1/27
0-13-76
25 cop DNTIS

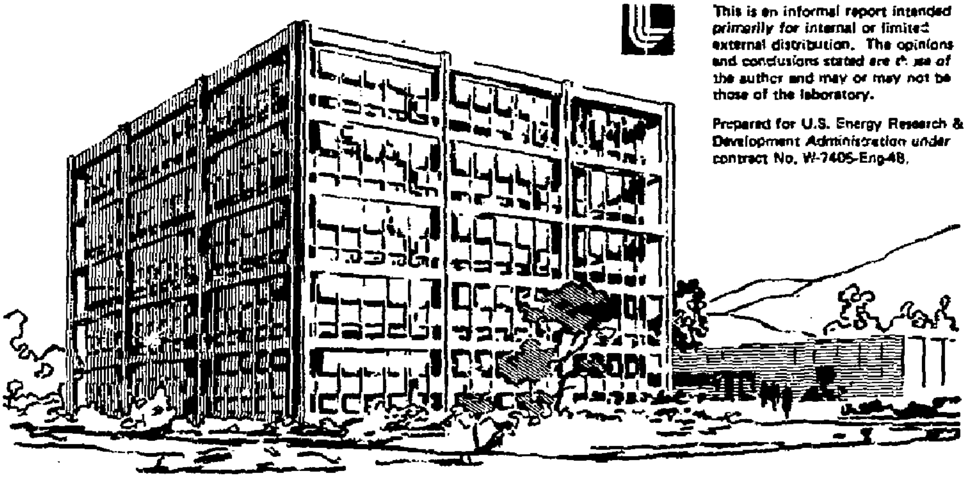
UCID-17222

Lawrence Livermore Laboratory

SURFACE AND BODY WAVES FROM SURFACE AND UNDERGROUND EXPLOSIONS

A.S. Kisubov

June 1976



This is an informal report intended *primarily for internal or limited external distribution*. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

CONTENTS

SURFACE AND BODY WAVES FROM SURFACE AND UNDERGROUND EXPLOSIONS

ABSTRACT

The characteristics of surface and ground waves were recorded for surface and underground explosions up to 100 tons and 40 kt in magnitude, respectively, and a preliminary analysis of these results is presented. The experiments were conducted at NTS in the Yucca Flats, Nevada. Ground motions were detected with triaxial geophones along seismic lines extending up to 16 miles from the point of explosion. A comparison of Rayleigh waves generated by surface and underground explosions in the same lake bed is presented indicating a very different behavior of surface and ground waves from the two types of explosions. The magnitude of the transverse wave for surface shots was smaller by a factor of two than its longitudinal counterpart. The dependence of apparent periods on the blast energy was not apparent at a fixed distance from the explosions. Changes in the apparent period with distance for both types of explosion are compared indicating a strong layering effect of the lake bed. The ground motion study was complimented by excavation of cavities generated by the explosions.

INTRODUCTION

Our program to study the effects of single and multiple explosions consisted of recording ground motions and cavity characteristics from explosions conducted at the Nevada Test Site. The Yucca Lake, where the ground motions were recorded, is located in the middle of the Nevada Test Site, and at times in early spring or after a heavy storm looks like a real lake, fortunately less than a foot deep (Fig. 1). Most of the time, however, it is a dry, hot lake bed providing a relatively uniform firing and diagnostics platform (Fig. 2).

EXPERIMENTS

The experiments recorded consisted of surface shots ranging from 1 lb to 100 tons of high explosive and underground shots ranging from 150 g to 40 kt (Fig. 3). The depth of the underground explosions varied from 2 to 50 ft for shots up to 50 lb and exceeded 1000 ft for the kiloton shots.

Fig. 1. Yucca Lake after a rain storm.

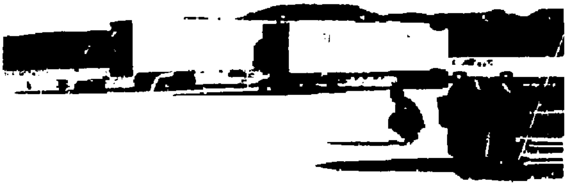


Fig. 2. Yucca Lake in the dry season, showing diagnostics facility.

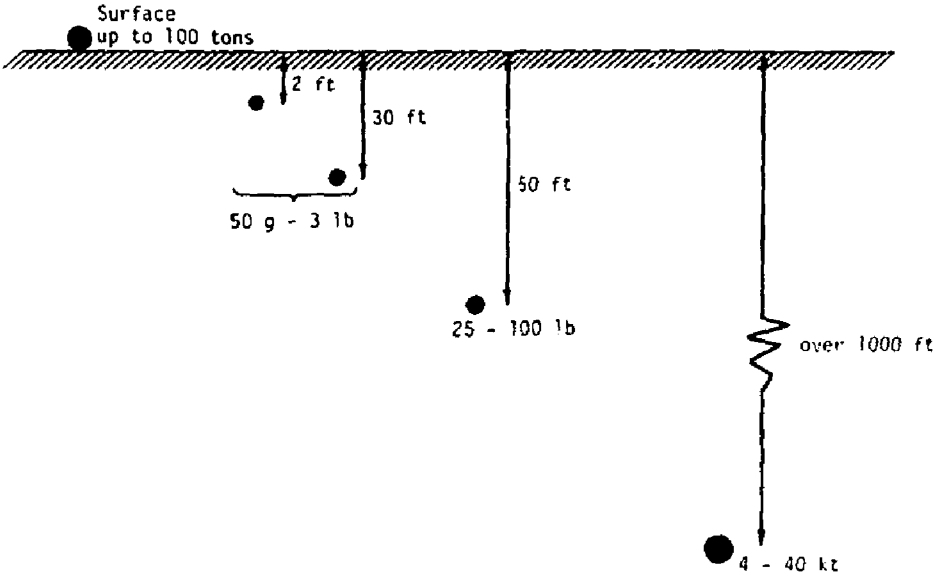


Fig. 3 Summary of seismic shots at Yucca Lake.

A number of underground experiments consisted of multiple explosions. In these experiments the effect of two or three charges fired simultaneously or sequentially was compared to a single explosion of equivalent weight buried at a depth corresponding to the center of the distributed charges. Figure 4 shows the schematic for a vertical arrangement of multiple charges; a similar setup was used for horizontal arrays.

INSTRUMENTATION

The instruments used to detect the ground motion consisted of 1.0- and 4.5-Hz, three-component geophones with a nominal response characteristic of 1.5 and 10 V/in./sec, respectively. The 4.5-Hz geophones (Fig. 5), manufactured by Mark Products Corporation,* were sealed into a waterproof container by the manufacturer and did not require special handling except for grouting in the field with plaster of Paris. The 1.0-Hz geophones (Fig. 6), manufactured by Geospace Corporation, were mounted in a special bracket for proper alignment (Fig. 7), and then placed into a waterproof container (Fig. 8). Both the bracket and the container were built to LLL specifications. The sealed container was then placed in the ground, leveled, and coupled to the surrounding medium with plaster of Paris (Fig. 9). Each geophone was calibrated *in situ* by recording its natural frequency, the resistance of the coil and the damping resistor.

DIAGNOSTICS

The diagnostics facility consisted of an instrument and a power-generating trailer (Fig. 2). The signals from the geophones were amplified in the diagnostics trailer, converted from voltage to frequency records by VCO's, and then recorded in the analogue form with several geophone signals per tape track (Fig. 10). This condensed form of recording

---

*Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable.

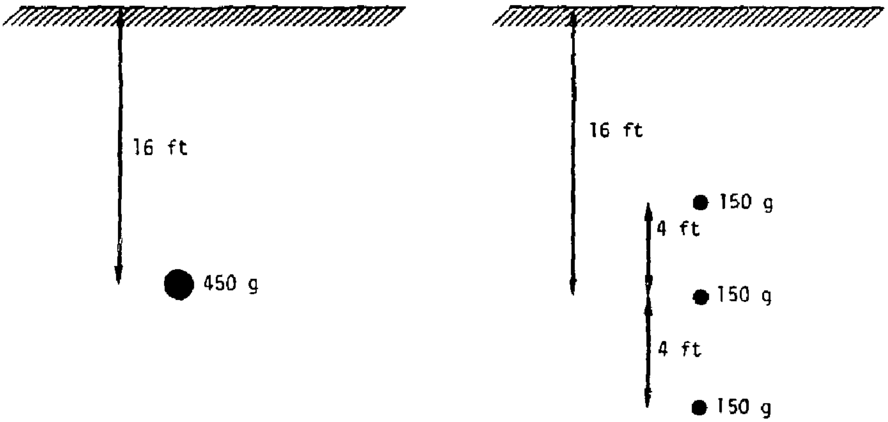


Fig. 4. Vertical array for multiple explosion experiment.

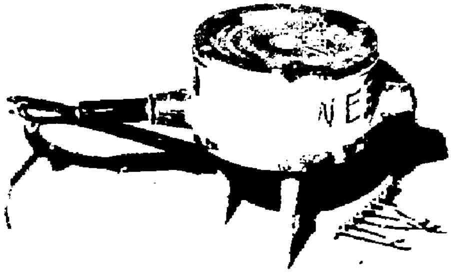
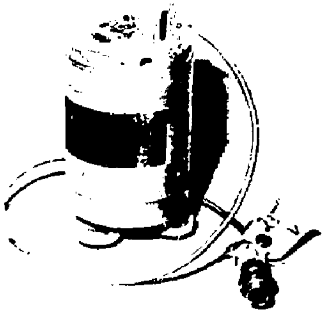
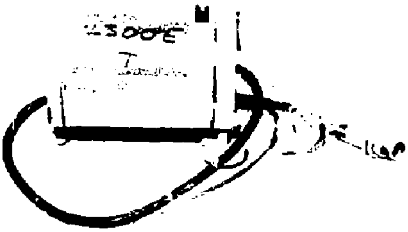


Fig. 5 Three-component, 4.5-Hz geophone (Mark Products Corporation).



(a). Vertical geophone.



(b). Horizontal geophone.

Fig. 6. 1.0-Hz geophones (Geospace Corporation).

Fig. 7. Geophone holder and alignment bracket for 1.0-Hz geophones.

Fig. 8. Assembled three-component, 1.0-Hz geophone package sealed in a waterproof container.

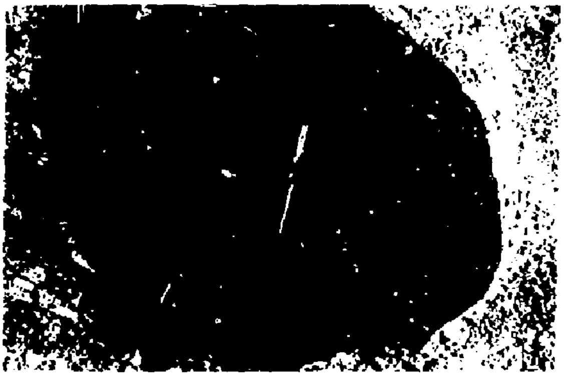


Fig. 9. Emplacement of three-component, 1.0-Hz geophone container.

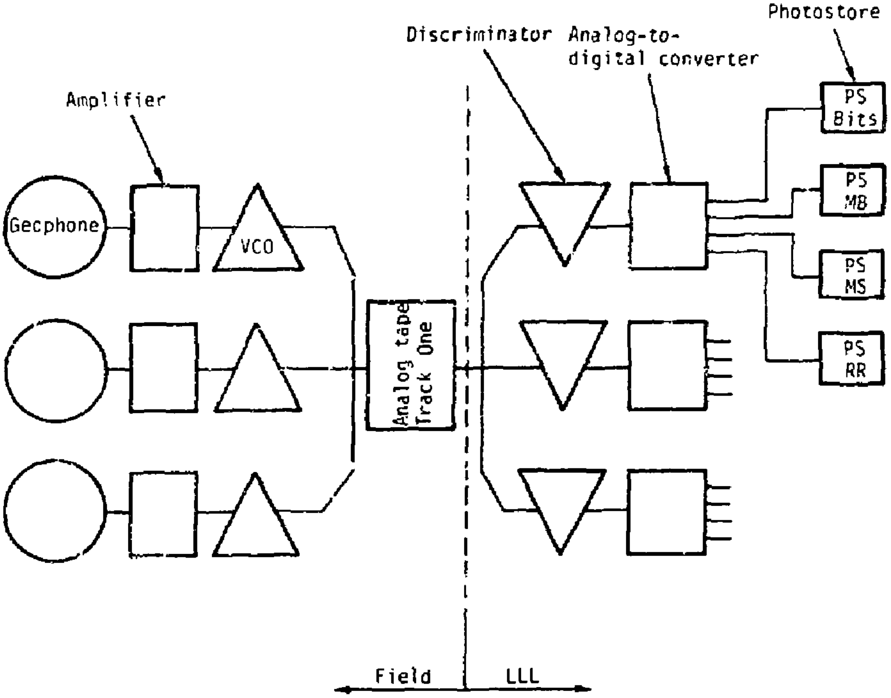


Fig. 10. Schematic of diagnostics and recording operations.

allowed us to record up to seven geophone records per tape track. The analogue tape recorded in the field was digitized in Livermore where the reverse process took place; namely, the condensed data were read with discriminators corresponding to the carrier frequencies of the VCO's and then converted to digital form. The digital records were processed by the 7600 computer and stored on photostore, thus providing an easy access for analysis and data handling.

PRELIMINARY RESULTS

Shown in Fig. 11 is a typical record for the vertical component from a surface shot of 1 lb of high explosive at 300 ft from the shot location. Here we see the P-wave, the airblast, and the Rayleigh wave. The lower trace is the same record filtered by a 40-Hz, low-pass filter on the computer.

The R-wave vs P-wave magnitude criterion often used to discriminate between earthquakes and explosions is illustrated for our experiments by a simple R/P ratio (Fig. 11). Typically for an explosion the R/P ratio is close to 3 whereas for an earthquake 10 is quite common. Our experimental effort was centered around this criterion with the recording of other effects from explosions used only to gain a more thorough understanding of this complex relationship.

Depth of Burial Effect

From single shots fired at different depths one can deduce that the amplitude of the Rayleigh wave is inversely proportional to the depth of the buried charge and reaches its maximum at the reduced depth coefficient ($m/kg^{1/3}$) of about 2 to 3 (Fig. 12).

Multiple Explosions

For multiple explosions where an enhancement of the Rayleigh wave could have been expected due to the directional firing upwards, no such enhancement was observed. The negative results can partly be explained by insufficient delay between detonations.

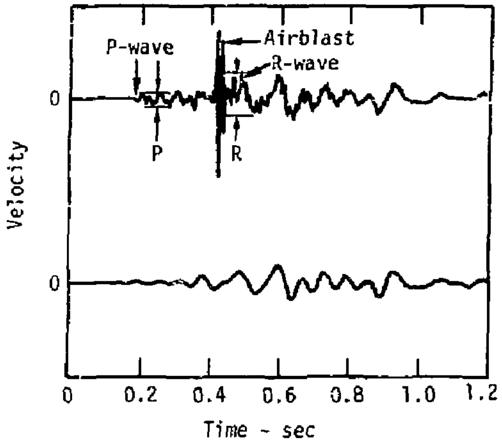


Fig. 11. Typical seismogram recorded 300 ft from 1-lb surface shot, and the definition of R and P magnitudes.

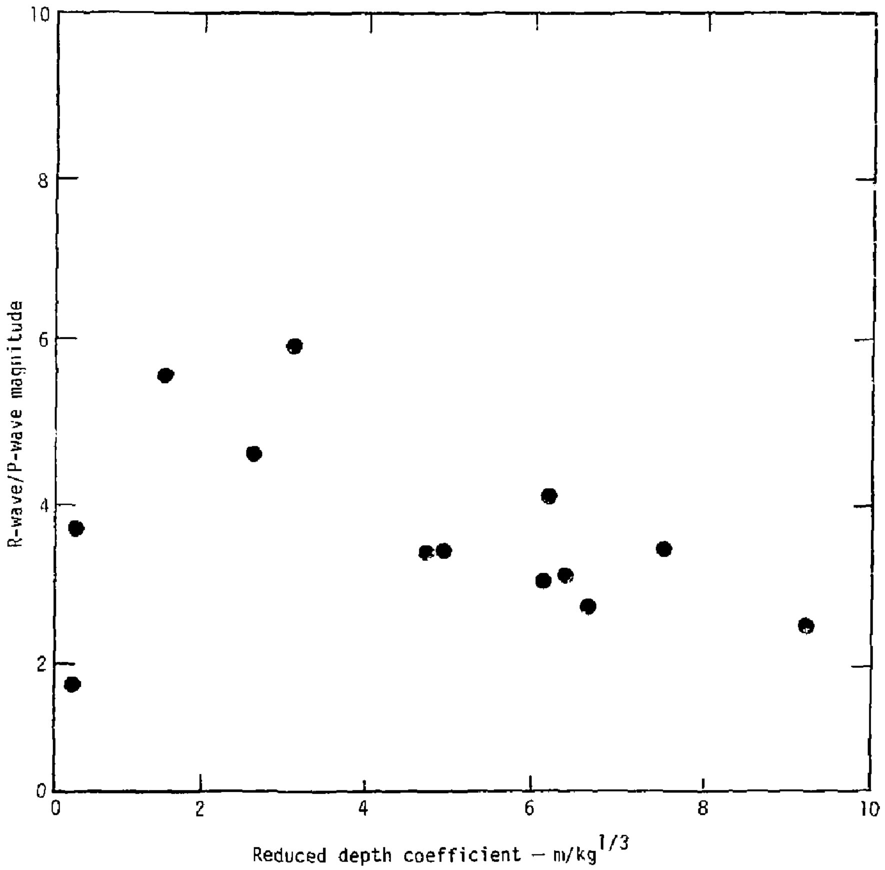


Fig. 12. R-wave/P-wave magnitude as a function of reduced depth coefficient.

Lake Bed Layering and Wave Propagation

The seismic records indicated a strong layering effect confirmed both by geophysical logging and seismic refraction. From these measurements the average sound velocity for the first layer was equal to 1250 ft/sec and for the second layer 2857 ft/sec. The depth of the second layer determined from the same measurements was 28 ft, and the Rayleigh wave velocity was about 1200 ft/sec with a characteristic frequency of approximately 8 Hz.

Surface vs Underground Explosions

Comparing the records generated by single surface and underground shots one can notice the following differences: the surface shots have an airblast that is absent in buried shots. The P-wave for surface shots did not increase at the same rate as for underground shots, although the Rayleigh wave can be scaled and compared favorably with buried shots. The dependence of apparent periods of the Rayleigh wave on the HE weight was not obvious at fixed distances from the explosions. The shear wave for surface shots was smaller by a factor of two from its longitudinal counterpart and from shear waves from similar underground shots.

Maximum Ground Velocity

The ground velocity results are summarized in Fig. 13. The maximum velocities shown in the figure correspond to surface waves of 1 to 10 Hz. The ground velocity, for buried shots up to 50 lb when plotted as a function of the distance from the shot on a log-log graph, can be represented by a straight line. For 7- and 100-ton surface shots one could infer a break in the ground velocity vs distance plot. The 4- and 40-kt shots are represented here by a single point each and were fired some 16 miles from the recording facility.

Excavation of Cavities

The seismic records were complimented by excavations of cavities generated by underground explosions. Figure 14 shows an excavated cavity generated by 150 g of Composition C-4 buried 4 ft deep. Notice the longitudinal crack that evidently prevented the formation of spall. This record also shows the well-developed radial cracks radiating from the center of the cavity at an angle of 45 deg with respect to the horizontal. A close-up of the same cavity is shown in Fig. 15. The diameter of this

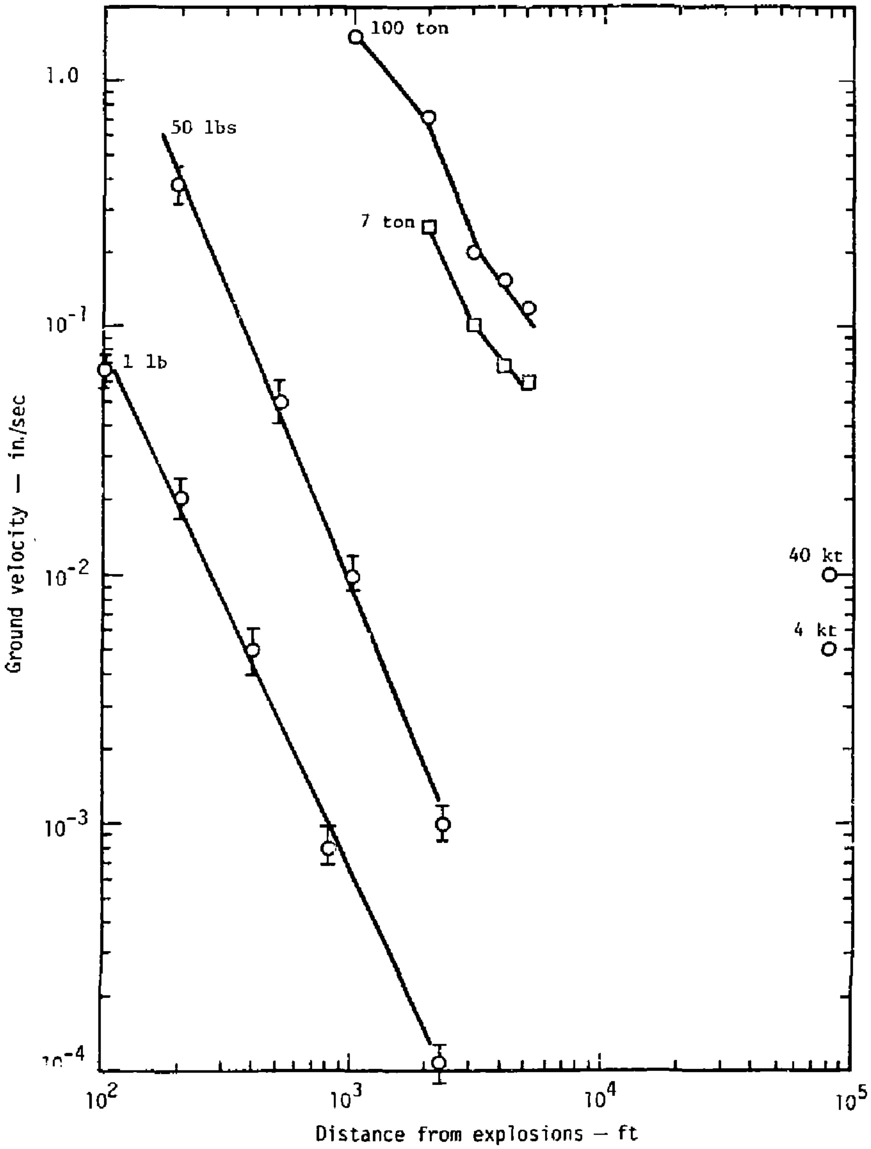


Fig. 13. Ground velocity vs distance from explosions.

Fig. 14. Excavated cavity generated by 150 g of Composition C-4 buried 4 ft deep (diameter of cavity = ~10 in.).

Fig. 15. Close-up of excavated cavity shown in Fig. 14.

cavity was about 10 in., and the rectangular sections of the cavity walls were close to 1 in. square. Figure 16 shows a view of a cavity excavated in such a fashion as to show the cracks along the vertical plane. The soot or smoke generated during the explosion served as an excellent marker for outlining cracks formed during and immediately after the explosion.

The excavation of cavities generated by a simultaneous explosion of three charges (Composition C-4, 50 g each) shown in Fig. 17 revealed that the longitudinal crack characteristic of a single explosion was present only in the upper cavity. However, the cavities compared favorably with those generated by single explosions and were about 7 in. in diameter.

CONCLUSIONS

These data are currently being used to check the TENSOR code calculations that consist of generating particle displacement time histories from a given source of energy in a layered medium. The calculated results will then be converted into seismograms and compared with experimental records.

Hopefully, these results will serve as a basis for future theoretical modeling of underground explosions.

Fig. 16. Vertical cracks of an excavated cavity.

Fig. 17. Excavated cavities generated by three simultaneous explosions of Composition C-4 50 g each with depths of 4.5 and 6 ft, respectively (cavities = ∿7 in in diameter).

ACKNOWLEDGMENTS

The reported work was made possible by continued support from the LLL Seismic Research Program manager, H.C. Rodean, and guidance in conducting the field work by W. Hannon and D. Larson. The original concept of directional firing and the investigation of the depth of burial effect was suggested by P. Rodgers whose continued interest and support of the program made it possible to yield these preliminary results. The data recording and firing of the high explosive charges were performed by S. Spataro, C. Cornell, K. Moyle and J. Scarofiati. Most of the field work support was provided by J. Taylor, the high explosive charges were assembled by S. Baker and F. Garecki, and data processing was assisted by M. Sharp, M. Higuera, M. Jepson, D. Taasevigen and T. Mayer.

The surface shots were conducted by Physics International under the direction of F. Sauer, and the participation in nuclear events was made possible by F. Beane, R. Ide, and L. Crooks.

WTF/jj/aj/mla

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $; *Microfiche $2.25*

Page Range	**Domestic Price**	**Page Range**	**Domestic Price**
001–025	$ 3.50	326–350	10.00
026–050	4.00	351–375	10.50
051–075	4.50	376–400	10.75
076–100	5.00	401–425	11.00
101–125	5.50	426–450	11.75
126–150	6.00	451–475	12.00
151–175	6.75	476–500	12.50
176–200	7.50	501–525	12.75
201–225	7.75	526–550	13.00
226–250	8.00	551–575	13.50
251–275	9.00	576–600	13.75
276–300	9.25	601–up	*
301–325	9.75		

---

*Add $2.50 for each additional 100 page increment from 601 to 1,000 pages; add $4.50 for each additional 100 page increment over 1,000 pages.