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FINAL REPORT ON THE PINOT
EXPERIMENT

LIVERMORE SITE

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FINAL REPORT ON THE PINOT EXPERIMENT

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ABSTRACT

Pinot is the code name for a small chemical explosive experiment carried out in August, 1960 in a mine controlled by the U. S. Bureau of Mines at the Anvil Points Experimental Oil Shale Station near Rifle, Colo. The project was designed to provide some indication of the extent to which gases from a confined underground explosion in oil shale would migrate parallel to the bedding planes.

At 0800 on August 2, 1960, 946 lb of nitromethane was fired in shot hole No. 1. There was no visible damage to the mine adit or to any structure associated with the workings. Gas samples collected from sampling holes near the shot hole were analyzed for Kr^{85} , which had been included with the nitromethane as a tracer. It appears that the Kr^{85} concentration in the samples out to 50 ft was more or less independent of space and time between +2 and +50 hours. Relatively little Kr^{85} was detected at 125 ft and none beyond. About $(20 \pm 10)\%$ of the Kr^{85} escaped into the adit.

The results of the Pinot experiment cannot be extrapolated quantitatively to the case of a nuclear explosion in oil shale. Even if the structure at the Pinot site is typical of oil shale, the generation of a smaller quantity of non condensable gases per unit energy in a nuclear explosion (as compared with a chemical explosion), the shorter time scale of the energy release, and the higher temperatures and pressures encountered will all have a definite influence on the effective containment distance. One can conclude, however, that, if the medium at the site of a potential nuclear experiment is similar to that at Pinot, the radioactive gases will not travel preferentially in direction parallel to the bedding planes, but rather will tend to expand more or less spherically from the shot point. In other words, an explosion in oil shale designed not to vent in a direction perpendicular to the bedding planes will be just as tight parallel to the bedding planes.

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INTRODUCTION

Pinot is the code name for a small chemical explosive experiment carried out in August, 1960 in a mine controlled by the U. S. Bureau of Mines at the Anvil Points Experimental Oil Shale Station near Rifle, Colo. The project was designed to provide some indication of the extent to which gases from a confined underground explosion in oil shale would migrate parallel to the bedding planes. This question has come up several times in the past, with the argument that, since the bedding planes are planes of weakness, the pressure generated in a nuclear explosion, both directly and from the decomposition of CaCO_3 and organic matter present in the oil shale, will force apart the layers and propel radioactive gases along these planes to the atmosphere. While the difference in gas movement parallel to and normal to the bedding planes was not expected to be at all large, it was felt that data on this effect are an essential part of the continuing study of the problems associated with the recovery of petroleum products from oil shale using nuclear explosive energy. Information on the containment of chemical explosions will be extremely useful when and if the design of a nuclear explosion in oil shale is authorized.

The program as designed consisted of two detonations of nitromethane (CH_3NO_2), a liquid whose explosive properties are similar to those of TNT. The first of these was approximately 1000 lb of explosive, containing about 1 curie of Kr^{85} as a tracer. The explosive device was grouted into the formation at a depth of 126 ft below the mine floor. The other detonation was to be 5000 lb of nitromethane in an analogous arrangement. Around each shot hole there was an array of 6 sampling holes located at ranges from 20 to 125 ft from ground zero. From analysis of the distribution of Kr^{85} , it was expected that useful information would be obtained about the movement of the explosively produced gases parallel to the bedding planes. This would assist greatly in the design of a nuclear experiment.

GEOLOGY OF THE SITE

A plan view of the Anvil Points Oil Shale Mine is shown in Fig. 1, and more detailed views of the adit in which the experiment was conducted are given in Figs. 2 and 3.

In order to understand the geological environment of the Pinot experiment, an NX core hole was drilled about 120 ft down below the floor of the adit. These cores, taken at sample hole 2.6, were compared with data from the U. S. Bureau of Mines core hole "A" (see Fig. 1). As one can see from Fig. 3, the materials of importance at the shot and sample locations are mainly lean to medium oil shale and marlstone. A lithologic description of the cores obtained from hole 2.6 is as follows:

<u>From Elev.</u>	<u>To Elev.</u>	<u>Description</u>
	8188.8	Collar elevation.
8188.8	8186.8	Oil shale, lean to medium, brown to grey well defined bedding. Good banding. Rare tuff stringers in upper part. Represented by 8-in. core.
8186.8	8184.3	Oil shale, lean, tan to grey, well defined bedding. Fair banding. 4-in. grey tuff at 8186.7, 1-in. rusty tuff at 8186.0 ft.
8184.3	8177.8	Marlstone, tan to buff, poorly defined bedding. Common streaks of lean oil shale. Rare pyrite, vertical fractures 8186.3 - 8182.8 ft and 8179.3 - 8177.0 ft 2-in. medium oil shale at bottom.
8177.8	8175.8	Marlstone, tan to buff, massive. Rare pyrite.
8175.8	8173.3	Oil shale, very lean, light brown to light grey, poorly defined bedding. Rare pyrite streaks.
8173.3	8167.8	Marlstone, tan, massive to faintly bedded. Silty in part.
8167.8	8165.0	Marlstone, silty, light grey to tan massive to poorly defined bedding.
8165.0	8164.3	Siltstone, tuffaceous, rusty, massive. 1-in. grey tuff bed in middle. Grades into silty marlstone.
8164.3	8149.9	Marlstone, silty, tan to light grey. Massive to faintly bedded. 0.6 ft rusty zone at 8155.4 ft. 1-in. grey tuff at 8155.1 ft. Rare pyrite streaks.
8149.9	8149.1	Siltstone, tuffaceous, grey to rusty, massive. Rare pyrite.

(continued)

<u>From Elev.</u>	<u>To Elev.</u>	<u>Description</u>
8149.1	8141.8	Sandstone, rusty, fine-grained, silica cemented in part. Rare silty zones.
8141.8	8139.4	Siltstone, light grey, massive.
8139.4	8137.4	Sandstone, rusty, fine-grained, porous, contains water.
8137.4	8135.9	Siltstone, tuffaceous grey, massive.
8135.9	8134.6	Sandstone, rusty, as in 8139.4 ft - 8137.4 ft.
8134.6	8101.5	Siltstone, grey to tan, poorly defined bedding. Changing to marlstone in lower part. Common pyrite stringers.
8101.5	8098.0	Marlstone, tan to grey, poor to well defined bedding. Rare bands of oil shale at 8101.5 ft to 8100.3 ft.
8098.0	8095.6	Oil shale, medium, dark brown, massive to poorly defined bedding. Vertical fracture in bottom 14 in.
8095.6	8092.1	Oil shale, lean to medium, brown to tan, well-defined bedding, excellent banding. Rare pyrite flakes.
8092.1	8089.6	Oil shale, medium, dark brown, massive to faintly bedded. 1-in. grey tuff beds at 8091.6 ft and 8089.7 ft.
8089.6	8086.4	Oil shale, lean to medium, brown to tan well defined bedding. Common pyrite. 1-in. tan tuff at 8089.0 and 2-in. grey hard tuff at 8086.6 ft.
8086.4	8084.9	Oil shale, medium, brown to grey, well defined bedding. Abundant pyrite flakes.
8084.9	8080.8	Marlstone, tan to brown, well defined bedding. Rare bands of oil shale.
8080.8	8076.3	Oil shale, very lean, grey to brown, well defined bedding, excellent banding.
8076.3	8075.0	Oil shale, medium, dark brown, poorly defined bedding.
8075.0	8069.8	Oil shale, lean, brown to grey, well defined bedding, excellent banding. Rare tuff stringers and pyrite flakes. 1/4-in. grey tuff at 8072.8 ft.
8069.8		Bottom of hole.

EXPERIMENTAL ARRANGEMENT

The 1000-lb shot hole, which is shown in Fig. 4, was 10 in. in diameter and was reamed out to 20 in. at the level of the explosion. The top of the nitromethane charge was 126 ft below the floor of the adit and 610 ft below the surface of the mesa slope. A picture of the explosive container appears in Fig. 5. The device package consisted, basically, of two booster blocks of Composition B enclosed in a polyethylene bag, a thin-walled stainless steel canister containing 1 curie of Kr^{85} , and an outer polyethylene bag to hold the nitromethane. It was lowered into the reamed section and expanded to its full diameter by pouring nitromethane through an access tube. The hole was then grouted back to the floor of the adit. Each booster block was detonated by sending an electrical impulse to two pairs of blasting caps, each pair of which ignited a short length of primacord, which in turn set off a tetryl pellet recessed into the block. The energy generated in one booster block was sufficient to assure detonation of the nitromethane.

The six sampling holes associated with the first shot were 3-1/8 in. in diameter and contained a 1/2-in. gas sampling pipe and a 3/4-in. pipe through which accumulated water could be removed. Each hole had one open section approximately 20 ft in length; in holes 1.2 and 1.4 the open sections were about 20 ft above the shot point, while in the other holes the open sections were more or less at the shot level. The characteristics of these holes are given in Table I. The arrangement for the 5000-lb shot was quite similar, except for the size of the device and the underreamed section of the shot hole.

EXPERIMENTAL PROCEDURE AND OBSERVATIONS

A few days before the scheduled detonation of the first shot it became evident that there was underground communication between the various holes associated with shot hole No. 1. * This fact suggested strongly that Kr^{85}

* During the drilling of the shot and sample holes, circulation was lost at one or more levels in most of the holes. While this observation proved that there were underground voids in the oil shale, it shed no light on the question of connectivity. It was believed that the voids were not connected, until tests with injected air proved otherwise.

Table I. Project Pinot Sample Hole Data.

Sample Hole No. *	Collar station (ft)	Collar elevation (ft)	Bottom bearing and distance from collar (ft)	Bottom elevation (ft)	Packer elevation (ft)	Horizontal distance from bottom of Sample Hole to No. 1 shot chamber (ft)
1.1	5 + 88.4	8206.3	N67° E, 1.2	8073	8089	34.6
1.2	5 + 34.5	8203.4	N82° E, 0.9	8094	8114	20.2
1.3	5 + 19.6	8202.8	N43° E, 0.9	8070	8089	34.6
1.4	5 + 04.5	8201.1	N38° E, 0.5	8093	8113	49.9
1.5	4 + 79.5	8199.8	N75° E, 0.2	8070	8089	75.2
1.6	4 + 29.5	8198.5	S76° E, 0.8	8070	8089	125.5
2.1	3 + 73.0	8193.8	N73° E, 0.9	8070	8090	181.7
2.2	3 + 17.0	8192.5	N13° W, 2.5	8087	8107	235.3
2.3	3 + 02.0	8191.7	East, 0.1	8070	8090	252.8
2.4	2 + 87.0	8191.3	N29° E, 0.8	8080	8100	267.4
2.5	2 + 62.0	8189.7	N88° E, 0.9	8070	8090	292.8
2.6	2 + 12.0	8188.5	N57° W, 0.9	8070	8090	342.3

* Diameter of holes was 3-1/8 in.

would travel significant distances through fractures and crevices after detonation; nevertheless, it was decided to proceed with the experiment, as the data to be gained would be valuable. One hour before the shot the water which had accumulated in 5 of the 6 sampling holes was blown out. (Hole No. 1.5, at a distance of 75 ft from the shot point, could not be de-watered by this technique.)

At 0800 on August 2, 1960, 946 lb of nitromethane (plus 7 lb of Composition B) was fired in shot hole No. 1. There was no visible damage to the mine adit or to any structure associated with the workings. Only a minor ground shock and a small audible air wave were experienced by people at the observation point (4000 ft from the shot point). Reentry for sampling began two hours after zero time and samples were taken from all six holes during the next half hour. The procedure at each hole was as follows:

- (1) The pressure in the hole was measured using a compound pressure gauge reading from 30 in. of Hg vacuum to 100 psi gauge pressure.
- (2) An evacuated bottle was attached to the sampling pipe and the valve on the pipe was opened to fill the bottle.
- (3) The pressure in the bottle plus hole system was read, and the pipe valve closed. The maximum pressure observed in any hole was 10 psi gauge. Since the volume of the bottle was 1.2 cu ft and the volume of each sample hole about 1.1 cu ft, the size of each sample was of the order of 0.5 cu ft of gas at standard temperature and pressure. The gas pressure, sampling times, and sample volumes are given in Table II.

An extra sample was taken from hole 1.6 (range 125 ft) ten hours after the shot. This sample was flown to Livermore, along with the other postshot samples and a background sample obtained from hole 1.3 four days before the shot, in order that analysis could begin with a minimum of delay. A second series of 6 samples was taken from the same set of holes at +48 hours. At +72 hours a series of 6 samples from the holes drilled for the second shot (at distances of 180 to 340 ft from shot hole No. 1) was also taken.

Samples were analyzed for Kr^{85} and, in addition, an aliquot of each sample was run on the mass spectrometer. The results are given in Table II. Kr^{85} was found in all samples taken at distances out to 125 ft, and none was detected beyond 125 ft. The Kr^{85} concentration in the samples out to 50 ft appears to be more or less independent of space and time between +2 and +50 hours. Unfortunately, the sample at 75 ft is not considered reliable, as the

Table II. Chemical Analyses.

Sample Hole No.	Radial range (ft, approx)	Time after detonation (hours)	Pressure in Sample Hole (psigauge)	Sample volume (ft ³ at STP)	Kr ⁸⁵ concentration [†] (fraction of Kr ⁸⁵ per ft ³ at STP)	Mass Spectrometer Analysis (Mol %, exclusive of H ₂ O)						
						CO ₂	A	O ₂	N ₂	CH ₄	CO	H ₂
1.1	37	+ 2.0	3.5	0.47	46 × 10 ⁻⁶	2.67	0.52	9.82	54.93	2.87	16.42	12.77
1.2	20	↓	< 1	0.81	94 × 10 ⁻⁶	0.49	0.54	5.08	58.29	3.55	18.17	13.88
1.3	35		9	0.67	97 × 10 ⁻⁶	2.36	0.50	10.77	52.00	3.21	17.84	13.32
1.4	50		< 1	0.58	23 × 10 ⁻⁶	0.51	0.89	9.63	77.33	1.13	5.46	5.05
1.5*	75		4	0.11	23 × 10 ⁻⁸	0.10	1.04	12.13	86.40	0.05	(trace)	0.28
1.6	125	+ 2.5	< 1	0.49	44 × 10 ⁻⁸	0.21	0.96	18.92	79.48	--	(trace)	0.43
1.6	125	+10.5	↓	0.40	54 × 10 ⁻¹⁰	0.26	0.97	19.28	79.20	--	(trace)	0.29
1.1	37	+50.3		0.13	40 × 10 ⁻⁶	0.50	0.62	9.12	61.48	2.90	12.80	12.58
1.2	20	↓		0.64	93 × 10 ⁻⁶	0.60	0.44	0.84	52.79	5.09	23.24	17.00
1.3	35			0.15	103 × 10 ⁻⁶	1.03	0.63	10.43	59.79	2.60	13.39	12.13
1.4	50			0.52	44 × 10 ⁻⁶	0.72	0.86	3.33	75.96	2.11	9.82	7.20
1.5*	75			~0.1	Sample not run							
1.6	125	+51.0		0.46	32 × 10 ⁻¹⁰	0.26	1.00	18.19	80.37	--	(trace)	0.18
2.1***	190	+74		0.57	** < 10 ⁻¹¹	0.14	1.04	13.63	83.33	--	(trace)	1.87
2.3***	260	+74		0.39	** < 2 × 10 ⁻¹¹	0.08	1.03	14.83	83.45	--	(trace)	0.60
1.3(background)		-4 days		↓	~0.5	--	0.03	0.96	19.63	78.59	--	--

[†]Total Kr⁸⁵ loaded = $(2.1 \pm 0.1) \times 10^{12}$ disintegrations/minute as of 8/2/60.

*Hole 1.5 water could not be blown out (the 3/4-in. pipe was apparently plugged). Since the water level was part way up sample pipe, these samples are probably meaningless.

**No Kr⁸⁵ detected. Upper limits are set according to the maximum which could have escaped unambiguous detection.

***Since no Kr⁸⁵ was found in these samples, samples from the other holes in this series were not studied.

accumulated water could not be blown out of the gas sampling pipe. At 125 ft the apparent Kr^{85} concentration was reduced from the close-in value by a factor of 100 at +2 hours and by a factor of 10,000 at +10 and +51 hours. It is not clear whether the +2-hour sample from hole 1.6 is really representative of the gas at 125 ft at 2 hours, or whether the sample was contaminated during the sampling process.

Venting of Kr^{85} into the adit after the shot was significant. Much of the gas apparently traveled through an almost vertical joint near the top of the hole. In addition, gas was found entering the adit from a newly formed crack in the grout plug. This crack was parallel to the joint just mentioned. About $(20 \pm 10)\%$ of the Kr^{85} escaped into the adit through these (and possibly other) cracks.

While it has been found possible to use the Pinot results for semi-quantitative interpretation, as will be seen below, the experiment was designed basically for qualitative data. Therefore, when Kr^{85} was found in all of the holes associated with the first detonation it was decided to cancel the second (5000 lb) shot.

RESULTS

From a study of Table II, it appears that out to 50 ft, the concentration of both Kr^{85} and nitromethane decomposition products is (roughly) independent of both the horizontal distance to the shot point and the vertical distance from the shot point, although there is a suggestion that both Kr^{85} and combustion products are somewhat less concentrated at 50 ft. There is relatively little Kr^{85} or decomposition products at 125 ft. It is evident from the small changes in concentration with time that relatively little of the gas movement can be ascribed to a diffusion process. The only large change in concentration occurred at 125 ft between +2.5 and +10.5 hours, and may not be real, as it was not accompanied by a corresponding change between +10.5 and +51 hours. One may therefore conclude from these observations that the force of the explosion distributed these products more or less uniformly throughout the medium to some distance between 50 and 125 ft from the shot point. Shortly after the explosion, the gas occupied between 4% of the total volume out to 50 ft and 1/4% of the volume out to 125 ft.

CONCLUSIONS

The fact that there was significant horizontal underground communication in the oil shale was not recognized until a few days before the Pinot detonation. It is not believed, however, that the site chosen for Pinot was anomalous in this regard.* At the location of the experiment (about 500 ft from the mesa slope), the vertical joints may be somewhat more open than they are deeper in the formation, but there is no reason to believe that the joint spacing at the shot site is particularly atypical.** Therefore, it is reasonable to assume that the results of the Pinot experiment are more or less equally applicable to other locations in the Green River formation..

Since about 20% of the Kr⁸⁵ found its way into the adit from the shot point (125 ft below the adit floor), it would appear that the distance shot gases travel normal to the bedding planes is not very different from the distance they travel parallel to those planes. In other words, the evidence does not support the view that shot gases are propelled unusually long distances parallel to the bedding planes of the oil shale. On the contrary, the evidence is quite consistent with the hypothesis that the gases were distributed by the force of the explosion essentially uniformly per unit volume out to some distance of the order of 100 ft. This is true in spite of the horizontal connectivity of the medium. Therefore, either a similar degree of vertical connectivity exists at the Pinot site, or else the force of the explosion opens up the medium sufficiently (and relatively isotropically) to provide most of the passages for gas movement.

The results of the Pinot experiment cannot be extrapolated quantitatively to the case of a nuclear explosion in oil shale. Even if the structure at the Pinot site is typical of oil shale, the generation of a smaller quantity of non-condensable gases per unit energy in a nuclear explosion (as compared with a chemical explosion), the shorter time scale of the energy release, and the higher temperatures and pressures encountered will all have a definite influence on the effective containment distance. One can conclude, however, that, if the medium at the site of a potential nuclear experiment is similar to that at

* K. Stanfield, U. S. Bureau of Mines, private communication.

** J. R. Donnell, U. S. Geological Survey, private communication.

Pinot, the radioactive gases will not travel preferentially in a direction parallel to the bedding planes, but rather will tend to expand more or less spherically from the shot point. In other words, an explosion in oil shale designed not to vent in a direction perpendicular to the bedding planes will be just as tight parallel to the bedding planes.

In order to understand the movement of these gases from a contained nuclear explosion in oil shale, further experiments will be required, especially with contained nuclear explosions in various media.

Fig. 1. General Plan of Anvil Points Oil Shale Mine, Project Pinot.

Fig. 2. Plan of Adit No. 3, Project Pinot.

PROJECT PINOT
ANVIL POINTS OIL SHALE MINE
RIFLE, COLORADO

MD-12059

MUL-12060

Fig. 3. Vertical Cross Section of Project Pinot.

Fig. 4. Shot Hole No. 1 Detail, Project Pinot.

Fig. 5. Photo of 1000-lb Device for Shot Hole No. 1, Project Pinot.

LIST OF PREVIOUS PLOWSHARE AND/OR RELATED REPORTS

<u>Report No.</u>	<u>Title</u>
UCRL-4659	Deep Underground Test Shots.
UCRL-5026	Non-Military Uses of Nuclear Explosions.
UCRL-5124 Rev. I	Phenomenology of Contained Nuclear Explosions.
UCRL-5253	Industrial Uses of Nuclear Explosives.
UCRL-5257 Rev.	Peaceful Use of Fusion.
UCRL-5281	Temperatures and Pressures Associated with the Cavity Produced by the Rainier Event.
UCRL-5457	Large Scale Excavation with Nuclear Explosives.
UCRL-5458	Mineral Resource Development by the Use of Nuclear Explosives.
UCRL-5538	Evaluation of the Ground Water Contamination Hazard from Underground Nuclear Explosions.
UCRL-5542 Rev.	Properties of the Environment of Underground Nuclear Detonations at Nevada Test Site. Rainier Event.
UCRL-5623	Radioactivity Associated with Underground Nuclear Explosions.
UCRL-5626	Underground Nuclear Detonations.
UCRL-5709	Hydroclimatology and Surface Hydrology of San Clemente Island.
UCRL-5757	Geologic Studies of Underground Nuclear Explosions Rainier and Neptune.
UCRL-5766	The Neptune Event. A Nuclear Explosive Cratering Experiment.
UCRL-5840	Industrial and Scientific Applications of Nuclear Explosions.
UCRL-5882	Chemical Reactions Induced by Underground Nuclear Explosions.
UCRL-5917	Excavation With Nuclear Explosives.
UCRL-5928	Nuclear Explosives and Mining Costs.
UCRL-5932	The Soviet Program for Industrial Applications of Explosions.

LIST OF PREVIOUS PLOWSHARE AND/OR RELATED REPORTS

<u>Report No.</u>	<u>Title</u>
UCRL-5949	An Application of Nuclear Explosives to Block Caving Mining.
UCRL-5968	An <u>In Vacuo</u> Electromagnetic Dispersion Experiment.
UCRL-6013	Probing the Earth with Nuclear Explosions.
UCRL-6030-T	Application of Nuclear Explosions as Seismic Sources.
UCRL-6054	Fracturing of Rock Salt by a Contained High Explosive.
UCRL-6175	The System $H_2O-NaCl$ at Elevated Temperatures and Pressures.
UCRL-6215	Can Peaceful Nuclear Explosions be Conducted Safely.
UCRL-6249-T	Distribution of Radioactivity from a Nuclear Excavation.
UCRL-6274	Final Report on the Pinot Experiment.
* * *	
Plowshare Series: Report No.2. Proceedings of the Second Plowshare Symposium (Held at San Francisco, May 13 - 15, 1959):	
UCRL-5675	Part I: Phenomenology of Underground Nuclear Explosions.
UCRL-5676	Part II: Excavation.
UCRL-5677	Part III: Recovery of Power and Isotopes from Contained Underground Nuclear Explosions.
UCRL-5678	Part IV: Industrial Uses of Nuclear Explosives in the Fields of Water Resources, Mining, Chemical Production, and Petroleum Recovery.
UCRL-5679	Part V: Scientific Applications of Nuclear Explosives In the Fields of Nuclear Physics, Seismology, Meteorology and Space.

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