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Impulse Radar Scanning of Intact Salt at the Avery Island Mine

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C. Wayne Cook

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IMPULSE RADAR SCANNING OF INTACT SALT AT THE AVERY ISLAND MINE

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ABSTRACT

A series of experiments was run in the Avery Island Mine to evaluate the capability of an impulse radar to locate anomalies and simulated waste targets in intact dome salt. Voids in salt were difficult to detect. On the positive side, metal targets and simulated waste (glass) were easily located in intact salt. Radar scanning at ranges of greater than 25 meters and short-range resolution of target positions to within a few centimeters were achieved.

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INTRODUCTION

If intact salt is to be used for the storage of nuclear wastes, it may be necessary to identify inclusions, structural discontinuities, and other anomalies within intact salt prior to excavation. This identification would provide an additional measure of operational safety during construction. Impulse radar is one tool that could be used for scanning intact salt.

This report discusses the results of the Avery Island mine radar experiments¹ conducted with the cooperation of the Office of Nuclear Waste Isolation (ONWI), RE/SPEC Inc. (under contract to ONWI), and Avery Island mine management. The experiments included a measurement of propagation velocity, scanning of three pillars, and the location of simulated nuclear waste and waste canisters.

IMPULSE RADAR SYSTEM

A Geophysical Survey Systems, Inc. (GSSI) SIR-7 impulse radar was used for the Avery Island experiments. Figure 1 is a block diagram of the radar system.

Borehole transducers with a center frequency of 100 MHz were used for the propagation velocity measurements. Four hundred MHz and 1 GHz transducers, each having a transmitting and receiving antenna in a single package, performed the scans. One hundred MHz, 400 MHz, and 1 GHz are the center frequencies of the Fourier spectrum of the transmitted impulses. The Fourier spectrum is very flat around the center frequency, and rolls off at approximately 20 db/octave at the upper (500 MHz for 400 MHz transducer) and lower (150 MHz for 400 MHz transducer) frequencies in the spectrum.

Impulses from the transducer are transmitted into the medium every 20 microseconds. The Sandia system is adjusted so that the receiver can look for echoes for up to 1.2 microseconds. This translates into a potential range of greater than 120 meters. After amplification, the received signals are sampled for recording both on a graphic recorder for field use and on magnetic tape for subsequent signal processing. Figure 2 shows the radar system setup in the mine.

The time base for the radar system is calibrated using the transit time of an impulse through a precise length of coaxial cable. This scheme gives a time base accuracy of a few tenths of a nanosecond.

PROPAGATION VELOCITY

Propagation velocity was measured so that the range of observed targets could be determined. Avery Island dome salt propagation velocity was measured by transmitting impulses between two boreholes in the ONWI test area. The holes had been drilled for the simulated waste and waste canister experiments described later in this paper. The two boreholes used were 8 inches in diameter, 2.26 meters deep, and 54.97 meters apart. Transmission time between the holes was 422.7 nanoseconds. This gives a propagation velocity of 0.130 m/nanosecond. The propagation velocity of radar impulses in air is 0.300 m/nanosecond.

PILLAR SCANNING

Four pillar scans were run on the 500-foot level of the Avery Island mine using the 400 MHz transducer. Figure 3 is a map of the mine showing where the pillar scans were run. The first scan was run along the east side of Pillar A. Figure 4 shows the results of this scan. A weak signal can be

seen at the west salt-air interface of pillar A. The vertical grid marks on this scan and on all other scans (except those shown in Figure 5) were manually placed on the records every 3.05 m (10 feet) of travel. Using the measured propagation velocity in salt, the radar indicates that the pillar thickness lies between 22.8 and 23.4 meters. These values are consistent with the physical dimensions of the pillar. Figure 4B is a replay of the data shown in Figure 4A using the range gain function of the radar. In this case, the interface signal is made much clearer.

A second scan was run on Pillar A in an attempt to see the 8-inch hole located approximately 16 meters from the south side of Pillar A and running from the east side. This scan was run by moving the transducer vertically 4.5 meters from the east side. The results of this scan are shown in Figure 5A. Grid marks were placed on the scan at the start, top, and end of the scan. A clear reflections is seen at 10.7 meters. An inspection of the pillar showed that this target was an extensometer that RE/SPEC had installed in the pillar. The weak signal seen at 16.5 meters is believed to be the open 8-inch borehole. Figure 5B is a repeat of scan 5A; however, in this scan the borehole caliper had been inserted in the hole. A slight increase in the signal from 16.5 meters can be seen.

The second pillar scanned was the triangular pillar, B, shown in Figure 3. The results of this scan (along the long side) are shown in Figure 6A. Several sharp targets were picked up, but they do not correspond to the opposite salt-air interface. It is believed that these signals came from discarded pipes and other metal debris left in the mine. The salt-air interface of the pillar shows faintly at both ends of the scan. Replaying the scan using range gain did not bring out the salt-air interface, Figure 6B.

The final pillar scan, C in Figure 3, was run from the point along the northeast side. Figure 7A shows the results of this scan. In this scan, the salt-air interface shows a weak signal. A stronger signal is picked up from the pillar across the drift (D). Replaying the data with range gain improved the detection of the opposite salt-air interface, Figure 7B.

LOCATION OF SIMULATED NUCLEAR WASTE AND WASTE CANISTERS

To conduct experiments on location of simulated nuclear waste and waste canisters, RE/SPEC drilled four holes on the west side and two holes on the east side of their test area (Figure 1). A backfill getter material (sand with 10% clay) was supplied by Sandia Laboratories' Division 5812 to install as simulated packages. The experiment matrix as constructed is summarized in Table 1.

The radar scans for the six holes are shown in Figure 8, Hole 1; Figure 9, Hole 2; Figure 10, Hole 3; Figure 11, Hole 4; Figure 12, Hole 5; Figure 13, Hole 6.

Table 2 summarizes the data read from the radar scans. As the data show, all the simulated targets were detected. The accuracy of locating the top of the targets varied between 2 and 3 cm. The bottoms of the targets, which coincided with the bottoms of the holes, were located with accuracies varying between 1.3 and 6.1 cm. In three out of the four cases where a dry getter-crushed salt interface existed, it was detected. The wet getter-crushed salt interface was easily detected.

The 400 MHz transducer took all the data presented in this section. The same scans were run with the 1 GHz transducer. Only Hole 2 showed readable results. These data were inferior to the 400 GHz data and were not included.

DISCUSSION AND CONCLUSIONS

The most interesting observation made during the Avery Island scans was the difficulty in detecting a salt-air interface. Conversely, an air-salt interface was easily detected. It was easy to measure the heights of ceilings in the various drifts. Theoretically, these two situations should provide the same echo. However, the situation in which we were looking for a void through a pillar was a little different, because it involved air-salt-air interfaces. It is theoretically possible in this situation for the salt to behave as a half-wave dielectric window, if its thickness is an integral number of half-wavelengths. At 400 MHz, a half-wavelength in salt is .163 m. However, it seems a little unlikely that a significant amount of the energy in the transmitted pulse would be negated by this mechanism.

Improved range gain amplifiers are now available for the GSSI radar systems. It is possible that this new circuitry might enhance the ability to detect a void in salt. As the system now stands the ability of the impulse radar to detect a gas-filled void in salt is marginal.

On the positive side, the impulse radar easily detects metal and glass targets in salt. Range accuracy is also quite good. Targets can be located to within a few centimeters. No brine targets were available, but the large reflections seen from the wet floor near the start of the scans on Hole 5 (Figure 12) imply that brine should provide reflections comparable to metal targets.

TABLE 1. EXPERIMENT MATRIX, SIMULATED WASTE AND CANISTER LOCATION

<u>Hole</u>	<u>Dia.</u>	<u>Depth</u>	<u>Simulated Waste</u>	<u>Sand/Clay Mix</u>	<u>Crushed Salt</u>
1	8 in	2.262 m	crushed glass 5" D x 36" L	first 1.323 m	sand/clay to surface
2	8 in	2.240 m	stainless steel tube with titan- ium end cap 5" D x 24" L	first .972 m	sand/clay to surface
3	3 in	2.271 m	stainless steel tube with titan- ium end cap 2" D x 24" L	first 1.332 m	sand/clay to surface
4	3 in	2.243 m	---	first 1.305 m (as provided dry)	sand/clay to surface
5	3 in	2.256 m	---	first 1.389 m (double water content)*	sand/clay to surface
6	3 in	2.268 m	---	---	entire hole filled with salt

*See Appendix I for mixing procedure.

TABLE 2. DATA FROM RADAR SCANS

	<u>Actual</u>	<u>Radar</u>
<u>Hole 1</u>		
Distance to backfill	.945 m	.945 m
Distance to glass target	1.308 m (1.219)*	1.198 m
Hole depth	2.262 m	2.278 m
<u>Hole 2</u>		
Distance to backfill	1.271 m	.991 m ?
Distance to steel target	1.600 m	1.567 m
Hole depth	2.240 m	2.179 m
<u>Hole 3</u>		
Distance to backfill	.919 m	.966 m**
Distance to steel target	1.652 m	1.631 m
Hole depth	2.271 m	2.219 m
<u>Hole 4</u>		
Distance to backfill	.939 m	.927 m**
Hole depth	2.243 m	2.256 m**
<u>Hole 5</u>		
Distance to backfill	.966 m	.966 m
Hole depth	2.256 m	2.271 m
<u>Hole 6</u>		
Hole depth	2.268 m	2.295 m

* Distance to filling nipple

**Very faint signal

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1. C. W. Cook and A. R. Sattler, Test Plan - Scanning of Intact Salt in the Avery Island Mine with Radar, November 19, 1979, Sandia National Laboratories.

APPENDIX I

PROCEDURE FOR ADDING WATER TO AVERY ISLAND BACKFILL SAND/CLAY MIX

1. Adjust amount of material in one plastic bag to 40 pounds.
2. Add 1 quart of water according to the following procedure:
 - a. Sprinkle 1/10 quart on surface of 40 pounds of backfill.
 - b. Roll material by raising opposite sides of bag 2 feet for 10 cycles.
 - c. Repeat a and b for a total of 10 times.

FIGURE 1: BLOCK DIAGRAM OF THE RADAR SYSTEM

FIGURE 2: RADAR SETUP IN MINE

FIGURE 3: A PORTION OF THE 500 - FOOT LEVEL OF THE AVERY ISLAND MINE

SURFACE →

RANGE ↓

3m

1.98m

23.4m →

FIGURE 4A: SCAN OF PILLAR A

SURFACE → **START** **TOP** **END**
RANGE ↓

10.7m →

16.5m →

FIGURE 5B: VERTICAL SCAN OF PILLAR A WITH CALIPER INSERTED

SURFACE

RANGE

3m

**SALT - AIR
INTERFACE**

1.09m

**APPROXIMATE
LOCATION OF
PILLAR APEX**

FIGURE 6A: SCAN OF PILLAR B

SURFACE →

RANGE ↓

3m

1.09m

FIGURE 7A: SCAN OF PILLAR C

SURFACE →

RANGE ↓

3m

1.09m

SALT - AIR INTERFACE

AIR

PILLAR D

FIGURE 7B: SCAN OF PILLAR C WITH RANGE GAIN

SURFACE →

RANGE ↓

BACKFILL

TARGET

.51m

HOLE BOTTOM

HOLE 1

HOLE 1

HEATER

FIGURE 8: SCAN HOLE 1

SURFACE

RANGE

.31m

?

TARGET

HOLE BOTTOM

HOLE 2

HOLE 2

HOLE 2

FIGURE 9: SCAN HOLE 2

SURFACE →
RANGE ↓

FIGURE 10: SCAN HOLE 3

SURFACE

RANGE

.31m

BACKFILL

HOLE BOTTOM

HOLE 4

HOLE 4

HOLE 4

FIGURE 11: SCAN HOLE 4

FIGURE 12: SCAN HOLE 5

SURFACE →

RANGE ↓

↑ .31m

HOLE BOTTOM

HOLE 6

HOLE 6

HOLE 6

FIGURE 13: SCAN HOLE 6

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