. Atomic Energy Commission, Washington, D. C. 20545, pp 196-200.
2. Thompson, T. J., 1970: Improving the quality of life - can Plowshare help? Proceedings of Symposium on Engineering with Nuclear Explosives, Jan 14-16, 1970. American Nuclear Society and U. S. Atomic Energy Commission, Las Vegas, Nevada, Vol 1 pp 1-4.
3. Kedrovskiy, O. L., 1970: Prospective applications of underground nuclear explosions in the national economy of the USSR. UCRL-Trans-10477. Lawrence Radiation Laboratory, Livermore, California.
4. Blume, J. A., 1970: On the prediction of building damage from ground motion. Proceedings of Symposium on Engineering with Nuclear Explosives, Jan 14-16, 1970. American Nuclear Society and U. S. Atomic Energy Commission, Las Vegas, Nevada, Vol 2, pp 1103-1117.
5. Werner, L. B., 1969: Radioactivity in the hydrologic environment. Proceedings for the Symposium on Public Health Aspects of Peaceful Uses of Nuclear Explosives, Southwestern Radiological Health Laboratory, Las Vegas, Nevada, April 7-11, 1969, pp 280-308.
6. Germain, L. S. and J. S. Kahn, 1968: Phenomenology and containment of underground nuclear explosions. UCLRL - 50482, November 1968. Lawrence Radiation Laboratory, Livermore, California.
7. U. S. Atomic Energy Commission: A Report on Underground Nuclear Testing. TID-25180, U. S. Atomic Energy Commission, Washington, D. C. 20545, September 1969, pp 25-27.
8. Mueller, H. F., 1969: Local fallout and diffusion of radioactive material. Ch. 13B in Technical Discussions of Offsite Safety Programs for Underground Nuclear Detonations. NVO-40. U. S. Atomic Energy Commission, Nevada Operations Office, Las Vegas, Nevada, May 1969, pp 261-270.
9. Stout, A. H., R. E. White, and V. E. Quinn: Weather and surface radiation estimates for the RULISON event. ARLV-351-4 Environmental Science Services Administration, Air Resources Laboratory-Las Vegas, Las Vegas, Nevada.

TABLE 1. MESOSCALE CLIMATOLOGICAL NETWORK

PURPOSE: TO IDENTIFY LOCAL VARIATIONS OF WIND, FREQUENCIES OF OCCURRENCE AND POSSIBLE CAUSES.
ALSO, TO IDENTIFY OTHER CLIMATOLOGICAL PROBLEMS.

<u>PARAMETER</u>	<u>SENSORS</u>	<u>NUMBER IN NET</u> *	<u>DURATION</u>
Surface Wind	Mechanical anemo. & vane	4 to 8 on > 30' masts	> 1 year
Surface Temperature	Thermograph	1 or more	> 1 year
Rainfall	Tipping bucket gage	1 or more	> 1 year
Winds aloft	Pibals to 10,000' above surface	1 to 4 stations	Intermittent series**

* The number and spacing in the network depends on the expected degree of terrain influence.

** A few days in each season, at hourly intervals, to determine correlation with the nearest NWS upper air station and to observe the wind variability.

TABLE 2. MESOSCALE OPERATIONAL NETWORK

PURPOSE: TO MAINTAIN ESSENTIALLY "REAL TIME" SURVEILLANCE OF THE ATMOSPHERIC CONDITIONS HAVING GREATEST INFLUENCE OVER THE TRANSPORT AND DIFFUSION OF AN EFFLUENT.

<u>PARAMETER</u>	<u>SENSORS</u>	<u>REPORTING FREQUENCY</u>	<u>DATA FORM</u>	<u>NUMBER IN NET</u> *
Surface wind	Anemo. & Vane	Variable 5 to 60 min.	Digital, teleprinter	4 to 8 on 30' masts
Surface temperature	Platinum resistance thermometers	Variable 5 to 60 min.	Digital, teleprinter	4 to 8 at 5' on masts
Winds aloft	Radars and pibals	Hourly (sometimes half-hourly)	Voice radio or telephone in standard code	4 or more
Temperatures aloft	Rawinsonde	3-hourly or as needed	Telephone in standard code	1 or more

Supplementary measurements are used, if needed, and include:

Vertical temperatures and winds by instrumented aircraft.

Vertical temperatures by tethered balloon or tower.

Air trajectories using constant volume balloons (tetroons) tracked by radar or visually.

Local air trajectories using series of toy balloons.

Precipitation surveillance using local radar or FAA radar.

* The number and spacing in the network depends on the results of climatological evaluation.

Fig.1 Natural gas formations considered for nuclear stimulation.

Fig. 2. Underground cavity and chimney formation.

FIG. 3 SURFACE AIR CURRENTS DURING PROJECT RULISON DETONATION.

FIG.4 TYPICAL NOCTURNAL AIR CURRENTS AT THE PROJECT GASBUGGY SITE.