APPENDIX C

CONCEALMENT AND DETECTION OF NUCLEAR TESTS UNDERGROUND

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I. General

Complete containment of a test explosion underground, though devised as a method for making testing easier by eliminating fallout, may also serve as the most effective method of concealing the existence of tests, and may make it very difficult to gather effective proof that such tests have been carried out in violation of a suspension agreement.

Such an explosion provides no electromagnetic signal, and the acoustic signal if it exists at all will be so muffled and distorted that it will not be characteristic even at a distance of a few hundred miles. No activity is released into the atmosphere, so that the only detection method is the seismic. To provide proof by scientific means the residual activity from the explosion must be located underground and sampled.

II. Results from Rainier Test

The only such shot carried out in this country which casts any light on such procedures is the Rainier shot of Operation Plumbbob. This was 1.7 KT in yield, and was buried 800 feet from the nearest ground surface, in volcanic tuff. About 1% of the energy appears to have gone into the seismic wave, producing a magnitude 4.2 earthquake indication on seismographs a few hundred miles distant from the shot. Accelerometers indicate that the top of the mesa under which the device was located moved up about a foot and then fell back again. Rocks on top of the mesa were displaced somewhat, and some were rolled down the side, but the appearance of the surroundings after the shot was not inconsistent with the results of a small earthquake; rocks moved by the shot could not be distinguished from those moved by past earth motions, and fissures were present both before and after. Most observers at a distance of 2-1/2 miles felt no earth shock. This is due principally to the absence of hard rock between the source and the observation point. (It is possible that an underground shot will create less disturbance above ground than an earthquake of the same seismic magnitude, and that this might be ascertained by examination of the ground around the event and by questioning of the local population, if any, but extensive experience in the local effects of underground shots would be needed before any such difference could be established.)

One could expect to contain the shot completely without venting by using as little as 500 feet distance to the surface if more disturbance of the surface were allowed; such disturbance would still not be characteristic of an explosion rather than an earthquake. Burial depth required will vary with somewhere between the 1/3 and 1/4 power of the yield; a reasonable formula is 400 $W^{0.3}$ feet (W in KT).

No activity above background was discernable either above the ground or in the tunnel leading to the explosion chamber, which was blocked off only 200 feet from the shot site. Thus the absence of activity is not merely absence of a radioactive cloud at several hundred miles, but of any radioactivity above ground or in any other region accessible without drilling. The horizontal access tunnel, 1700 feet long from the portal, showed some slabbing and cavein for several hundred feet beyond the point where it was blocked.

Exploration of the region around the zero point by drilling in from the tunnel at a distance of 210 feet has revealed that the solid fission products are contained in a shell a few feet thick at a radius of 55 feet. After four months the peak activity measured along a line at the level of the zero point was 800 mr/hour, while along a line aimed at a point 50 feet below zero from a point 210 feet away horizontally the peak was 40 r/hour. Outside of the shell the activity as measured by a counter was indistinguishable from background. Peak temperature along the horizontal line was 45°C, along the other line it was 65°. Diffusion appears to have carried elevated temperature into the zero point, and some rise above ambient is also noted out to about 70 feet.

Thus a 55-foot radius hole appears to have been established momentarily but then to have collapsed, and the falling in appears to have continued up to a point 400 feet above zero, where a hole 25 feet in radius and 25 feet high was discovered in drilling. This hole contained gaseous fission products at the same concentration as they appear inside the 55-foot radius region around zero, so the entire volume in between appears to be simply connected. This accounts for only a few percent of the gaseous fission products, and it is thought that the remainder were trapped in the resolidification of the molten rock. The region from 55 feet to 130 feet is still impervious but was apparently crushed since the drilling shows water return but no core return. It has not yet been feasible to detect this crushed region by sonic measurements even from inside the tunnel, so that detection by sonic means from above the surface is at least very difficult.

III. Diagnostic Experiments

Diagnostic experiments necessary for weapon development can be easily carried out underground. The yield can be measured by shock arrival time measurements in the rock, analagous to the fireball measurements above ground. This was done on Rainier and appears to be accurate to 10% even without a calibration. The radius of the radioactive debris or the amount of material melted might also be used if the medium is calibrated by a shot of known yield. The prompt diagnostics such as neutron and gamma ray measurements to give time interval or propagation burning data, streak camera work, etc., can be done better below than above ground since the shielding is free and one need only drill holes as desired. Radiochemistry has not been demonstrated to be satisfactory, since fractionation does occur. However, the use of hollow pipes leading into reception chambers from the device may give a substantial fraction of debris unfractionated, and may lead to satisfactory radiochemical diagnostics.

Preliminary estimates indicate that a test operation can be carried out more cheaply underground than on towers and balloons. The diagnostic stations could also be underground for clandestine tests (in fact they probably will be even if the tests are not hidden). Keeping underground tests secret will increase the costs by preventing the use of a single diagnostic bunker for many shots on the basis that more than one in a given vicinity increases suspicion and the possibility of proving a violation. It may mean that each shot must be in a completely different area, but this conclusion may be modified to some extent, because also natural earthquakes have aftershocks. In any event, such extra costs are associated with clandestine tests generally rather than underground tests specifically and are not likely to be more than a few million per shot, which is not a large percentage increase.

IV. Dependence of Seismic Signal on Yield and Medium

On the basis of observations, it is believed that the amplitude of the earth motion from an underground explosion increases as the

1.2-power of the energy released. This scaling law is obtained on the basis of explosions of conventional explosives underground (quarry blasts). The law is somewhat surprising; theoretically one would expect that the seismic amplitude would go as the square root of the energy release. The empirical law has been used in Appendix A to predict the frequency of earthquakes in the USSR which might be confused with subsurface shots of various yields. The empirical law clearly gives more larger results for the seismic signal to be expected from shots of larger yield than Rainier than the "theoretical expectation" would give.

The empirical law indicates that a larger fraction of the energy release goes into seismic waves at higher yield. This effect certainly must stop at some point; at about 100 kilotons the entire energy would be converted into seismic energy if the 1.2-power law held up to that yield. Experiments are urgently needed to establish the actual relation between yield and seismic signal. These should be carried out with nuclear explosions since conventional explosives may not give the same effect due to the evolution of large amounts of gas.

The seismic signal will depend strongly on the medium in which the test is conducted. The volcanic tuff in which the Rainier test was conducted probably gives a relatively small seismic signal; it is only equivalent to an air shot of about 20 times greater yield. Hard rock would almost certainly give a stronger seismic signal while on the other hand it may contain the radioactive products in an even smaller volume. On the other hand, unconsolidated material which is found in many places near the surface of the earth may well reduce the seismic effects below those observed in the tuff because the signal should decrease with decreasing yield stress, and unconsolidated material may have a yield stress as low as one-tenth of that of tuff (which has about 10,000 psi).

It may also be possible, by excavating a large chamber to begin with, to reduce the energy found at large distances by a factor of 10. One possibility which may reduce the seismic energy is the excavation of large cavities in salt domes. Such cavities may be tens or even hundreds of millions of cubic feet in volume, and need not be spherical. For example, a cavity 150 feet in diameter and 3000 feet long may have nearly the same effect as a spherical one of the same volume. The excavation of such a cavity would be fairly costly, and its use might be limited to a single occasion because it might cave in. To find out to what extent the seismic signal from an underground explosion could be reduced by suitable choice of medium, many tests would be required but most of these could be carried out at low yield.

It is likely that reduction of seismic signal is easier for low-yield shots than for high-yield ones. Unconsolidated material is found only in the top layers of the earth and the required burial depth increases with yield, so that it may be difficult to find such material deep enough to successfully contain a 50-kiloton test. The digging of underground caves large enough to give a substantial reduction of the seismic signal from a 50-kiloton explosion will be very costly and may in fact be impossible, especially since for mechanical stability a cave must be smaller at great depth than near the surface. Thus it may well be possible to reduce the signal from a 5-kiloton explosion so that it "looks like" 1/2 kiloton, but more difficult to make a 50-kiloton explosion appear like 5 kilotons.

V. Identification

It is shown in Appendix A that the seismic wave from a 1-kiloton subsurface explosion in surroundings similar to those of the Rainier shot will be detected by the net of seismic stations proposed for the USSR in that appendix. However, there are about 2500 earthquakes per year in the USSR which give signals of similar strength. The most promising feature of seismic signals from underground explosions distinguishing them from earthquakes is that the first pulse from explosions always corresponds to compression while the first pulse from an earthquake is compressive in two quadrants, while it corresponds to dilatation in the other two. It is estimated in Appendix A that there will be about 300 earthquakes of strength equivalent to 1 kiloton or over which will give signals in the proposed seismic detection net which cannot be distinguished from nuclear explosions and therefore will require further investigation on the spot. If the limit is set at 5 kilotons the number of unidentifiable earthquakes will be about 35.

It should be pointed out that 1 and 5 kilotons refer to the size of the seismic signal, not to the actual yield. By proper choice of the medium as discussed in Section IV, tests of 10 kilotons might be made to look like a normal 1-kiloton explosion, and perhaps, with more difficulty, 50 kilotons to look like 5. According to seismologists, it is unlikely that a nuclear explosion could be so conducted (by proper shaping of the explosion chamber) that the signal is dilatational in some directions.

The seismic signals would locate the source within about 5 miles. Investigation on the spot will then be necessary to decide whether the signal could be due to a test, this is described in Section 3e of Appendix A.

One would presumably try to find the entrance to the tunnel which was used for the test. The experiment could be carried out in a remote area, where there would be no people to give away the game, but then such indicators as roads, unusual human activity, etc., might make the inspection team dispatched on receipt and study of the seismic signal suspicious. They would still have to find the entrance (say a 6 foot hole, since covered up), proceed to the correct part of the tunnel, and drill successfully to get proof. This is made difficult by the small radius of the shell in which the radioactivity is concentrated (55 feet for Rainier). Alternatively one might use an area of substantial human activity, thus producing less unusual change in what is going on, but perhaps requiring more local people to know about what was going on or become suspicious about it.

To summarize:

1. Detection of underground shots depends entirely on a seismic net. Identification depends on local investigation.

2. Adequate proof of violation probably depends on location of the debris, which is confined to a shell whose radius is of the order of 40 $W^{1/3}$ feet where W is in KT, and whose depth is of the order of 400 $W^{1/3}$ or larger as desired. Within the five mile radius circle of uncertainty identified by the seismic signals, the entrance to the tunnel or hole must be found as a beginning in finding the activity. Broad access is required to have a good chance of locating the debris and thus providing proof.

3. Adequate diagnostic information for weapon development can almost certainly be obtained at no great increase (and perhaps some decrease) in cost by testing underground. It has not been proven that radiochemical detectors can be used, but it appears possible that some can by appropriate design of underground chambers. Some extra cost may be incurred if it is required to duplicate diagnostic bunkers, etc., in order to avoid testing several devices in one region so as to reduce suspicion; this is characteristic of clandestine rather than of underground shots.

4. Experimental data is lacking or insufficient and should be acquired either prior to or as part of an agreement on the following subjects:

   (a) Reducing the seismic energy by choice of medium and design of explosion chamber. Reducing the radius of the radioactive region by choice of medium.

   (b) The complete range of radiochemical detectors in diagnostics of underground shots.

   (c) Possible distinctive characteristics of underground explosions which will enable them to be told surely from natural earthquakes. This includes the seismograph records at a distance, and earth motions nearby. Possible special chamber design to remove such distinctions if any are found to exist must also be studied.

   (d) Use of acoustic sounding from above the surface to detect the disturbed region below the surface. This has not yet proven feasible even from inside the tunnel.