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Visual Inspection for CTBT Verification

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Cover photo: *Surface crack induced by an underground explosion and the shadow of a tripod-mounted documentation device.*

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Ward Hawkins
Ken Wohletz

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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VISUAL INSPECTION FOR CTBT VERIFICATION

by

Ward Hawkins and Ken Wohletz

ABSTRACT

On-site visual inspection will play an essential role in future Comprehensive Test Ban Treaty (CTBT) verification. Although seismic and remote sensing techniques are the best understood and most developed methods for detection of evasive testing of nuclear weapons, visual inspection can greatly augment the certainty and detail of understanding provided by these more traditional methods. Not only can visual inspection offer "ground truth" in cases of suspected nuclear testing, but it also can provide accurate source location and testing media properties necessary for detailed analysis of seismic records. For testing in violation of the CTBT, an offending party may attempt to conceal the test, which most likely will be achieved by underground burial. While such concealment may not prevent seismic detection, evidence of test deployment, location, and yield can be disguised. In this light, if a suspicious event is detected by seismic or other remote methods, visual inspection of the event area is necessary to document any evidence that might support a claim of nuclear testing and provide data needed to further interpret seismic records and guide further investigations. However, the methods for visual inspection are not widely known nor appreciated, and experience is presently limited. Visual inspection can be achieved by simple, non-intrusive means, primarily geological in nature, and it is the purpose of this report to describe the considerations, procedures, and equipment required to field such an inspection.

This report summarizes evidence supporting the validity of visual inspection as a worthwhile component of on-site inspection for CBTB verification. A well-based understanding of the visual features of underground testing is first required before inspection can be implemented for clandestine tests. In this light, further work on the field procedures and case histories, outlined in this report, are needed to develop a comprehensive operational manual for visual inspection. Specifically, field procedures need to be defined in more detail. This will require training, drills, and mock inspections. Case histories must be developed based upon a full literature search to compare and contrast successes/failures of visual inspection techniques.

I. INTRODUCTION

The draft Comprehensive Test Ban Treaty (CTBT) prepared by the Ad Hoc Committee on a Nuclear Test Ban (1996) stipulates on-site inspection (OSI) as a component of the treaty verification. The inspections will be carried out by designated personnel from members of the CTBT Organization. This aspect of the treaty results from conclusions drawn by experts at the 1994 Conference on Disarmament, who stated that OSI "should be an integral part of the overall CTBT verification regime and conducted with the view of obtaining scientific evidence which could be used to determine whether an 'ambiguous' event is a nuclear explosion carried out in violation of the Treaty's provisions."

Evasion ploys are a reality in potential treaty violations. Edward Teller testified before the Senate Disarmament Subcommittee in 1958 stating:

> It would be a mistake to think underground tests are the only means of evasion. It is wrong to think that a net of seismic stations in the Soviet Union will make us safe. There are all kinds of other ways how a test moratorium could be circumvented. I would not like to go into this question because the subject is infinite. I should just like to assure you that the thinking along these lines has just started.

Numerous advances in seismic detection techniques since Teller's pronouncement have addressed issues of testing in areas of natural or engineered (mining) seismic activity or by decoupling the explosion energy from the surrounding media by testing in a cavity (e.g., Bolt, 1976). One must acknowledge that any attempts at concealment require expensive and advanced engineering techniques, and that these techniques affect the testing environment. For example, Bolt (1976) shows that to optimally decouple a 50-kt explosion at a depth of 1.2 km would require a spherical cavity large enough to contain a thirty-five story building, and "concealment of such mining activity and dispersal of mined rock would be next to impossible." While for tests of smaller yields or partial decoupling, the requirements for concealment are probably manageable, consider the experience gained from underground nuclear test containment at Nevada Test Site (NTS) where the ability to fully contain underground nuclear explosions required years of empirical and theoretical effort to achieve. One might conclude that concealment is not a trivial engineering feat, and it might dominate the test program if the program depended on it (see for example, "Caging the Dragon—The Containment of Underground Nuclear Explosions, " Carothers et al., 1995).

Because experience with nuclear testing is dominated by underground deployment, we will limit this report to considerations of such tests. We assert the following statements in justification of our work described in this report.

1) Visual Inspection = *Ground Truth*: the most likely method for concealing a nuclear test on land is underground deployment

- Teleseismic interpretation is enhanced by detailed geologic knowledge of the source region.
- Testing will leave evidence of cultural activities.
- Visual inspection constrains or confirms possible source mechanisms (e.g., mining, tectonic, testing).
- Visual inspection documents the geology of the testing media (crystalline rock vs. alluvium) and for tamped shots the degree of likely seismic coupling.
- Visual inspection guides radionuclide and seismic aftershock detection by locating surface ground zero (SGZ) and identifying permeable pathways for gas escape.

2) Visual inspection of the "pink elephant" (no observable surface effects) is valid

- If on-site inspection is employed to investigate an area of suspected testing activity, remote (e.g., teleseimic, satellite) signals have prompted the investigation.
- Upon inspection, if no natural (geologic) or manmade (engineering) features explain the remote observations, a false negative is likely, and a major paradox must be explained.

3) Visual inspection can be achieved through simple means, primarily geological in nature

- Several key activities involve simple documentation of cultural, geological, and biological disturbances.
- Key activities have poor documentation and are not publicized, but they can be established by careful assessment of the nuclear testing experience base.

4) Visual inspection procedures must be defined for uniform CTBT implementation

- Presently there are no general procedures for visual inspection, no bounds on activities it encompasses, and no standardized approach.
- A document defining the process, the activities, the equipment, the personnel required, and applications of visual data can provide guidance for treaty negotiations.

Purpose of the work. Our ultimate objective is to produce a visual inspection manual that incorporates experience gained from underground nuclear testing programs in the U.S. and other countries. The manual is intended to define procedures, personnel requirements, and equipment, as well as serving as a reference guide for training designated personnel from the international organization (U.S. Department of Energy, 1994a). The manual will also address the issue of integration of visual inspection with other on-site inspection activities. We acknowledge that for such a manual to be effective for development of treaty protocol, it will require contributions and editing from other treaty countries and approval through the treaty negotiations. While this report serves only as a primer, our goals for such a complete visual inspection manual include:

1) Describe visual inspection logistics, activities, personnel, and equipment.
2) Define diagnostic features and procedures for determining if an underground explosion has a nuclear source.
3) Suggest follow-on activities for data documentation and interpretation techniques.
4) Illustrate examples of visual inspection case studies.

II. FEATURES AND EFFECTS OF UNDERGROUND NUCLEAR TESTING

In this report we limit our realm of considerations to underground testing. While underground explosion phenomena can have both natural and manmade sources and many large manmade underground explosions are nonnuclear, our experience with nuclear testing has taught us that there are a number of surface/subsurface geologic, floral/faunal, and cultural effects that generally accompany underground nuclear testing. As described in the Threshold Test Ban Treaty (USACDA and USOSIA, 1990), there are two main underground testing designs: (1) vertical emplacement and (2) horizontal emplacement. While surface features can always be inspected, depending upon implementation of these testing geometries, subsurface features may or may not be accessible.

The phenomenology associated with underground nuclear testing (e.g., Houser, 1969; U.S. Congress, Office of Technology Assessment, 1989; Kunkle, 1994) includes these important aspects, illustrated in Figure 1. When an underground nuclear explosion occurs, the shock wave dynamically vaporizes and melts the rock in the immediate vicinity of the detonation point. The shock-induced outward motion and high internal cavity pressure cause the cavity to expand until the pressure has decreased to the point that the rock can no longer be deformed. The material then rebounds to form a large compressive stress field around the cavity. After cavity growth ceases and internal pressure drops below the amount necessary to support the overburden, the rock above the cavity falls into the void, forming a rubble chimney. Depending on the yield and overburden characteristics, collapse may extend to the surface forming a subsidence crater. As a result of cavity growth, rock fracturing may occur within several cavity radii of the detonation point. At the surface, reflection of the shock produces a rarefaction that propagates downward, causing spallation of surface materials. Surface cracks generally form within this zone of surface spallation and as a response to crater subsidence if it occurs. Geologic structure and pretest in situ stresses influence the nature and extent of fracturing in subsurface and surface materials. All of the above phenomena are strongly controlled by the depth of burst, rock lithology and structure, hydrogeology, and topography.

Adushkin and Spivak (1994) compiled one of the most comprehensive reviews of the geologic characterization of underground nuclear explosions. Their review covers experience gained from the underground testing of high-yield explosions for military use, peaceful use, the stimulation of energy and mass exchange in geologic media, and development of long-distance detection techniques. The geological regimes that form in test media after an underground explosion affect the media to ranges (r) scaled to the explosive yield in kilotons (kt). These regimes, though not always observed, include (1) the melt *cavity* where rock vaporization and motion have produced a void ($r = 4$ to $12\ m/kt^{1/3}$); (2) the *crushed* zone where the medium has lost all of its prior integrity ($r = 30$ to $40\ m/kt^{1/3}$); (3) the *cracked* zone characterized by radial and concentric fissures ($r = 80$ to $120\ m/kt^{1/3}$); and (4) the zone of *irreversible strain* that causes local media deformation ($r = 800$ to $1100\ m/kt^{1/3}$). While the scaled ranges of these regimes are highly dependent upon the test media structure and lithology (strength, compressibility, sound speed), rocks within these regimes experience irreversible explosion deformation resulting in changed porosity, permeability/filtration character, and material strength.

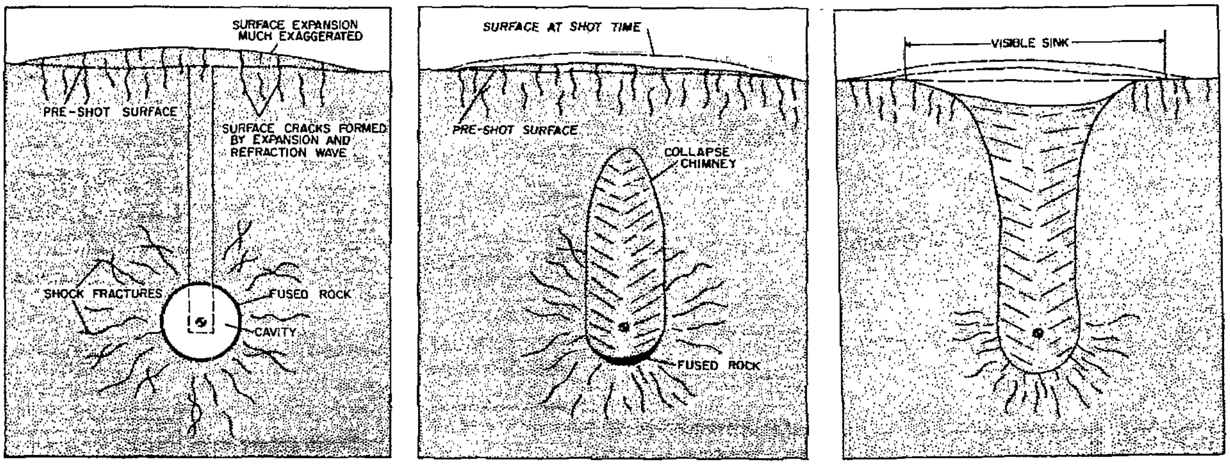

Figure 1. Schematic illustration of underground testing phenomenology (Houser, 1969).

The following discussion covers surface and subsurface features and effects by describing their character. This discussion is not intended to be complete, but rather an outline of significant features [see also Hawkins (1983) and Allen et al. (1997) for a more detailed discussion]. Of surface features and effects, geological, cultural, and floral/faunal types can be observed, while subsurface effects are primarily geological in nature. While both surface and subsurface effects are strongly dependent upon the device yield and material properties of the test medium (geology), surface features develop as a function of depth of burial (DOB), scaled to device yield (W in kilotons), giving scaled depth of burst (SDOB): SDOB = DOB/$W^{1/3}$. From Nevada Test Site experience, an SDOB of ~90 to 125 m/$kt^{1/3}$ is sufficient to contain an underground test from releasing radioactivity to the atmosphere; this depth is approximately 9 to 10 times the cavity radius. However, surface collapse occurs in most (95%) contained underground tests in tuff with SDOB < 150 m, but only about half of the tests with SDOB < 180 m/$kt^{1/3}$ cause surface collapse. It is apparent that with greater SDOB, the chance of producing surface effects decreases so that a clandestine test would be overburied with respect to that depth needed for containment. Considering the results provided by Adushkin and Spivak (1994), for which the zone of irreversible strain reaches up to 1100 m/$kt^{1/3}$, concealment by overburial could be practically achieved for only small yields or decoupled configurations.

1. Surface Geological Effects from Underground Explosions

A) Craters. For underburied tests, surface materials may be accelerated to the point where they are launched as ejecta, leaving a surface crater with a surrounding apron of ejecta. Such craters are typically circular in plan view, conical in profile, and range in diameter and depth from a few tens of meters to several hundred meters, depending upon the yield and depth of burial (Nordyke, 1964; Glasstone and Dolan, 1977). The formation of a crater over an underground nuclear test would only happen in the event of inadequate clandestine test design.

B) Collapse Sinks. The cavity formed around the point of explosion generally collapses, producing a chimney of rubble that migrates upward within several minutes to hours after detonation. If the chimney reaches the surface, the rocks and soil sink, forming a crater that is generally bowl-shaped, ranging in size from a few tens of meters to nearly a kilometer in diameter and a few to several tens of meters deep. There are many notable variations of crater shape, including polygonal, irregular with reentrants, and steep to vertical walls. An important concept illustrated in Figure 2 shows that crater volume is logarithmically proportional to the size of the cavity needed to produce it. For situations of underground explosions, collapse craters of large size require cavity volumes in ranges produced only by nuclear detonations. We note that where testing is designed to avoid detection, surface collapse will be unlikely, but considering the NTS experience, scaled burial depth would have to be >110 m/kt$^{1/3}$ in hard rock to 240 m/kt$^{1/3}$ in soft rock in order to avoid surface collapse.

C) ***Depressions.*** Recognition of subsidence of broad areas over underground tests generally requires surveying techniques. Generally centered around SGZ and circular in shape, the amount of subsidence is generally greatest at SGZ, decreasing outward to several hundred meters away from SGZ (App, 1985; Houser, 1969, 1970). Where these structures interact with local geological structural features such as faults, the depressed area can take on an oblong shape.

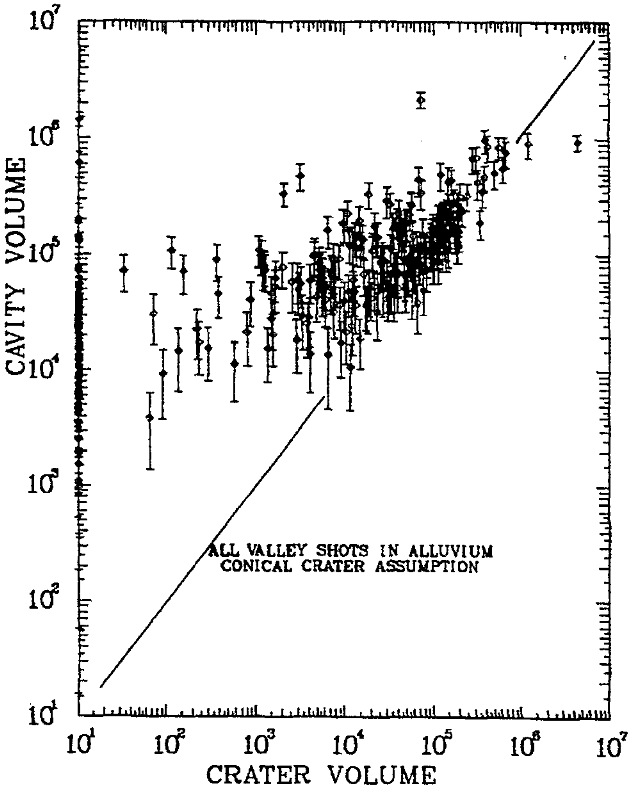

Figure 2. Plot of cavity volume vs. crater volume (m^3) for underground nuclear tests in alluvium. Note that the character of this plot should change for testing in different media and depth of burst (Kunkle, 1994).

D) ***Fractures.*** Fractures in rock and soil are caused by underground testing and are often referred to as "cracks". Surface expression of these cracks are a manifestation of rock movement (due to propagation of stress waves and their reflection from the surface downward as a rarefaction) and subsidence of the chimney zone and crater. Cracks often follow zones of rock/soil weakness caused by tectonic faults and naturally occurring rock joints and have various dimensions. Explosion-produced cracks can be classified as radial, linear, and concentric (Figures 3 and 4).

1) Radial - Cracks that extend radially outward from a point at the surface directly above the explosion (surface ground zero or SGZ).
2) Concentric - Cracks that form roughly concentric to SGZ.
3) Linear - Cracks that have an orientation other than the radial and concentric cracks; they are indicative of preexisting geologic conditions and cultural features.

E) Other Features.

1) Pressure ridges - Linear zones of broken ground that are elevated from the surrounding surface.
2) Disturbed ground - Elongated zones of ground rubble that have the same elevation as the surrounding surface, or zones of inflated soil ("fluff") caused by rapid accelerations.
3) Faults - Linear cracks with one side offset from the other (usually vertical).
4) Water table rise - Decrease in the depth to water in wells or new surface seepages.
5) Water impoundments - Evidence of water movement in ponds, tanks, etc.
6) Rock falls - On high angle slopes loose rocks may be displaced downhill.
7) Thermal anomalies - Present only where there has been cavity gas leakage.
8) Ground slump - Downslope movement of soil and rock along natural and manmade slopes.

2. Subsurface Geological Effects from Underground Explosions

A) Fractures. Cracks in the rock that are formed in a tunnel complex as a result of an explosion; they can be almost any orientation and dimension.

B) Bedding Plane Movement. Cracks and/or offsets that occur along contacts of different rock types are usually sub-horizontal.

C) Microfracturing. Zone near explosion that shows little distinguishable cracking but has been significantly weakened by the explosion.

D) Faults. Fractures that have offset (when radially oriented from the explosion point, the motion is always compressive).

E) Others.

1) Water seeps - Free water entering tunnel can be evidence of formation damage.

2) Tunnel deformation - Walls, floor, and ceiling may shift or collapse.
3) Thermal anomalies - Present in rock near the detonation point.
4) Rock hardness variations - Explosive-driven shock waves degrade rock hardness.

3. Cultural Features (Artifacts)

To conduct an underground nuclear test requires the utilization of facilities and equipment not normally associated with commercial operations. Additional security and safety issues must be addressed. Utility demands will be increased. Diagnostic instrumentation must be fielded to assess the performance of the explosive device.

A) Structures. Facilities required for the housing of sensitive equipment and special nuclear materials as well as scientific personnel (Boardman, 1970).

1) Roads - Roadways improved beyond what would be necessary for commercial operations.
2) Buildings - Secure and weatherproof facilities for technical activities associated with a test.
3) Surface preparation - Excessive surface excavation, treatment, and grading.
4) Wellheads and casing - Required for emplacement of explosive device (large diameter), subsurface instrumentation, and post-shot sampling tools.

B) Equipment. The execution of an underground nuclear test may require equipment not associated with regular operations and incorporates unusual levels of safety and precision.

1) Emplacement equipment - For a vertical emplacement, this would include lifting and backfilling equipment; for tunnel emplacement, loading and handling equipment not typical of commercial operations.
2) Instrumentation - Utilities (power, compressed air, ventilation, etc.) and sophisticated electronic equipment that are in excess of requirements for commercial activities. Cables which would be associated with data acquisition endeavors are typically expensive coaxial or fiber-optic types, only used for the highest quality data transmissions (Figure 5).

C) Other.

1) Containment features - Materials, equipment, and activities that would be necessary to contain radioactive gas and debris from escaping to the atmosphere (i.e., sealing of shaft/tunnel with low permeability - high strength materials, gas blocked cables)
2) Security precautions - Limited access areas with protective fencing and/or guards, and excessive surveillance equipment.

4. Floral/Faunal Features

Ground acceleration produced by underground nuclear tests can be sufficient to disrupt surface floral and faunal feature. Disruptions include felled trees, disturbed ground at base of trees, vegetation-filled lineations indicating previous cracking, disoriented/agitated wildlife, and renewed or destroyed animal burrows (Allred et al., 1965). These features are very sensitive to site environment.

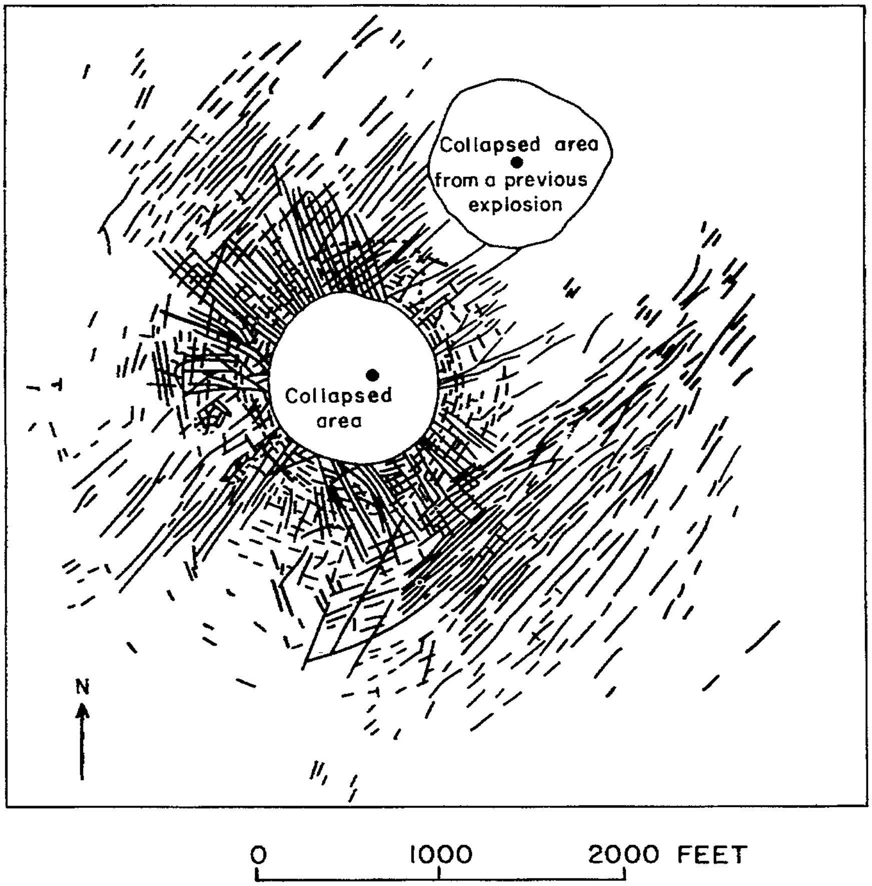

Figure 3. Map illustrating surface cracks around a collapse crater at NTS. Note the radial, concentric, and linear cracks (Barosh, 1968).

Figure 4. Photograph of surface crack through bedrock.

Figure 5. Cables typical of sophisticated diagnostic measurements and a perimeter security fence post.

III. DIAGNOSTIC TECHNIQUES FOR VISUAL INSPECTION

As described above, underground nuclear testing is generally performed by one of two emplacement techniques: vertical or horizontal. Vertical emplacement requires drilling or mining a large-diameter shaft to the depth necessary to insure containment of explosive effects or conceal the test so that it can not be detected by obvious explosion-induced surface disturbances (Figure 6). On the other hand, horizontal emplacement is achieved by horizontally mining into a mountain or plateau or from a vertical shaft. In the horizontal case surface cultural features near SGZ will be minimal, but in both cases surface geological effects can be evident. Because of the difference in emplacement techniques, we expect that cultural and geological effects may differ and suggested detection techniques will similarly be somewhat different.

The following discussion of diagnostics and detection is based on a informal workshop held with LANL geologists and Bechtel Nevada scientists experienced with post-shot effects at the Nevada Test Site.

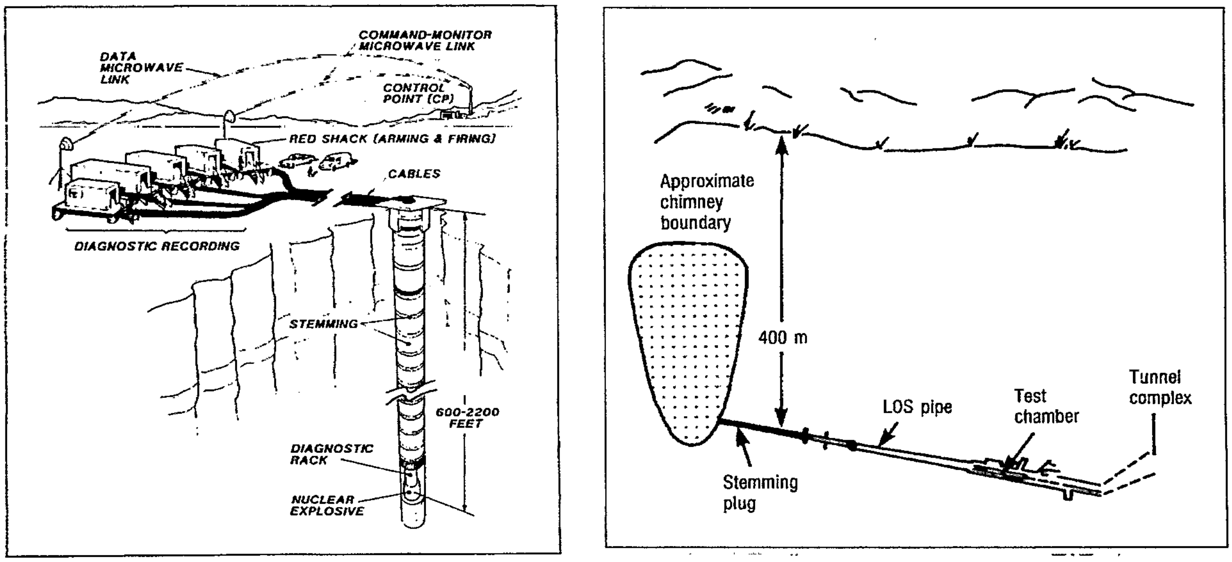

Figure 6. Illustration of typical vertical (left) and horizontal (right) emplacements of underground nuclear tests conducted at the Nevada Test Site (U.S. Congress, Office of Technology Assessment, 1989).

1. Vertical Emplacement

Table 1 lists expected cultural artifacts and geological/geophysical effects of underground nuclear testing by vertical emplacement. The table also shows characterization techniques used at the Nevada Test Site and expected to be useful in visual inspection activities.

Further work will expand this table to include site-specific considerations for other testing environments and further description of its contents.

Table 1. Vertical Emplacement Artifacts and Diagnostic Techniques

CULTURAL	*GEOLOGIC*	*TECHNIQUES*
cables	craters (subsidence)	air photo survey
holes	fractures and cracks	sampling (material properties)
mud pit for drilling	pressure ridges	rocks
stemming material	block motion and spall	debris
instruments	rockfalls	operational assessment
pre- & post-construction	floral/faunal disturbance	geologic mapping
prepared ground and roads	ground rubble and "fluff"	stratigraphy
buildings	groundwater anomalies	structure
trailers	geophysical anomalies	surface effects
trash disposal	temperature	shallow measurement holes
security	magnetic	hand trenches
perimeter fencing	electric	displacement measurements
sign posts	surface water disturbances	geophysical surveys
surveillance equipment		magnetic
lifting equipment		temperature
crane		resistivity
"strongback"		geodetic survey
utilities		photography

2. Horizontal Emplacement

Table 2 lists expected cultural artifacts and geological effects of underground nuclear testing by horizontal emplacement. The table also shows characterization techniques used at the Nevada Test Site and expected to be useful for visual inspection activities.

Further research will expand this table to include site-specific considerations for other testing environments and further description of its contents.

Table 2. Horizontal Emplacement Artifacts and Diagnostic Techniques

CULTURAL	GEOLOGIC	TECHNIQUES
muck pile	Surface	geologic mapping
mining equipment	craters (subsidence)	stratigraphy
muckers, etc.	fractures and cracks	structure
grouting equipment	pressure ridges	effects
instruments	block motion and spall	geodetic survey
utilities	rockfalls	sampling (material properties and geochemistry)
ore removal & preparation	vegetation disturbance	
security	disturbed ground "fluff"	rocks
cables	groundwater mounds	soils
"normal" operations infrastructure	thermal anomalies	radiation survey
diagnostic tools	magnetic anomalies	geophysical surveys
containment hardware	fauna disturbance	magnetic
stemming materials	surface water	resistivity
epoxies, etc.		thermal
tunnel hardening	Subsurface (near field)	seismic velocity
mine design features	microfracture zone	Schmidt hammer
	block motion	
	radioactivity	
	device debris	
	temperature	
	s-wave velocity decrease	
	Subsurface (far field)	
	spall	
	floor heave	
	block motion	
	reverse faults	
	bedding planes	
	temperature	
	grout injection	
	tunnel collapse	
	tunnel offset	
	absence of HE products	

IV. PROCEDURES

The experts of the 1994 Conference on Disarmament concluded that "OSI should be conducted in the least intrusive, most cost-effective and timely manner, consistent with the effective achievement of its objectives." Although the study of surface effects of underground testing at the NTS has a long history, documented in numerous reports and memoranda, that effort has been directed at planning and siting of tests (e.g., Howard, 1983), the understanding of geologic phenomena, and identification of features that might adversely affect containment. For this reason, no standard procedures exist for visual inspection. Garcia et al. (1989) began an effort to standardize and document the procedures used in mapping surface effects at the NTS, but their effort remains unfinished and unpublished. To begin a remedy for this lack of visual inspection procedures, we offer the following section as an outline of the activities, logistics, and personnel we envision as necessary procedural components of a visual inspection.

1. Activities

The basic approach to visual inspection activities involves a *remote-to-target* strategy. This approach follows these steps: (1) initial efforts will compile as much geological and cultural information around the target site as possible by literature searches, remote sensing techniques, aerial photography, and seismic records; (2) with data from step 1, a rough reconnaissance map will be compiled, showing access routes, target objects such as geologic contacts and structural features, and evidences of human activities; and (3) on-site documentation of features on the reconnaissance map with addition of new features and supporting data. This last step will consist of four components as described below. Each component will add to the observational data base and allow the design of diagnostic geological, geophysical, and sampling tests to be performed. The summarized procedures described below are further discussed by Allen et al. (1997).

A. Reconnaissance and Initial Visual Survey. After obtaining access to the target area and setup of necessary support facilities (e.g., housing, communications), the rough reconnaissance map will be checked. The area encompassed by this map is expected to range from a few square kilometers to as large as 100 km^2 (not to exceed 1000 km^2), based upon the scaling relationships for irreversible strain given above where the effects of a large (1 Mt) test might extend 10 km from the explosion point. This range should allow observation of the natural (undisturbed) environment for a comparison basis and to establish "background" conditions. The initial visual survey may require special transport vehicles (e.g., ATVs—all-terrain vehicles) in order for designated personnel to completely cover the area to verify objects found by remote techniques and to add new features. Location of all features will be accomplished through use of a Global Positioning Satellite (GPS) system. For example, Figure 7 shows use of GPS that allows rapid and accurate geodetic measurements for mapping features in a test area. The results of this reconnaissance and initial visual survey will provide a working map serving as a reference for ensuing activities. Sites for geological sampling, geodetic surveys, or detailed geophysical measurements will be designated at this point.

B. Photo Documentation: Aerial, Surface, and/or Subsurface. On-site photography will document all features identified on the working map by location and type (geological, cultural, biological). If the site includes mine shafts and boreholes, subsurface photographs will be made where possible. If permitted, aerial photography by low-altitude (up to 1500 meters above the surface) overflights will provide a photographic basis for the working map and augmentation of previously obtained aerial photos or remote images. Photogrammetric mapping techniques developed by Van de Werken (1983) and Garcia (1987, 1989) were developed specifically for documentation of surface effects.

C. Geological, Topographic, Cultural Feature Mapping. Detailed mapping activities will focus on the acquisition of as much information as possible on the location of different geological media, their contacts and structure. Detailed mapping will also involve description of topographic/geomorphologic elements, some of which will require precise geodetic surveys. Drellack (1988, 1989) and Baldwin and Townsend (1995) provide a framework upon which mapping procedures can be based. In addition, cultural features, such as roads, buildings, and debris from human activities, will be mapped and described in detail.

D. Sampling, Geological and Geophysical Measurements, and Geodetic Survey. With compilation of a detailed site map, specific areas will be designated for sampling, geological/geophysical, and geodetic survey activities. The purpose of these activities will be to test hypotheses that nuclear testing has occurred within or under the map area. A complete set of detailed procedures has yet to be defined, but the implementation of those procedures at a given site will be based on the unique characteristics of the site and its studied objects. Apart from radiological/chemical sampling, which is a separate activity, visual inspection sampling is important for activities that will determine any media damage by explosive shock, rock properties important for understanding seismic wave propagation, and relative age of site alterations by human activities. Geological/geophysical measurements (see Tables 1 and 2) will document the existence and location of the possible geological artifacts of nuclear testing. These exercises will require geodetic information from designated surveys.

At the time of writing this report, no standard methodology exists for these general activities, using techniques described in the Tables 1 and 2. However, a document of methods, prepared by Allen et al. (1997), is being drafted, based on their experience with post-shot investigations at the Nevada Test Site (e.g., Drellack, 1988).

2. Logistics and Equipment

Logistics includes the overall infrastructure of the visual inspection team, how the team is deployed, chain of authority, how information is exchanged, communication, reporting, and documentation requirements, on-site support, and negotiations with the testing party. Equipment needs are also part of the overall logistics because such equipment will have to be transported within the host country, certified and regulated by treaty protocol, and strictly maintained for operations and accountability.

Table 3 shows a list of equipment desired for visual inspection by activity type. This equipment represents what is typically applied to geological investigations, and it has proven to be useful for characterization and documentation of nuclear test effects and artifacts. In Section VI of this report we describe example activities that incorporate some of the equipment listed below. Operational equipment includes notable logistical support (transportation, lodging, interpreters, etc.), materials and supplies for general on-site operations, and provisions for safety and industrial hygiene. Visual and surveying equipment is necessary for effective mapping (location) and documentation. Geological equipment is required to make direct measurements and characterize visually apparent surface and underground features and effects. In contrast, geophysical equipment is useful for non-intrusive measurement of features and effects that are not usually visible but nonetheless important for a complete characterization, especially where observable features have been purposely concealed. For example, radiation detectors used for rock property characterization can make positive detection of underground testing even in areas where there are no visual clues.

Visual inspection logistics for designated personnel, on-site operations, and equipment specifications, costs, training procedures, and transportation alternatives have not been developed for the CTBT, but we suggest the TTBT protocol as a model.

Table 3. Equipment Required for Visual Inspection

OPERATIONAL	*VISUAL/SURVEYING*	*GEOLOGICAL*	*GEOPHYSICAL*
personal computer	binoculars	Brunton compass	Schmidt hammer
drafting and office supplies	GPS	transit	seismometer and geophones
all-terrain vehicle	35 mm cameras	thin section machine	material properties kit
communications	Polaroid cameras	petrographic microscope	bulk density
industrial hygiene	video cameras	geologist hammer	psychometer
Drager tubes	tape measure	shovel and pick	gas analysis
PPE	altimeter	Jacob's staff	radiation monitors
combustible gas indicator	stereoscope	geological maps	KUT, beta, gamma, alpha
flame ionization detector	aerial photos	sample containers	magnetometer
photoionization detector	topographic maps	air samplers	thermal detector
oxygen meter	transit	6' soil auger	shallow borehole logging sondes
decontamination setup			bulk density meter
radiation safety			neutron logger
logistical support			data logger

3. Personnel

A key component to an OSI will be the personnel involved with visual examination of the site and their systematic recording of their observations. In addition to expertise in specific aspects of visual inspection, the OSI team should include personnel familiar with equipment used in testing and diagnostic evaluation of nuclear explosions as well as normal commercial operations.

Table 4 lists personnel by discipline and minimum number to complete activities within a reasonable time frame. At the time of writing this report, there is not enough information available to address considerations of actual time needed for operations allowed for visual inspection; however, there is a 60-day limit, which can be extended an additional 70 days. From experience at the Nevada Test Site, 2 geologists can complete field geologic mapping of the effects of a low-yield event in several days, while for larger events in rugged terrain, 4 geologists might require several weeks. Training will play a major role in selection of team members (e.g., the team might benefit from a geologist familiar with the geologic setting of a particular test area).

Safety is a major component of all personnel activities. Work in the vicinity of SGZ might present specific hazards, but weather and natural hazards are always a factor. Considerations of heat and cold, dehydration, indigenous wildlife, topography, and disorientation must be addressed when sending a field team out. Hazards for radiological and chemical exposure are expected in test areas, as are those of operations of vehicles, drilling/construction equipment, and postshot surface collapse, block fall, and gas release.

Table 4. Personnel Requirements

DISCIPLINE	***PERSONNEL***
Geologists	2
Geophysicists	2
Field Engineer	1
Mining/Drilling Engineer	1
Industrial Hygienist	1
Surveyors	2
Logistics	1
TOTAL	**10**

Figure 7. Photograph of a field-portable GPS system using a base station system for precise location.