30/8-30-93 JS (1)

UCRL-ID-113780

On-site Inspection: A Brief Overview and Bibliography of Techniques Pertinent to Assessing Suspected Nuclear Test Sites

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March 1993

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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SUMMARY

This document provides a brief overview of techniques that are applicable to on-site inspection with consideration given to the bases for application of these techniques. A bibliography is included as a starting point for investigations into the potential inspection methods that are described.

INTRODUCTION

The purpose of this report is to provide a brief overview and bibliography of those techniques that may have application for the evaluation of a site to determine if a high energy release event is nuclear in nature. This effort is motivated by recognition of the changing world political climate and the perception that low yield and non-proliferation issues will grow in importance as countries become increasingly involved as signators to treaties that are intended to limit the development and testing of nuclear weapons. Along with an increasing interest in such issues is the awareness of the need to implement improved capabilities for treaty monitoring programs that must deal with assessing suspicious occurrences of high energy release events.

In preparing this report, it is recognized that monitoring can take two main forms. The first involves the resolution of unidentified events detected by seismic and satellite National Technical Means. Events of an indeterminate nature could occur world-wide and could induce tension in neighboring countries. If an on-site measurement capability were available, a monitoring team could be sent to the suspected site of an event to take measurements that could confirm or disprove the occurrence of a clandestine nuclear test. The second monitoring form is the confirmation that a clandestine event is not masked by a declared event. For example, a large mining explosion could mask a decoupled nuclear explosion. On-site measurements before and during the test could confirm that a clandestine event did not occur and could provide assurance that the party carrying out the explosion is not taking advantage of clandestine testing opportunities.

APPLICATION SCENARIO

A systematic set of decision-oriented, analysis procedures would be invoked by the treaty monitoring organization following detection of a distant unidentified event using remote sensing (e.g., seismic or atmospheric observations, overhead imagery) or human intelligence data. Analysis and decision making methodologies utilizing a data base and advanced computer based technologies, such as an expert system, would be used to estimate a probability that the event was a violation and that an on-site inspection could resolve the nature of the event. If the likelihood of resolution by inspection was acceptable, an on-site inspection would be requested. The treaty monitoring team would then be deployed with the transportable hardware and analysis package. Subject to developed procedures, a variety of seismic, chemical, radiologic, electromagnetic and other field exploration techniques would be employed to search for signatures characteristic of bomb related anomalies. On-site computer analyses of the initial tests, aided by a diagnostic data base, would permit a site-specific refinement of the inspection plan. Following completion of the on-site inspection, signatures from the suite of tests would be analyzed to determine the nature of the event and to estimate the probability of correct identification. This foregoing application, giving a sequence of steps for assessing an unidentified event, may be generalized to include the possibility of making pre-, during and post-event measurements under both co-operative and non-co-operative scenarios.

SCIENTIFIC BASIS

An important aspect of the inspection process is the integration of different kinds of observations of a site or a high energy release event into the analytical framework that ultimately provides an identification of the event. Most of the methods mentioned below have been employed separately to detect and evaluate anomalies resembling some of those encountered in a nuclear test environment, i.e., cavities, tunnels, buried cables, isotopic gas flow from the ground, etc. However, it is anticipated that these methods would also be employed in a manner that would provide complimentary information about a target, reducing the level of nonuniqueness in its identification. Thus, it is anticipated that a number of techniques will be employed for the evaluation of a specific suspect site. Each technique has its own scientific basis and for most techniques that we will mention, some level of scientific validation already exists. We briefly summarize the bases for several of the techniques for remote and local measurements of anomalies characterizing a nuclear test environment.

Remote Measurements: These methods can provide initial indications that an event has occurred.

(1) Surface Observations, Overhead Imagery and Aerial Surveys: In addition to being useful as an indicator of unusual human activity in a suspect region, surface examination, overhead imagery and aerial surveys can also help identity changes in surface properties such as reflectance or topography caused by an event.

(2) Regional Prompt (Shot-time) Electromagnetic Measurements:
Based on preliminary work we have done in cooperation with EG&G, we expect that shot time EMP signals can be observed at regional distances. Although further characterization of these signals is needed, such as their distance and depth dependence, they represent a promising approach for detecting suspect events.

(3) Regional seismic measurements:

Recent work in the Treaty Verification program at LLNL suggests that it may be possible to use regional seismic measurements to determine the depth of an event. If so, such measurements could help identify the source of a suspect event because current limitations on drilling constrain nuclear testing to the upper few kilometers of the Earth's crust.

On-Site Measurements: These methods are typical of those that would be employed on-site if a decision was made for an inspection.

(4) Soil gas analyses and atmospheric pumping: Nuclear tests produce radioactive isotopes of krypton (^{85}Kr), argon (^{37}Ar) and hydrogen (T-tritium) that migrate in soil gases away from the detonation site and to the surface. Based upon our experience at NTS, flows often occur in fracture networks causing gas to be transported much more rapidly than by porous diffusion. Isotopes may appear at the surface in measurable quantities within days to weeks following an event. It has been discovered that atmospheric low pressure zones forming over a site set up a regional vertical pressure gradient that speeds the arrival of such isotopes to the surface. Measurement of these isotopes in quantities occurring above background levels would be very strong indicators of a nuclear test. This would be particularly true for measurements of ^{37}Ar which has a half-life of only 35 days. Because of its transience, the presence of measurable ^{37}Ar could be used to estimate the age of an event at sites where other events have taken place previously.

(5) Post-test microseismicity: Microseismicity is an indication of a redistribution of stress in Earth's crust. It typically occurs following earthquakes, volcanic activity and explosions at depth or in mining or geothermal areas. Although, microseismic

observations in all these areas have some common features, we have observed some distinct differences such as event depths and waveform frequency content that can be used to distinguish them.

(6) Electrical resistivity surveys: Resistivity surveys, often used in prospecting, employ an artificial source of current that is supplied to the ground through electrodes. The method involves measuring potentials at other electrodes in the vicinity of the current flow. From measurements at a number of locations, resistivity maps of the subsurface can be produced. Because resistivity changes in the rubble zone produced by a nuclear test, a resistivity signature will exist. Like the seismic imaging method for rubble zones, this kind of survey will be most valuable in complementing the observations of other methods. Three dimensional simulations of the surface voltage distribution resulting from a known resistivity source distribution, such as a rubble zone, will aid in evaluating the potential usefulness of resistivity surveys.

(7) Self-potential method: Ground-water is driven into a large volume of sometimes freshly produced pore space following an underground nuclear event. It is expected that this redistribution of ground-water will have a significant influence on the static electric fields that typically exist in the Earth because they are known to transport charges.

Recent measurements, at NTS, of self potential anomalies at the site of past nuclear tests support the above suggestion. Further investigation of these phenomena are needed before they can be utilized for identifying suspect events.

(8) Rubble zone seismic imaging: Recent experiments by Zandt and Jarpe (LLNL) show that the formation of rubble zones by underground detonations can reduce P-wave seismic velocities by as much as 40% in comparison to the original material. They

found that the size of the affected region is comparable to the diameter of the craters. It is not clear that the method alone could validate the occurrence of an event since the signature of the rubble zone is comparable signatures associated with normal geologic variation. However, this technique could be used to complement the results of other techniques involving post-test microseismicity and electrical methods.

(9) Monitoring of hydrologic changes: From a hydrologic perspective, NTS is unusual owing to the extreme depth of its water table at many locations (≈ 500 m). At most other places on Earth, the water table tends to be much shallower (meters to 10's of meters) and most nuclear tests are likely to take place well below the local water table. Monitoring of NTS hydrology indicates that significant changes in water table elevation (10's of meters) may be associated with nuclear tests. For shallow water tables this suggests readily observable (e.g., monitoring in existing water wells) anomalous changes to the local hydrology of a region. In addition to direct observation, electrical resistivity and self-potential methods both offer the possibility of monitoring temporal changes in the water table location of a site.

(10) Electromagnetic Measurements at Time of Detonation: In cases where co-operative parties invite an inspection team to document that a planned event is not nuclear or that a low level nuclear event is not hidden by a chemical event, shot-time measurements capable of detecting emp signals may be called for. Electromagnetic pulse signals are well studied for nuclear events but not for chemical events. Small electromagnetic signals have been associated with underground chemical explosions that produce a seismo-electric effect. Comparison of the electromagnetic signatures at shot-times of chemical and nuclear events would provide useful background data for the on-site inspection package.

(11) Reflection and Refraction Seismic Imaging:

To a first approximation, the Earth is a layered medium whose velocity increases with depth. Using this attribute and the physics of waves it can be shown that waves generated by vibrators or explosions at the surface can be used to image structures at depth. For example, in a recent refraction study at NTS, LLNL found significantly slower P-wave velocities in the vicinity of the shot point of a previous nuclear test in comparison to the surrounding medium. Such changes in seismic velocity are expected in seismic reflection profiles because relatively smooth layers in the vicinity of a nuclear explosion would be destroyed or significantly altered.

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